F-35

IN SERVICE

WITH AIR FORCES AROUND THE WORLD



GÉRARD KEIJSPER

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Gerard Keijsper



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The Lockheed Martin X-35B has been called a flying collection of doors. The amount of doors on this aircraft that had to function all right for the propulsions system to do its magic made this aircraft an engineering challenge. (*Lockheed Martin*)

The History of the F-35

During the 1980s the United Kingdom and the USA had co-operated on supersonic Short-Take-Off-and-Vertical-Landing (STOVL) fighter studies to replace the Harrier. In 1986 NASA and the USMC, among others, asked if DARPA could help out the stalled programme. DARPA got involved and the work performed from 1986 till 1992 is considered phase 1. DARPA (Defense Advanced Research Projects Agency) issued a request for proposals (Rf P) for the ASTOVL (advanced-short-take-off-and-vertical-landing) aircraft technology demonstration programme in 1992. The aim was to build a supersonic STOVL fighter with an empty weight of 24,000lb, similar to the F-18C, to keep weight and cost in check. The cost of a fighter was its weight in gold, US$1,500 per pound in 1993. Since then the cost of gold has increased

As the United States Marine Corps (USMC) had trouble with the Bell Boeing V-22 Osprey which was under attack by US Vice President Dick Cheney, they could not afford another high-profile programme on their own. United States Air Force (USAF) Brigadier General George Muellner, deputy chief of staff for requirements, Headquarters Air Combat Command, Langley Air Force Base, received a presentation from Lockheed/ DARPA about a replacement for the F-16 with more range, the kind of range the USAF craved, after he objected that the USAF had no money to start another project since they had the F-22 just about selected. The financial situation was tight: everyone expected a peace dividend after the collapse of the USSR just a couple of years before and did not want to put budgetary pressure on the F-22 programme. DARPA pointed out that the USMC had a similar problem and that there could be a possibility of co-operation as the extra fuel tank could be replaced by a lift fan offering a supersonic capability for which the USMC yearned. The USAF was interested in this DARPA programme to provide the technology by the end of the 1990s.

Many had tried to develop a supersonic STOVL fighter but had failed. The history books are full of examples of experiments that were imaginative, but problems such as hot-gas ingestion, suck-down forces and the fountain forces made them unsuccessful. Hot-gas ingestion and the transition from conventional flight to hover and lifting its weight had proved to be the three biggest problems in developing a successful supersonic STOVL fighter. For this reason, DARPA assigned an experimental X designation to the prototype, the X-32.

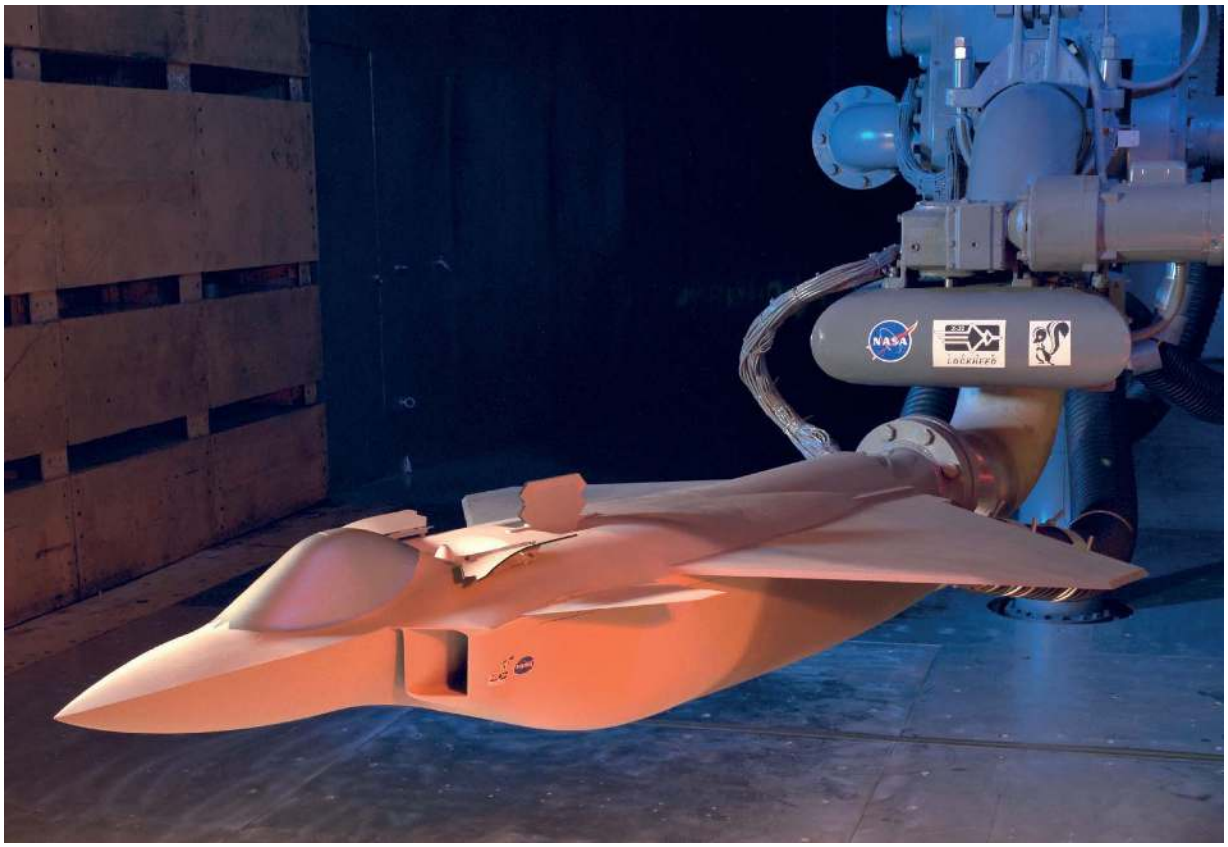
General Dynamics had been testing a full-scale E-7 ejector propulsion model in the NASA 80 x 120-feet wind tunnel but, in the end, offered a fan-in-wing propulsion concept similar to that of the Ryan XV-5A. McDonnell Douglas went in with an offer for both shaft-driven-lift-fan (SDLF) and gas-coupled-lift-fan (GCLF) propulsion systems. Northrop offered a similar propulsion system as used in the Russian Yakovlev Yak-38, the lift+lift-cruise propulsion system. Boeing offered the Harrier propulsion system called direct lift. The Lockheed and McDonnell Douglas designs could remove the lift fan for the conventional fighter and Northrop could do the same with the lift engine. Only Boeing did not have this advantage and, for that reason, selected a delta wing which can hold a larger fuel volume. A requirement set by DARPA was that a full-scale model had to be developed to prove that a design could carry its weight in the STOVL flight regime to prevent a repeat of the Rockwell International XVF-12A.



The Boeing X-32A was doing the up and away flight demonstrations and also the work for the US Navy and as such was also performing Field Carrier Practice Landings. (*Boeing*)

In March 1993 Lockheed with the SDLF propulsion system and Mc Donnell Douglas with the GCLF system were selected; General Dynamics, Boeing and Northrop lost out. Boeing rallied their senate representatives arguing that the sole concept that had been proven in history had been rejected. Boeing, through the Senate, got an agreement with DARPA to continue but had to fund 50 per cent themselves and Northrop continued with their funds. Lockheed and General Dynamics were in talks over taking over the Fort Worth Division. The tipping point was that General Dynamics Fort Worth missed out on the possible replacement of the F-16 and so it was sold to Lockheed. Two years earlier the ATA General Dynamics A-12 Avenger II had been cancelled and F-16 production was expected to come to a halt soon since the USAF had decided to stop buying it. With General Dynamics losing out on this DARPA contract it was expected that Fort Worth could soon be out of business.

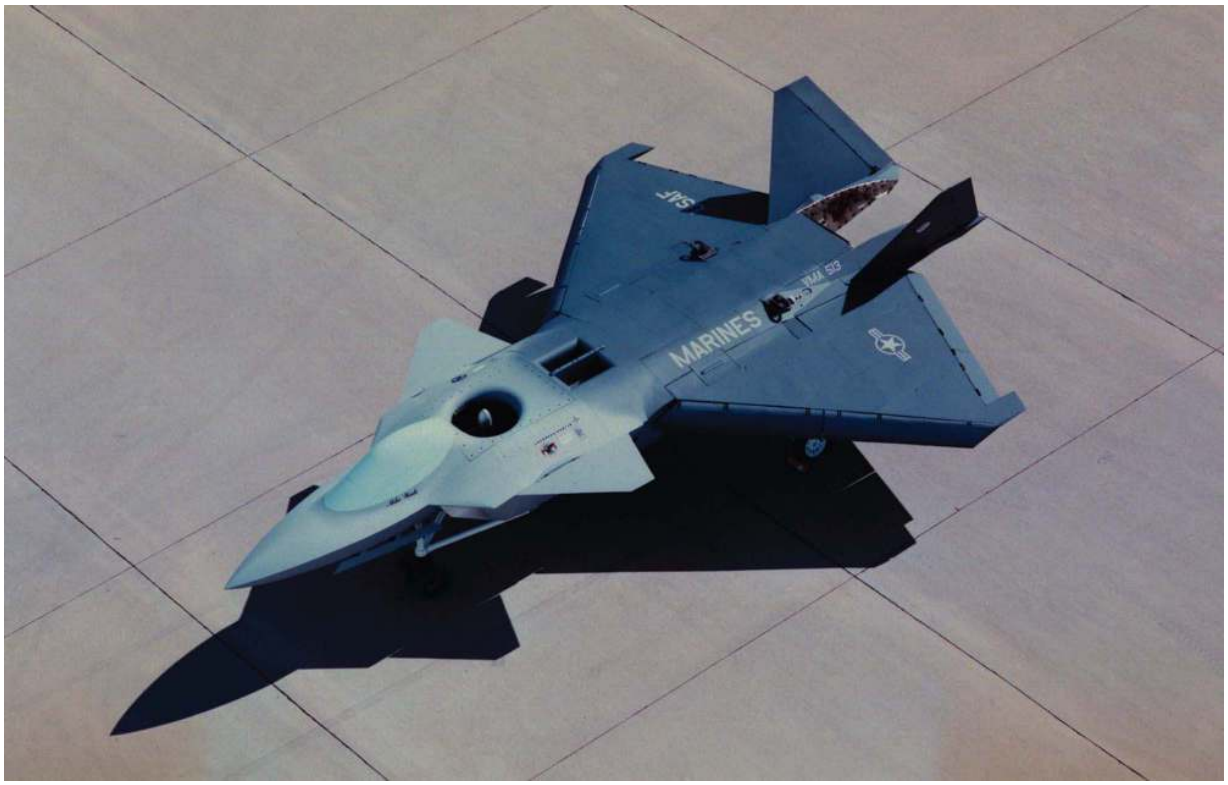
McDonnell Douglas was co-operating with British Aerospace in an exclusive deal on the GDLF. A full-scale model was prepared for testing. McDonnell Douglas had selected the General Electric YF120 for their GDLF. McDonnell Douglas with British Aerospace teamed up with Northrop-Grumman forming the dream team, as all Western operational STOVL experience and recent naval experience was in one team, leaving in all three competitors. The McDonnell Douglas team left the GDLF concept, much to the chagrin of NASA and soon adopted the lift+lift-cruise propulsion system that Northrop had pursued. The dream team did not bother with a full-scale model for the lift+lift-cruise propulsion system as they reasoned they were developing a proven propulsion technology that was capable of lifting its weight. While changing propulsion system, they changed propulsion provider, as they now wanted to offer lower risk and a proven engine, the Pratt & Whitney F119. From the outset both Boeing and Lockheed had selected the F119 engine and, as such, there was never an engine competition for the JSF.



A 1996 wind tunnel model of the X-35. Note the Skunk Works and the X-32 sticker above the model. Further note that the inlet design was that of the F-22. (*NASA Lewis Research Center*)



The X-35B with the hattrick tail was a sign of the confidence that the Skunk works team had in their aircraft. It would be the first to perform a short take off, transfer to conventional flight and go supersonic in level flight and convert to a hover and perform a vertical landing. (*Lockheed Martin*)



This is the Large-Scale Powered Model seen here right after roll out at the Skunk Works in Palmdale. Its designation was the X-32. The model was used at NASA Ames Outdoor Aerodynamic Research Facility and 80 × 120 ft windtunnel. This model can now be found at Lockheed Martin's scrapyard at Fort Worth right beside the HALO model of the F-35. (*Lockheed Martin*)



Boeing proved its weapon bays on the X-32A; this was done as Boeing wanted to repeat the succesful Lockheed/General Dynamics/Boeing YF-22 demonstration programme where they actually fired an AMRAAM missile during the fly-off. (*Boeing*)



The General Dynamics E-7 based on the F-16 seen here in the 80 × 120 ft windtunnel at NASA Ames in 1988. The ejector propulsion system had been tried during the ASTOVL programme but in the end General Dynamics went in with a Fan in Wing design based on the Ryan XV-5B design. (*NASA Ames*)

The DARPA programme was absorbed by the joint-advanced-strike-technology (JAST) programme and the programme was changed so that, with the down select, two contractors would get the chance to build a demonstrator aircraft. For this reason the X-35 designation was added. With the demonstrators to be built under the JAST programme, the programme became more than technology development: it became an aircraft demonstration programme, to reflect which the name changed to the JSF (Joint Strike Fighter) programme.

Both Boeing and Lockheed Martin were selected on 16 November 1996 and received a contract to build and test two prototypes on what was to become the JSF. McDonnell Douglas was the fighter powerhouse with the legacy of the F-4 Phantom II, F-15 Eagle and F-18 Hornet, but had no work in the future since the F-22 and the JSF would replace the entire US

inventory of fighter aircraft with no new fighter designs expected for another thirty years. McDonnell Douglas had once been a major company on the civil side of aviation but that had been diminished by competition from Boeing and Airbus. So, soon after, McDonnell Douglas was sold to Boeing. British Aerospace and Northrop Grumman had to decide who to join and both selected Lockheed. The prototypes, or concept demonstration aircraft as they were called, had to prove that the design would be stealthy, could replace the Harrier by landing vertically, have a short take-off run and could be launched from a conventional aircraft carrier while having a fighter performance equal to the F-16. In short, it should fulfil the requirements of all three US services; many other export orders were expected to follow automatically.



An early computer design for the Boeing proposal which was considered an outsider. As such it was a big surprise that Boeing managed to gain one of the two contracts available in November 1996. (*Boeing*)

The Lockheed effort

The task at hand was not an easy one but Lockheed's Advanced Development Company, better known as the 'Skunk Works', was on the job with innovative technology. The main new technology, the SDLF, from the Skunk Works for the lift concept was met with some optimism as it seemed

to tackle most of the problems. The idea for the SDLF design was refined by Skunk Works' engineer Paul Bevilaqua and his team and was patented in 1993.

Reasons for Lockheed to pursue the SDLF technology were threefold:

- The extra weight incurred by the lift fan and the shaft was insignificant compared to the extra thrust gained by this new technology
- As the lift fan used no combustion the exhaust was colder, making the ground environment more suitable for operations
- STOVL thrust requirements can be disconnected from the main engine so that the engine is conventionally sized to the requirement of up-and-away thrust required for transonic acceleration.

The Boeing effort

Boeing was not accepted by DARPA since it was not offering 'new technology', its propulsion system being a more modern version of the Harrier's. Boeing reasoned that their offer was less risky as it had already proven itself on the Harrier and thus they had to solve only the hot-gas ingestion problem. The propulsion system selected required that the engine be located in the centre of the aircraft close to the centre of gravity. This made the design stubby looking.

A British company, Fairey Hydraulics Ltd (FHL), was responsible for a system called the attitude control system (ACS). ACS took care of the conversion from conventional wing-borne flight to jet-borne flight. The ACS was formed by eight variable-area nozzles: two pitch nozzles positioned in the nose, two pitch nozzles in the tail, two yaw nozzles on the tail of the aircraft and, finally, two roll nozzles in the wingtips. The jet screen located between the lift nozzles and the two pitch nozzles in the nose provided additional pitch control which could be achieved by adjusting the jet screen; the system was activated by a switch on the instrument panel. Once the pilot activated the switch, the doors of the lift system opened; simultaneously a built-in test check of the ACS actuators took place, followed by a switch of the flight controls. To complete the conversion the pilot had to push the flow switch control button on the throttle. The ACS had to close the main exhaust, so that thrust would move through the vectoring nozzles at the centre of the aircraft. Once the flow switch had

been completed, the X-32B was in STOVL mode. Once in STOVL mode deceleration was commanded by vectoring the nozzles



The McDonnell Douglas/Northrop/BAe design for their lift plus lift cruise propulsions proposal which was based on technology proven in many demonstrators and operationally in the Russian Yak-38 Forger. (*McDonnell Douglas*)



The schematics of the propulsion and Attitude Control System used in the X-32B. (*Boeing*)



The Boeing Preferred Weapon System Concept mock up seen here at the ramp with a couple of Super Hornets. The X-32B was too heavy and Boeing promised to have that solved with this design.



The Boeing X-32B in a hover at Patuxent River. The Boeing X-32B achieved what the Harrier never was able to do: supersonic flight. This was made possible by the raw power of the engine. (*Boeing*)

The Boeing X-32A CTOL took off for its first flight piloted by Fred Knox on 18 September 2000, making it the first of the JSF concept demonstrator aircraft (CDA) to fly. Boeing was flying for about a month without competition, experiencing small technical problems and learning that they would have to make do without aerial refuelling. On 24 October Boeing test pilot Dennis O'Donoghue experienced an unpleasant situation when he noticed that his brakes were not working and he had to land on a dry lake bed and let the aircraft come to a standstill. It was grounded for three weeks. Also, on 24 October, Tom Morgenfeld took the X-35A for its first flight. He flew it to 10,000 feet with the landing gear down to Edwards Air Force Base (AFB). In a short period, Lockheed managed to qualify the X-35A for aerial refuelling and ticked off all the test points one by one at

impressive speed. The Boeing X-32A re-joined the flight programme one week before Lockheed completed the flight-test programme of the X-35A with a supersonic flight. The X-35A had reached a 20-degree angle of attack (AoA) and an altitude of 34,000 feet. Boeing, it seemed, had to play catch up; but Boeing did not need to refurbish one of their test aircraft while Lockheed did.



The X-32B seen here in hover. Note the missing landing gear doors, inlet cowl and the lift improvement device that was to trap the exhaust fountain under the fuselage. (*Boeing*)



The X-35A seen here powering up its engine prior to flight test. This engine test paved the way for the first flight. (*Lockheed Martin*)



The lift fan is lowered into the airframe of the X-35A which would be transformed into the X-35B. The people in the image illustrate the size of the liftfan. (*Lockheed Martin*)

The X-35A was being reconfigured so that it could function as the X-35B. The X-35A aeroplane had a ‘dropin’ cylinder with ballast attached to

the floor of the cylinder. When the X-35 was converted from a CTOL variant to a STOVL variant, the ballasted cylinder was removed and replaced with the lift-fan. The Boeing X-32 continued with its flight test programme and set a really aggressive pace.

The X-35C took off for its first flight on 16 December with Joe Sweeney at the controls. The X-35C has more control surfaces and a reinforced structure to deal with carrier landings which have a greater impact on the structure of the plane. After completing aerial-refuelling qualification, the X-35C was flown from Edwards AFB to the Lockheed Fort Worth Division and, a day later, completed its transfer to NAS Patuxent River, therewith performing a first for any X-plane in history – a cross-continental flight. Both the X-32A and the X-35C performed up-and-away flight tests, many field carrier landing practices (FCLP), bolters and wave offs before completing demonstration flights.

On 29 December a major milestone was passed by adapting the X-35A to the X-35B when the lift-fan was installed. The cockpit was equipped for this part of the flight-test programme with a new control unit beside the throttle and the stick. The new control unit was a thrust vector lever (TVL). By operating this unit in the X-35B the pilot could vector the exhaust of the main engine from 22 to 95 degrees and similarly could vector the thrust of the lift-fan nozzle through a range of 34 to 95 degrees. The TVL was located right beside the throttle on the outboard side.

The business end of the programme arrived with the first flight of the X-32B on 29 March 2001. The X-32B flew some conversion flights at Edwards, getting the speed down to 140 knots before transferring to NAS Patuxent River. As NAS Patuxent River was at sea level things would be easier there for Boeing. The aircraft was technically adjusted, which meant that landing-gear doors and the inlet cowl were removed to save weight. The fear that the aircraft was too heavy was a real one, but Boeing pointed out that their preferred weapon system concept (PWSC) was lighter and would not incur this problem. Boeing did not want to have the embarrassment of a repeat of the old experimental STOVL planes that could not lift their own weight. On 23 June 2001, the X-35B lifted from the ground vertically for the first time with BAE Systems pilot Simon Hargreaves at the controls. The capability of hovering and vertical take-off and landing was proven at Palmdale. As soon as the X-35B was at Edwards AFB the testing was geared to transitioning from normal flight to hover.

The Boeing X-32B made its first vertical landing with Denis ‘Irish’ O’Donoghue at the controls. In the demonstration flights, during the vertical landings, the X-32B encountered the problem of hot-gas ingestion, causing a pop stall on one occasion.



The Boeing X-32A performed its Field Carrier Practice Landings at Edwards AFB while Lockheed chose a different tactic by sending its X-35C to Patuxent River. (*Boeing*)



The first operational western STOVL fighter with the technology demonstrator of its replacement. DARPA was instigator of this project although some at the outset had to be persuaded that designing a supersonic STOVL fighter was a worthy DARPA hard programme. (*Lockheed Martin*)



A computer rendition of the Dream Team proposal, each aircraft depicts a service, USAF, USMC, US Navy and RAF/RN. (*McDonnell Douglas*)

USMC test pilot Major Art Tomassetti made aviation history on 20 July as he was the first pilot to make a short take off using the lift-fan. He then proceeded to level flight during which he achieved supersonic speed. After the supersonic dash, he landed the aircraft vertically, performing exactly the mission profile it was anticipated the PWSC had to fulfil. To prove a point that it was no accident, Lockheed repeated the feat but this time with Simon Hargreaves at the controls on 26 July 2001. In answer to Lockheed Martin's X-mission, the Boeing X-32B flown by USMC Major Jeff Karnes executed a short take-off, transitioned into conventional flight, broke the sound barrier, transitioned back to the STOVL mode in such a manner that he was still airborne due to aerodynamic forces, and made a low-speed landing. On the last day of flight test, 28 July 2001, a vertical landing was not risked; for this flight, the inlet cowl and landing gear doors were re-installed.

Both the X-32B and the X-35B had exceeded the weight limit set by DARPA at the outset of the programme. Lockheed Martin had proven that

the X-35B had excess power in hover but Boeing was on the edge of its capability. For future growth capability, the decision to select the Lockheed Martin F-35 was a no-brainer. The success of the lift-fan allowed the F-35 to become significantly heavier than 24,000lb and this, in turn, caused a cost increase.



X-35A performed mostly up and away flight for the USAF requirement. Lockheed managed a very agressive flight schedule putting Boeing under pressure. (*Lockheed Martin*)



X-32A seen here with a gaping hole through the middle alowing the imagination to workout the size of the engine in proportion of the aircraft. The demonstrator aircraft would have a minimum of mission systems. (*Boeing*)

Aircraft Specifications

Dimensions	Boeing X-32A CTOL/CV	Boeing X-32B STOVL	Lockheed-Martin X-35A/B CTOL/ STOVL	Lockheed-Martin X-35C CV
Length	13.72 metres 45ft	13.33 metres 43ft 8.6in	15.5 metres 50 ft 9in	15.5 metres 50 ft 9in
Height	4.06 metres 13ft 4in	4.06 metres 13ft 4in	4.8 metres 15ft 9in	4.8 metres 15ft
Wingspan	10.97 metres 36ft	9.14 metres 30ft 0in	10.05 metres 33ft 0in	10.97 metres 36 ft
Empty weight	10800kg 23810lbs	11340kg 25000lbs	11256.8kg 24,765lbs 13383.6kg 9,444lbs	12328.6kg 27,123lbs.
Total flights	66	78	66 (27+39)	73
Total flight time	50.7 hours	43.3 hours	48.9 hours	58 hours
Number of Vertical landings	n/a	6	27	n/a
Number of Vertical take-offs	n/a	0	18	n/a

The announcement made on 26 October 2001 by Ed Aldridge, Undersecretary of Defense for Acquisition, Technology and Logistics, that Lockheed-Martin had won paved the way to initiate the 126-months-long system development and demonstration (SDD). The SDD officially started on 1 November 2001, which was a milestone called ‘authority to proceed’ (ATP). During the system development and demonstration, Lockheed Martin encountered many problems that delayed the programme. Probably the two biggest problems were software and weight. With a delay of some six years the SDD was complete. The last test flight took place on 11 April 2018.

The Quality-versus-Quantity Debate

The saying that quantity has a quality all of its own was already recognised by the time of the Cold War. It was, however, feared that Western countries could not compete with the Soviet Union's numbers game. It would have to come up with a quality product that could overcome the quantity. For this reason, the USAF was going for the bigger, higher, faster, farther mantra. If it was bigger it was reasoned it could take more weapons, more fuel, more engines. If it could go higher than the adversary it could survive. If it could go faster than the adversary it could outrun everybody. The farther was important so that the pilot could strike anywhere or last longer in combat without the aid of aerial refuelling. Another reason was that the USAF was led by generals coming from bomber units that believed the days of air-to-air combat were something for the history books. In fact, every aircraft designed had to have an air-to-ground capability.

A fighter pilot named John Boyd, at the time an unrecognised genius, had fought in Korea flying the North American F-86 Sabre and, according to Pierre Sprey, had shot down some aircraft on the wrong side of the Yalu River. Aircraft shot down on the wrong side were not counted but, in fact, were denied. John Boyd became a fighter weapons instructor at Nellis AFB, flying the North American F-100 Super Sabre or 'Hun' as it was known where he became known as 'Forty Second' Boyd: he would invite anyone to meet in the air, take a position on his tail and that he, Boyd, would pay US$40 to anyone he would not have gun-camera footage of within forty seconds. John Boyd never lost the bet. Becoming a tactics instructor, he came up with his energy-manoeuvrability (E-M) theory. It was with this theory he was able to tell which aircraft would do better in air-to-air combat. According to his theory, the MiG-15 Faggot was better than the North American F-86 Sabre. In fact, with the details he learned about Soviet Union aircraft, he realised that the USAF was in a dire situation.

Boyd was asked to help with the F-X programme, where he tried to keep the weight out of the aircraft while applying his knowledge from the E-M theory. However, USAF leadership, enamoured with new technology, kept

including technology – gold-plating the aircraft as John Boyd would have said. High wing loading (W/S) does not help in a dogfight; high thrust-to-weight (T/W) creates manoeuvring while high W/S decreases manoeuvring ability. High load factor manoeuvring point-of-view: want low W/S with high T/W. Out of the F-X programme the F-15 was born, already a better aircraft than its predecessor but gold-plated and therefore not as good as it could have been.

Most of the aircraft that were planned for replacement originated from the USAF HQ prototype study from 1971. John Boyd was involved in that study, from which five prototype systems were recommended:

Advanced Medium STOL transport	Lightweight Fighter aircraft
Very Low Radar Cross Section vehicle	Quiet aircraft
Large Tanker aircraft	Remotely Piloted Vehicle (RPV)

Of interest to us at this time are the very low radar cross section (RCS), which turned eventually into the F-117, and the lightweight fighter (LWF), which continued as a fly-off between the YF-16 and YF-17; both were developed further as the F-16 and F-18. The F-16 was a day fighter but, again, Boyd was disappointed although improvements were made that helped make the F-16 what it is today, an excellent multi-role fighter.

As the main actor in the fighter mafia, his E-M theory was used by him and industry to evaluate the designs of aircraft coming out of the lightweight fighter competition, aircraft every fighter pilot would crave for. The USAF did not want this fighter but John Boyd initially proposed the programme as a technology demonstrator rather than as a replacement for the F-15. The lightweight fighter programme was set up so that only the bare essentials would make it onto the aircraft – austerity in the sense of new technology with ‘clocks and bells’ kept to a minimum and ‘no pound for air-to-ground’. Boyd also took care that the evaluation pilots would fly both the General Dynamics YF-16 and Northrop YF-17, so that they would be able to compare them properly. To his surprise the pilots favoured the General Dynamics YF-16, the reason being that it was able to perform a manoeuvre called the Buttonhook turn. Moreover, the YF-16 could change faster between manoeuvres than the Northrop YF-17. This surprise made John Boyd study air combat even more and also evaluate the discrepancies in air-to-air combat. The F-86 had had the better kill ratio over the MiG-15, some of it due to pilot training; but Boyd found that a major part was workload and the speed with

which the pilot could react and flick transients. He was close to his second breakthrough, the observe-orient-decide-act (OODA) loop. The OODA loop was important since it exemplified that *Observe* was made possible by the sensors and eyes and ears of the pilot; *Orient* can be enhanced by mission systems fusion for the pilot; with the correct data the pilot would, thanks to his training, make the right *Decision* and *Act* accordingly. As such this would be repetitive. The USAF listened to the industry again and started adding all kinds of clocks and bells; thus the production F-16 became heavier and lost its ability to perform the Buttonhook turn. Although the USAF leadership did not like it, the F-16 had a better turn rate and longer range than the F-15.

In the late twentieth century and early twenty-first century, the same was argued as being of importance in the face of growing expansion by China, which was developing many military aircraft. The quality-against-quantity discussion raged from the moment that the lightweight fighter mafia had won its first battle with the F-16.

For the advanced tactical fighter (ATF) programme, a study in quality versus quantity was again performed and fuelled the debate. That debate was often simplified, but a good example was the McDonnell Douglas F-15 Eagle, designed with the MiG-25 in mind, for which reason the requirement to fly at Mach 2.5 was endorsed. This had an undeniable impact on the F-15 design. Fiscal limitations caused the F-15 to be bought at less than the optimum yearly production rate, pushing up the procurement cost. Initially, the reliability of the F100 engine was a problem and a bone of contention for the advocates of the quantity debate.

The advanced tactical fighter under development from the early 1980s would exploit a group of new technologies and be more capable in many ways than the aircraft it was going to replace. However, in 1981, under a request for information, industry was asked to evaluate the quality-versus-quantity question to see which way the ATF was going to go. From the responses the Air Force selected its options. From the outset the USAF wanted the ATF to have enhanced avionics, supersonic cruise capability, stealth characteristics to make it less visible to enemy radar, short-take-off-and-landing capability, high reliability and maintainability, long flight ranges, and improved survivability for the aircraft and crew in environments contaminated by nuclear fallout or biological warfare materials. At the time it was considered that such capabilities might be needed to match Soviet quantitative and qualitative increases. The improvements were going to have a negative impact on cost and make the ATF very expensive. To counter this it was planned that the ATF

would be bought at a rate of seventy-two units per year. The F-15 provided air superiority: in the end, the ATF F-22 Raptor provides air dominance but was never acquired in such numbers that it could be considered a replacement of the F-15. Cost had proven to have a detrimental impact on the numbers acquired and it was openly feared that the same would happen with the JSF. This fear was real since the total cost of LRIP I was not released as it could cause major concern.

In fact, the JAST programme office got the job to juggle requirements so that force level sustainment would not be a problem but, on the other hand, would provide sufficient force modernisation to improve quality over existing platforms. Capabilities were therefore traded off against cost, and cost was reduced by using built-on technology developed from the ATF. JSF was '70 per cent air-to-ground and 30 per cent air-to-air' at its inception, according to General George Muellner.

However, not everyone was in agreement with the JSF programme office. In 2008 a Rand report, co-authored by John Stillion, was leaked in which it was stated that during a simulation in the Pacific the F-35 was put up against Su-35s and lost badly. The reaction from the JSF programme director, General Charles Davis, was almost immediate. He was quoted as saying that the F-35 is at least 400 per cent more effective in air-to-air combat capability than the best fighters available in the international market, including Sukhois.

In 2011 a technical problem caused the F-22 fleet to be grounded for four months. The technology was evaluated and no cause was found but the cost caused the F-22 to become a laughing stock since older generation fighters performed without such problems. The general joke was complete when the entire F-35 fleet was grounded during the same period; at the time it was still in development. The critics asked the difference between fifth-generation and fourth-generation: the fifth is grounded and the fourth are performing the function they were designed to do; Eurofighter, Rafale and Gripen, plus all American F-15, F-16 and F-18 were operating over Libya.

The fact that the F-16 was a highly-manoeuvrable fighter and its replacement less so, and more expensive, made the critics say that the replacement was a step back, especially people connected or in agreement with the so-called lightweight fighter mafia. The case was not helped when, in early 2012, it was announced that one of the key performance parameters was being lowered. Little did the public know that, during this decision, other key performance parameters were also decreased. The first reduction in capabilities was in connection with range. A report by Dr J. Michael Gilmore,

Director, Operational Test and Evaluation (DOT&E), released information that that was not the case. The joint programme office planned reducing:

- F-35A turn performance from 5.3 to 4.6 sustained Gs and extending the time for acceleration from 0.8 Mach to 1.2 Mach by 8 seconds.
- F-35B turn performance from 5.0 to 4.5 sustained Gs and extending the time for acceleration from 0.8 Mach to 1.2 Mach by 16 seconds.
- F-35C turn performance from 5.1 to 5.0 sustained Gs and increasing the time for acceleration from 0.8 Mach to 1.2 Mach by at least 43 seconds.

These changes were due to the results of air vehicle performance and flying qualities evaluations. Another report that was published shortly after on the 'operational utility evaluation', which occurred during late autumn 2012, quoted three student pilots over the severe impacts of the visibility shortfalls in combat or in training of a more tactical nature. One said, 'A pilot will find it nearly impossible to check their six o'clock position under g.' Another commented, 'The headrest is too large and will impede aft visibility and survivability during surface and air engagements,' and 'Aft visibility will get the pilot gunned every time,' referring to close-range visual combat.

Programme director Lieutenant General Christopher C. Bogdan made a statement on the comments in a press release. 'We have yet to fly a single air-to-air engagement with another F-35 or another aeroplane,' he said. 'The aeroplane's not ready to do that. We're still doing basic training on the aeroplane, we're still doing basic testing on the aeroplane. So for someone to assess that the visibility behind the aeroplane is such that it will "get gunned down every time" is a little premature.'

However, Pierre Spey from the lightweight fighter mafia who played a role in the development of the F-16 and the Fairchild A-10 Thunderbolt was rather critical of the F-35. He was of the opinion, which he expressed during a lot of interviews to anyone who wanted to listen, that the F-35 was a disaster; the aircraft was one big compromise. The lift-fan made all three aircraft fat, due to which the aircraft had gained a lot of drag. The wings are short to facilitate a vertical take-off. Due to the short wings, even the CTOL version can't turn and so won't be able to win a dogfight. Furthermore, the F-35 would not be able to replace the A-10 in the close air support role as it can't fly low and slow due to the small wings. He compared the F-35 with the F-105 Thunderchief that was shot down in big numbers during the Vietnam War, even by MiG-15s dating from the Korean War.

	F-35A CTOL	F-35B STOVL	F-35C CV
Length	15.58m/51.1ft	15.58m/51.1ft	15.64m/51.4ft
Wingspan	10.67m/35ft	10.67m/35ft	13.11m/43ft
Wing area	42.73m²/460ft²	42.73m²/460ft²	57.6m²/620ft²
Combat radius	>1,092km/590nm.	>833km/450nm	>1,111km/600nm
Empty weight	13,300kg/29,300lb	14,700kg/32,300lb	15,800kg/34,800lb
Internal fuel	8,280kg/18,250lb	6,125kg/13,500lb	8,860kg/19,750lb
Max take-off weight	31,800kg/70,000lb	27,300kg/60,000lb	31,800kg/70,000lb
Thrust/weight ratio • full fuel: • 50% fuel:	 0.87 1.07	 0.90 1.04	 0.75 0.91
Internal fuel range	2,220km/1,200nm	1,670km /900nm	2,520km/1,400nm
Combat radius on internal fuel	1,082km/584nm	869km/469nm	1,141km/615nm

It was not until 2015 that the discussion about dogfighting skills rose again and was called in question once more. AF-2 had participated in basic fighter manoeuvring with an F-16 and the result mentioned by Lockheed Martin sounded that there were reserves which could be implemented during upgrades after the SDD had finished. In short, the basic manoeuvring capabilities could be improved upon by software improvements in later development blocks. A couple of articles referred to a 'For Office Use Only' (FOUO) document in which an F-35 pilot said that the F-35 could not stand the test of basic fighter manoeuvres against current fighters. Some phrases quoted from the report were:

- 'Energy deficit to the bandit would increase over time.'
- 'Insufficient pitch rate exacerbated the lack of energy manoeuvrability.'
- 'The flying qualities in the blended region (20–26-degrees AoA) were not intuitive or favourable.'
- 'Once established at high AoA, a prolonged full rudder input generated a fast enough yaw rate to create excessive heading crossing angles with opportunities to point for missile shots.'
- 'The helmet was too large for the space inside the canopy to adequately see behind the aircraft.'
- 'The test was extremely effective at providing data that are not achievable with scripted test cards.'

In short, everything that John Boyd had taught pilots to be important in air combat.

The test took place on 14 January 2015. The single-seat F-35A with the designation AF-02, an early development aircraft, took off clean without weapons alongside a two-seat F-16D Block 40 flown with two 370-gallon external fuel tanks under the wings. The F-35 (AF-02) and the two-seat F-16D block 40 would be performing Dissimilar Air Combat Training (DACT), the roles of opposing fighters in an air battle, which the Air Force organised specifically to test out the F-35's prowess as a close-range dogfighter in an air-to-air tangle involving high angles of attack and aggressive stick/pedal inputs. The F-35 pilot would fly his jet hard, turning and manoeuvring to 'shoot down' the F-16, whose pilot would be doing his own best to evade and kill the F-35. According to the report the test included seventeen engagements starting between 18,000 and 22,000 feet with a 10,000-foot floor, with starting speeds between 380 and 440 knots indicated airspeed, The F-35 pilot was defeated many times during this exercise. One important matter that should not be forgotten was that at the time of the tests the F-35 was flying with Block 2B software, which was not capable of reaching the design maximum of 9g.

The Joint Programme Office reacted to this with the following statement:

The F-35 involved was AF-2, which is an F-35 designed for flight sciences testing, or flying qualities, of the aircraft. It is not equipped with several items that make today's production F-35s [fifth-] Generation fighters.

Aircraft AF-2 did not have the mission systems software to use the sensors that allow the F-35 to see its enemy long before it knows the F-35 is in the area. Second, AF-2 does not have the special stealth coating that operational F-35s have that make them virtually invisible to radar. And third, it is not equipped with the weapons or software that allow the F-35 pilot to turn, aim a weapon with the helmet, and fire at an enemy without having to point the aeroplane at its target.

The tests cited in the article were done earlier this year to test the flying qualities of the F-35 using visual combat manoeuvres to stress the system, and the F-16 involved was used as a visual reference to manoeuvre against. While the dogfighting scenario was successful in showing the ability of the F-35 to manoeuvre to the edge of its limits without exceeding them, and handle in a positive and predictable manner, the interpretation of the scenario results could be misleading. The F-35's technology is designed to engage, shoot, and

kill its enemy from long distances, not necessarily in visual 'dogfighting' situations. There have been numerous occasions where a four-ship of F-35s has engaged a four-ship of F-16s in simulated combat scenarios and the F-35s won each of those encounters because of its sensors, weapons, and stealth technology.

If this is the case then a Douglas F6D Missileer type of aircraft should be produced so that the number games would always be in the advantage. Otherwise, in close-range dogfighting situations the stealth coating is not going to be much of an advantage.

The statement, however, ignored the fact that aircraft without the mission systems should be lighter; the same applies to the stealth coating. The third part of the statement was the HMD; most fourth-generation fighters were equipped with HMD systems, perhaps not as advanced as the F-35's but also able to point weapons without having to point the aeroplane at its target. The next point is that within visual range (WVR) missiles will not be inside the weapon bays but on underwing stations which, by Lockheed Martin's own admission, is not stealthy and it is questionable how often the underwing stations will be used because of survivability. Another important message from the statement was that it did not deny the results of the encounter. The question remained for countries on strained budgets, such as the smaller European countries: was it wise to put their eggs in this one basket?

The Paris Air Show at le Bourget in 2017 was the point when the F-35 made its first visit to an air show with a regular display. Billie Flynn was the Lockheed Martin test pilot flying the USAF aircraft. The display was comparable to other displays but, of course, not as spectacular as the thrust-vectoring aircraft shown at previous shows by the Russians. What was important to remember was that the aircraft being flown was a Block 3i aircraft. It was still limited and could not fly through its full envelope.

Mission Systems

Display system

The panoramic display is a high resolution, high brightness night vision compatible 20″ x 8″ Active Matrix Liquid Crystal Display (AMLCD). The panoramic display is divided into different windows, each called a portal. The upper inch of the display has icons for household functions, such as engine function, fuel and hydraulics and, if the pilot requires it, by a touch on the screen, voice command or cursor hook, it can be made a full portal. The remainder of the display screen can be divided up to twelve portals and the pilot can select the size of the portals to increase his situational awareness at any given time. If the pilot selects the maximum twelve portals, he uses four main displays (larger-sized portals) with eight sub-displays (smaller-sized portals) below them. If the pilot selects only two displays he would have two portals each 7 by 10 inches. The upper inch of the display has icons for household functions, such as engine function, fuel, hydraulics, Integrated Caution, Advisory, Warning System (ICAWS) and if the pilot requires by a touch on the screen, voice command or cursor hook can make it a full portal. The pilot can select images from the radar, EO-DAS, EOTS, EW System or a mixture of all on the tactical display which will display the information gained from all the sensors and will give the pilot options on how to deal with the threat. Out of fear that information might be lost it will be possible for the pilot to call up a dedicated screen for each system, for example for the EW System. The first time that the display was presented in Europe by L-3 was during the Paris air show at le Bourget in 2009. The Large Area Avionics Display, as L-3 now called it, was presented with a rather high reliability mean time between failures (MTBF), stated to be better than 5,000 hours. Resolution of the display (2560 x 1024) was divided evenly in two. The display itself was rather thin but the display processors came in a separate LRU, which would be placed behind the panoramic display screen.





In the words of Mike Skaff: every button and dial had to earn its way back into the cockpit. (*Lockheed Martin*)



A detail of the left side instrument panel. It is rather clean compared to previous generation cockpits. (*Lockheed Martin*)

ELD
MFD
AUTO RECOVERY
APU BATT
CDC-2000A
VOR
BAT
UTCR



A detail of the right-hand instrument panel of AA-1. (*Lockheed Martin*)

An important part of the display system is the actual presentation of the information. The display system uses different colours and symbols to help the pilot differentiate the information; for example, other aircraft in the air are shown in different colours. Other friendlies are displayed in green, white aircraft are unknown, yellow aircraft are suspect, red aircraft are confirmed enemy and cyan, a colour between blue and green, are other F-35s. The pilot can select what he wants to see, so the display can show him only the green aircraft or rather only enemy and suspect aircraft. For the air-to-ground mode the display has similar aids since it shows the radars on the ground. These show on the display and reflect the shape and the size of the F-35's radar cross signature (RCS); the areas which are better avoided as they are covered by ground radar stations called blobs. The pilot can turn his plane in such a way that his reflection to the radar is minimal.

In June 2017 Elbit Systems of America announced that it had received a contract to develop a new panoramic display for the F-35. The new display would be introduced in lot 15 in the same timeframe as the Technical Refresh 3, which was being developed for Block 4.2 aircraft. The size of the display will remain the same but it will be a high-definition, high-performance large-area touch-screen display that integrates and displays flight and mission information on a single screen according to the Elbit Systems statement.



An immensely important aircraft, the NF-16D VISTA also used for evaluation of the Direct Voice Input. (*AFFTC*)

Direct Voice Input

Voice recognition is only for household tasks and for those household tasks that ease pilot workload. Voice Interaction had been thoroughly evaluated by the JSF programme office and the advantages were clear. For this reason, Direct Voice Input (DVI) was to form a major part of the human/machine interface.

The goals of speech recognition were:

- reduction of operator task loading
- decreasing data entry time
- improving information management
- reducing manning requirements

The system selected for the F-35 was developed by SRI International; SRI, Stanfords Research Institute, was established in 1946. SRI International is

an independent non-profit technology research and development organisation with a long history in speech-recognition technology and also had a few patents regarding speech-recognition technology. DynaSpeak was one of their speech-recognition products. On 13 September 2006 it was announced by SRI International that DynaSpeak was licensed exclusively to Adacel for selected aviation voice-activated cockpit applications. DynaSpeak was to support the large vocabulary continuous speech-recognition technology already developed by SRI International. One thing that had to be taken care of during the development of DynaSpeak was the memory footprint. The speech-recognition system would be software-based and could therefore not be too large. Furthermore, the system was required to recognise and react to commands quickly. DynaSpeak fulfilled these requirements from the outset. DynaSpeak is a speaker independent system which supports continuous speech which means that the pilot does not need to speak deliberately slowly but can talk in a natural way. Another advantage of DynaSpeak is that it adjusts to different speakers automatically. This is an important feature as it is not always the same pilot in the cockpit. Furthermore, DynaSpeak features noise-filtering design tools; in noisy acoustic environments the system rapidly tunes in on the voice and locks out surrounding acoustic noise.









The Helmet Mounted Display Generation III.

3-D Audio

As the IHAVS programme's recommendations were clear that 3-D audio was a benefit to the pilot, it was clear that Lockheed Martin and the programme office also wanted it integrated in the F-35. Discussions with pilots about systems they wanted in the cockpit, however, caused this capability to be deferred. Not that the pilots did not want this capability, but other preferences ensured that the money available had already been spent on other capabilities. The 3-D audio capability was important enough, however, to put the wiring and other hardware for it in place. 3-D audio is, according to Mike Skaff, only a software capability update and so, whenever the customer is ready to finance this capability, it will be installed in the F-35. The 3-D system would help the pilot with threat-warning localisation. It is also good for the radio channels: there are four audio

channels on the F-35, which can be differentiated between in space, explains: ‘So, for example, if a pilot is speaking with someone else, he can still focus in on other people’s discussion without looking. In your mind you can make your ears hear in a direction, but, if it is all out of the same speaker, that is very hard to do’.

From HUD to HMD

The JSF would be the first fighter since the introduction of the Head-Up Display (HUD) to fly without one. The deletion of the HUD provides a cost and weight reduction. More importantly, it clears important space for other instruments within the instrument panel. The HMD system for the JSF has binocular-wide field of view (FOV) with a twenty-four-hour-mission capability, meaning also night-vision capability and compatibility. The FOV is 30 by 50 degrees partially overlapped binocular which will feel slightly unusual to the pilot since it does not mimic natural human eyesight (full overlap does mimic natural human eyesight). Binocular HMD will be better suited since both eyes will be employed.

Development of the HMD was protracted and controversial. After two generations of HMD developed for the F-35, which had five problems identified, Rockwell-Collins and Elbit came to the conclusion that to sort the five problems they needed to design the third generation of HMD. Critical design review (CDR) of the HMD gen III, as it was called, occurred in October 2012 and only three problem areas were found. The problems for the VSI HMD for night vision were to be solved by a new camera integrated on the HMD. The new digital night vision camera was from the same company as the original, according to Louis Taddeo from VSI. Instead of the Intevac ISIE-10 (ISIE stands for Intevac silicon imaging engine) digital night-vision camera they would use the ISIE-11 digital night-vision camera, solving the acuity problem. The new camera is due to meet the requirements and offer almost Night-Vision Goggles acuity. According to Lockheed Martin chief test pilot Al Norman, the jitter problem was only a small fine line which occurs only during flight phases where the aircraft experiences buffet. That buffet was a larger problem than anticipated was also mentioned in the *Quick Look Review* that was leaked in December 2011. The problem of jitter caused by buffet was due to the fact that the helmet transmitter unit on the ejection seat vibrated. This would not be a problem if the pilot’s neck would not try to compensate for the vibration

caused by the buffeting. This discrepancy is the cause of the jitter the pilot experiences during flight, according to Louis Taddeo. The Director of Operational Test and Evaluation (DOT&E), however, stated in his report published in January 2013: 'Jitter, caused by aircraft vibrations and exacerbated by aircraft buffet, makes the displayed information projected to the pilot hard to read and unusable under certain flight conditions.' The other four problems with the HMD at the time of his report were latency, acuity, boresight alignment and green glow. Another report followed shortly was the readiness for training Operational Utility Evaluation (OUE) report. In that report the statement about the HMD was rather mild, but the critics could get enough ammunition to say that the programme had more problems. The report stated:

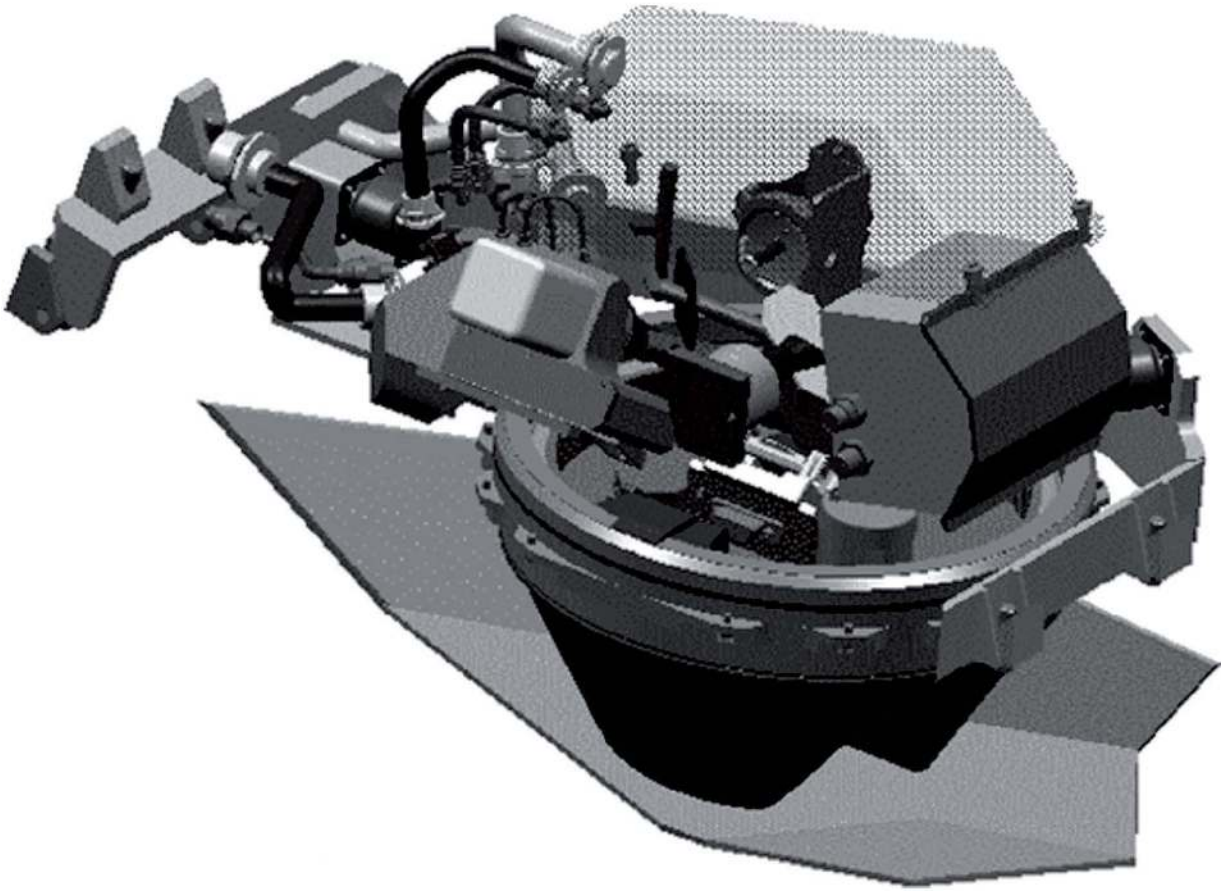


The Electro-Optical sensors can be seen on the nose of this F-35. The EOTS and two positions of the EO-DAS are clear as well. (*Lockheed Martin*)

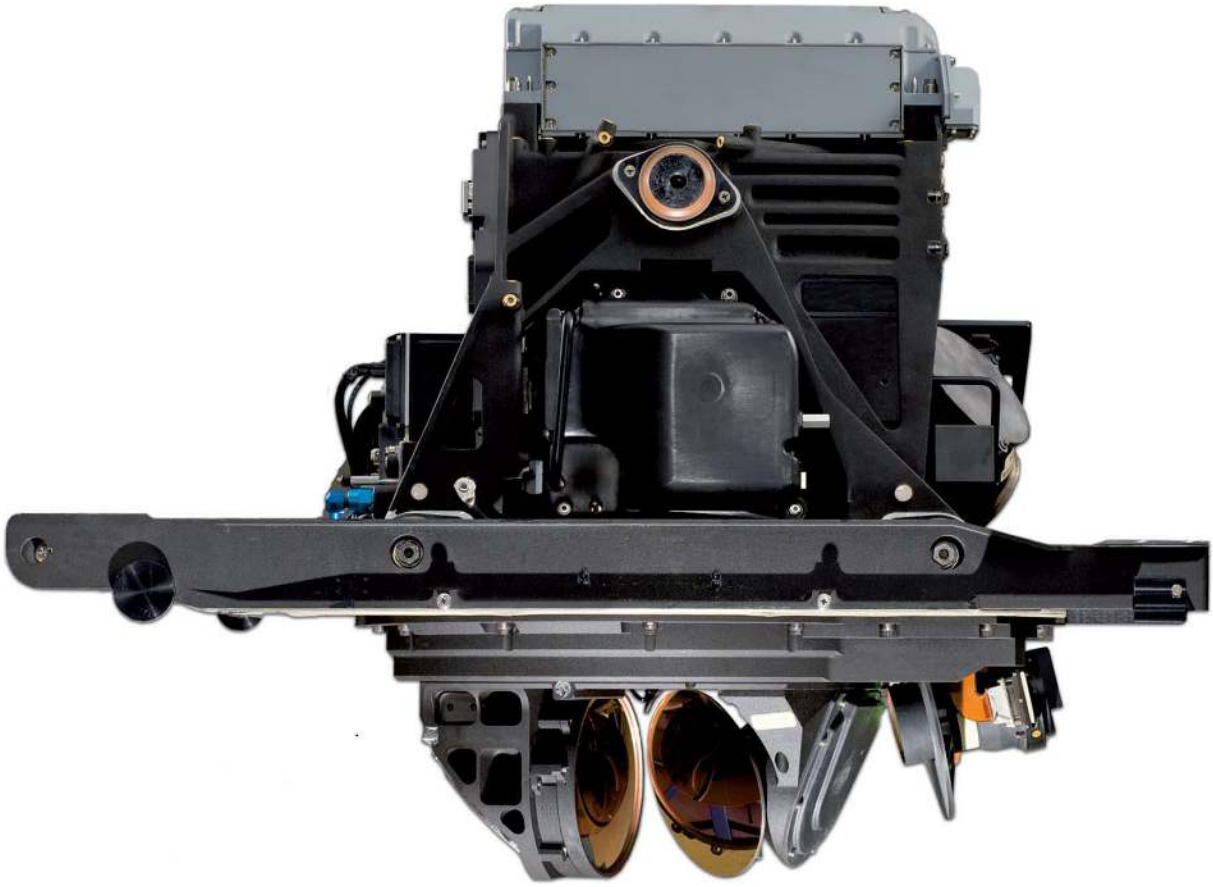
while the Helmet Mounted Display functioned more or less adequately for the purposes of the Operational Utility Evaluation (OUE) (even though it could not be used as a primary flight reference), the system presented frequent problems for the pilots. In the Operational Utility Evaluation (OUE) there were four student pilots and five instructor pilots. Five pilots

reported problems on at least one of their flights with their Helmet Mounted Display. Problems encountered included misalignment of the virtual horizon display with the actual horizon, inoperative or flickering displays, and focal problems – where the pilot would have either blurry or 'double vision' in the display, jitter, latency and brightness of the presentation in the Helmet Mounted Display. As all students and instructor pilots were experienced fighter pilots a comparison was made with aircraft equipped with a Head Up Display. One pilot was cited that the HMD is too large of a presentation causing the heading display to be overlaid on the canopy bow (and therefore hard to see).

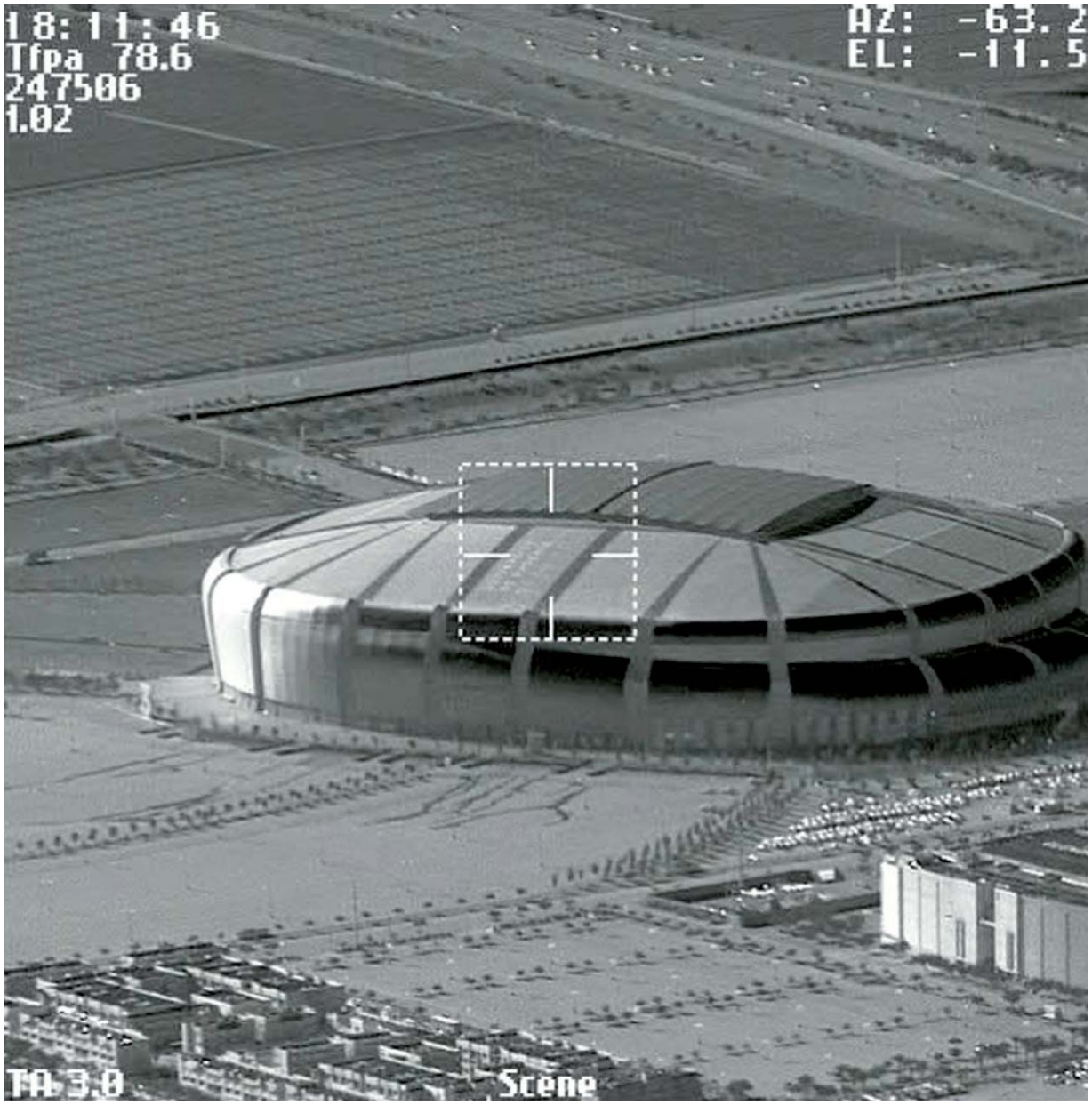
Of all the problems involving the HMD, including jitter, green glow, DAS and acuity, according to Lieutenant General Chris Bogdan green glow and DAS latency had been taken care off by 14 February 2013.



This technical drawing of the EOTS gives an impression of the packaging involved. (*Lockheed Martin*)



The height of the system within the window changes depending the turning of the system. For easy maintenance the complete EOTS comes down out of aircraft. (*Lockheed Martin*)



An early image released of the EOTS, this can be presented on the pilots HMD and/or Head-down display if the pilots want to. (*Lockheed Martin*)

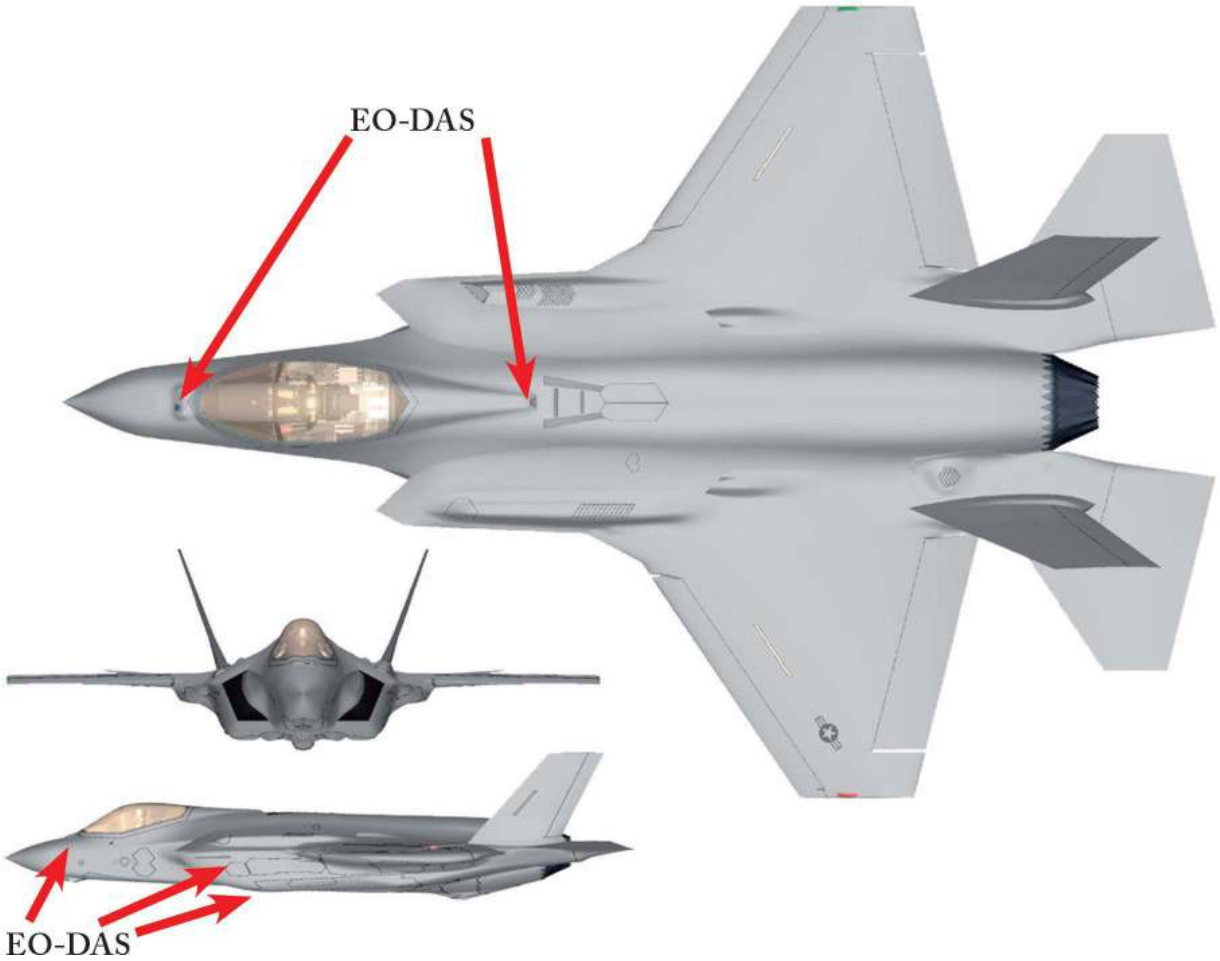
A second-generation HMD, modified with the ISIE-11, was tested in a twin-engine King Air from St Mary's County Regional Airport near Patuxent River. The first third-generation HMD was delivered by Rockwell-Collins ESA (Elbit Systems of America) Vision Systems LLC for software integration into the F-35 on 15 July 2014. (VSI was dissolved and replaced by this new joint venture in 2012.) The US Marine Corps, however, would have to make do with the second-generation HMD for their Initial Operational Capability (IOC). The third-generation HMD is expected

to be included from LRIP VII entering service in 2016. Development of the third-generation HMD was, however, due to be completed as of late 2017. The first test flight with the third-generation HMD took place on 9 September, followed by the first night flight only nine days later on the 18th. The first delivery of a third-generation HMD was announced by Rockwell-Collins ESA on 11 August 2015.

In the Director, Operational Test and Evaluation report published in early 2016 was some news about the functioning of the new-generation HMD. The problems encountered with the second-generation HMD were:

- jitter or stability of the display
- latency of imagery of the Electro Optical Distributed Aperture System (EO DAS)
- light leakage, also referred to as green glow
- night vision acuity

Jitter had not disappeared totally in the third-generation HMD but solutions already evaluated in the second-generation HMD had helped reduce jitter which still occurred during buffet and high g manoeuvres.



The location of the EO sensors graphically displayed. (*Northrop Grumman*)

Latency of the imagery of EO-DAS and from the night-vision camera was tackled by doubling the update speed. Although a significant improvement, it was noted that pilots would still need to learn an acceptable head-movement rate.

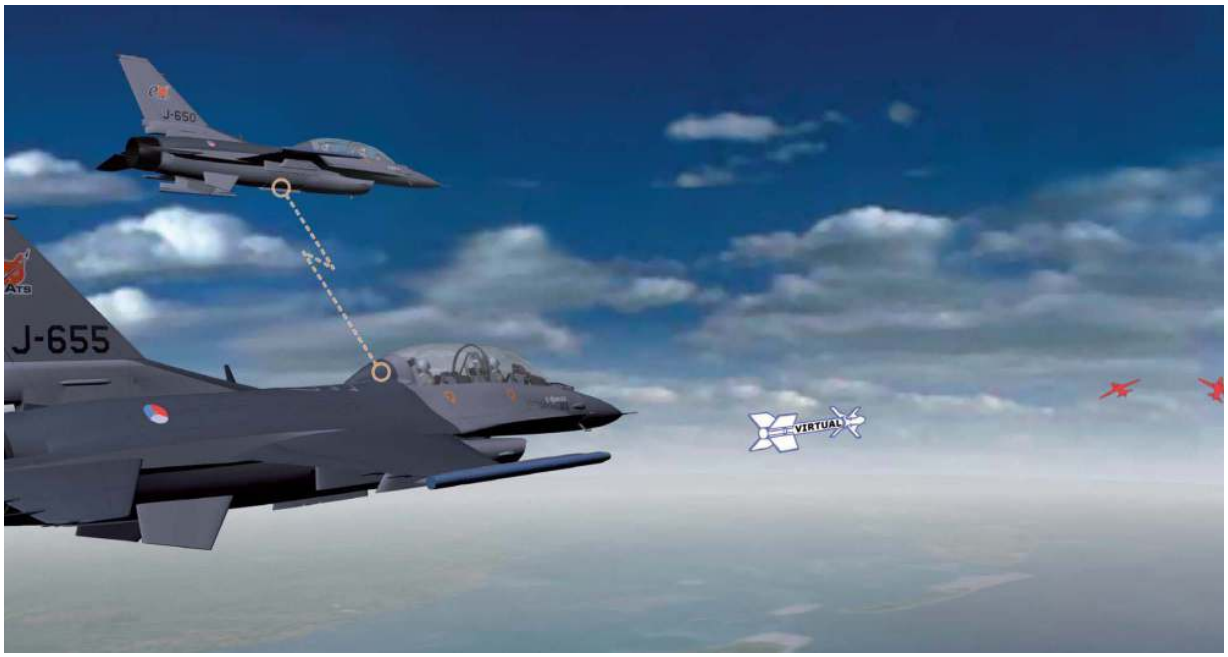
Green glow was reduced compared to the second-generation HMD. Third-generation HMD was equipped with new displays with higher contrast control. Green glow was one of the problems during the first carrier trials of the F-35C. One night operation was tried but green glow affected the sortie and no further attempts were made. The problem with green glow had the potential of being a show-stopper but at the Paris Air Show in 2017 Jeff Babione from Lockheed Martin provided information about a technology based on Organic Light Emitting Display (OLED) similar to technology used in cell phones and televisions, but in a micro-display

configuration, to solve the green glow problem. It was reported that the technology was not ready to be integrated in the third-generation HMD as its maturity was Technology Readiness Level 6. The US Navy Mantech programme initiated a technology maturation programme for Organic Light Emitting Display (OLED) by August 2017. In June 2018 the Government Accounting Office (GAO) said that the Active Matrix Liquid Crystal Display (AMLCD) in use still had a green glow problem but that the Organic Light Emitting Display (OLED) could be introduced by 2019. This green glow makes it difficult to see the full resolution of the night-vision video feed. Organic light-emitting diode displays avoid this effect by only illuminating the active pixels, according to the GAO. By October 2019 solicited for support for a one-day technology comparison for partner nations and other involved staff. The comparison would be between a AMLCD-equipped HMD and an OLED-equipped HMD. Although sixty-two organic light emitting display (OLED) HMD had been ordered for initial operational test and evaluation (IOT&E), the introduction of the OLED HMD for operational use was not planned before the end of 2021. The cost of the OLED HMD development was stated to be $3,706,000. Return on investment was expected to be worthwhile. The investment was in addition to HMDS performance improvements; this project demonstrated cost savings in assembly time and parts handling: part count was projected to be reduced by 27 per cent, and touch-time labour was projected to be reduced by 10 per cent through improved tooling concepts. The projected savings for the F-35 programme were $17.4m.



A launch of the Falcon 9 which as can be seen is a huge missile. (*Chris Thompson_SpaceX*)

Night-vision acuity was addressed by replacing the single 1280 x 1024-pixel night sensor with two 1600 x 1200-pixel night sensors. Besides the change of sensors, additional image-processing software changes were intended to provide improved resolution and sensitivity.



A computer graphic explaining how a flight of two real aircraft communication and training together against virtual red air with virtual missiles would work. Real red air would not be required. (NLR)



The two-seat F-16B could be flown with a safety pilot. Tom Burbage had a presentation flight to convince him of the advantages of the system, which was developed by the Dutch in cooperation with the NLR'? It's a little confusing as it is. (*Dutch Space*)

For all four problems improvements were reported but questions remained if they were sufficient for operational environments which had to be evaluated during the remainder of SDD and IOT&E. The changes caused the third-generation HMD to increase in weight compared to the previous

version. That increase had to be battled due to problems in relation to neck injuries to the lighter part of pilot community and therefore another HMD system was developed which received the designation Gen III Lite. Part of the weight reduction to this version involved removing one of the two installed visors (dark and clear). However, this posed a new problem for missions during the transition from day to night where both visors would be required.

EO/IR system

The EOTS was to be placed under the nose of the aircraft with only four inches protruding at all times. A special sapphire-shaped window is faceted to allow EOTS to work under all kinds of angles with minimum impact on the aircraft's stealth signature. The design of the window was taken from the ATF YF-22 programme. The EOTS is similar in size to an original 17-inch computer monitor (not a flat screen one) and is located between the radar and cockpit bulkheads: EOTS is 32.1 inches long, 19.4 inches wide and 27.5 inches high and weighs less than 194 lbs. EOTS provides the following capabilities:

- Air-to-air targeting IRST modes while
- Air-to-ground targeting third-generation mid-wave FLIR
- Battle-damage assessment confirmation
- Wide area IRST
- Laser designation
- Laser spot tracker for co-operative engagements
- Digital zoom for greater detail
- Geo-Co-ordinate generation for joint series weapons

The fact that EOTS is integrated in the aircraft means that the JSF will not have to carry any targeting pods. Ease of maintenance was kept in mind as well. If the maintainer wants to access EOTS he lowers the panel and the system comes down with the forward hinged panel, providing the maintainer with easy access to the line replaceable units (LRUs). He can stand up as he inspects or changes the LRUs because of the space available between the radar and cockpit bulkheads in the forward fuselage. According to some reports, there is a total of fifteen different LRUs on EOTS.

EOTS received its Army-Navy designation AN/AAQ-40. As the programme went through some serious delay, and development of targeting pods was continuing, EOTS became rather outdated by the time the F-35 could complete its SDD phase. In 2015 this was acknowledged both by the programme leadership and Lockheed Martin, who stated that they had a package ready to upgrade EOTS under Block 4 if the customer so wanted. The programme office saw it as a high priority for Block 4. The fact that EOTS was outdated by the time it was implemented was also confirmed in a report from Dr J. Michael Gilmore to the House Armed Services Committee. He stated that many pilots consider the electro-optical targeting system (EOTS) on the F-35 to be inferior to those currently on legacy systems, in terms of providing the pilot with an ability to discern target features and identify targets at tactical ranges, along with maintaining target identification and light amplification by stimulated emission of radiation (LASER) designation throughout the attack.

The DAS should give the JSF 360 degrees spherical threat warning, including missile threat warning, IR aircraft search and track, situational awareness, pilotage, battle damage assessment and weapon delivery support. Furthermore, increasing situational awareness makes it possible for the pilot to evade high-risk areas and gives a better chance of survival. The system saved a lot of weight as fixing it to the aircraft prevented the requirement of pointing and stabilising the sensor as required with EOTS. The six sensors would only require a software solution covering the entire field of view of 360 degrees around the aircraft.

The complete EO-DAS had received the AN/AAQ-37 designation by February 2004. The designation from the electronic equipment identification system, which originates from the US Army and Navy (AN) means basically that the AN/AAQ-37 is designed for a manned aircraft (A) and works on invisible light radiation (A) and has a special purpose (Q).

The EO-DAS is supposed to find launch points of man-pad fired missiles, surface-to-air missiles (SAMs) and even anti-aircraft artillery (AAA), allowing the pilot to react and destroy these stations. If flying in formation, the EO-DAS can even tell which aircraft in the formation is being targeted. The EO-DAS system information to be displayed on the HMD would give this imagery day or night. The night imagery would have an acuity of 20/20, better than night-vision goggles. It was expected to be a

major facilitator for carrier pilots for night landings as even sea waves could be seen by the EO-DAS at night.

The EO-DAS beyond locating the launch points of missiles on the ground has also use for air-to-air warfare. In an air-to-air battle the EO-DAS can keep track of aircraft in the area and, for the pilot's ease, will identify each aircraft so that the pilot is aware at all times where the friendlies and the enemy are located, which would reduce the risk of blue-on-blue fire.

'DAS is an omni-directional infrared system that can simultaneously detect and track aircraft and missiles in every direction, with no practical limit on the number of targets it can track. DAS truly revolutionises the way we think about situational awareness,' said Dave Bouchard, programme director for F-35 sensors at Northrop Grumman's Electronic Systems sector. 'In recent testing, DAS has proven to have applications and capabilities beyond its initial requirements for the F-35, including ballistic missile detection and tracking, and counter-rocket, artillery and mortar (C-RAM) capabilities.' This statement pointed out that the capability the EO-DAS could supply was one of missile defence. A software update would suffice to ensure that the data collected would be sent by datalink or any other communication available without the interaction of the pilot or him being aware of it. That would mean that the F-35 aircraft would become nodes in the missile-defence system; if one took into account the amount of F-35s planned it could become a lot of effective nodes in the inventory supplying this capability without increasing pilot workload.



The blue forces and red forces can be virtual or can be constructive, meaning they can be in simulators connected through the ETS and data-link. (*NLR*)

To the question how information overload is prevented (because to be able to see everything in a 800-miles/1,300 kilometres radius around the aircraft can be a rather disturbing thought) Mike Skaff from Lockheed Martin answered that the regular surface-to-air missiles are not that big and therefore doubts that in that sense the system will cause information overload as only the information of direct importance to the pilot is shown. The information will be available after download for evaluation purposes.

However, on 11 February 2013 Northrop Grumman announced that, during a test flight aboard its BAC 1-11 (N162W), the AN/AAQ-37 EO-DAS had detected and localised tanks firing live rounds. Northrop Grumman believes that the system is capable of detecting and pinpointing anti-aircraft artillery firing.

After some news that the EO-DAs was one of the main factors of the F-35 not being 'full mission capable' but due to malfunctions – often just 'partially mission capable' – it should not have been a surprise when the news broke and was confirmed shortly after with a press release by Lockheed Martin that Raytheon had gained a contract for a replacement unit in 2018. The EO-DAS should become available five years later, that is in 2023, after some 750 aircraft would have been delivered. Lockheed expected lifetime acquisition savings while increasing the range of the sensors.

The Electronic Warfare system

The EW system for the F-35 weighed 200 lb, considering that it is doing the work of a system that previously would have a weight of around 1400lb. BAE Systems was not just waiting but already aiming to reduce the size and weight even more so that other capabilities can be added. The Electric Warfare suite for the F-35 gained the designation AN/ASQ-239 and nickname Barracuda. On the F-35 the AN/ASQ-239 Barracuda will have 6 apertures located on the leading edge of the wings, 2 apertures are located on the trailing edges and the last 2 apertures located on the trailing edges of the horizontal stabilisers accounting for a total of 10 apertures.

From the embedded training system to Live, Virtual, Constructive (LVC) training

Initial training was to take place at Eglin AFB. However, once the pilots are back at their units training continues but at a different level. With only a limited number of F-35s based there, pilot training was dispersed to other bases. The USMC took their training squadron to Beaufort Marine Corps Air Station and the USAF to Luke AFB. Training was being done on a daily basis, but in Europe space for training is sparse. For the US services the problem of the sensors becoming longer range required larger areas to train. 'Train as you fight, fight as you train' is easier said than done. That the training of fighter pilots is becoming ever so expensive has been clear for a while. The things that a pilot has to do and manage during a flight have also increased. The pilot-training syllabus has changed over the years. First of all, the pilot has to earn his wings and then go to a unit that will teach him how to fly an advanced jet. After this, the pilot goes to a conversion unit to be taught to fly the fighter aircraft to which they will be assigned. After completing conversion training, the pilot has achieved limited operational capability and goes to an assigned unit, which is where skills will be honed.



Cubic's Secure LVC Advanced Training Environment (SLATE) is cutting edge technology that has been demonstrated a fully capable TRL 8 LVC solution in 2018. (*USAF*)



One of the Aero L-29 involved in the testing for LVC demonstration here pictured during F-35 HMD evaluation. (*ITPS via Panos Vitsas*)

The embedded training system (ETS) should be able to emulate at least some of the sensors on the fighter aircraft such as radar, electronic warfare (EW) system, radar warning receiver, datalink, and those on pods such infra-red search track (IRST), forward-looking infra-red (FLIR) and electro-optical (EO) systems.

Embedded training is thought to bring some advantages to the user:

1. Cost reduction
2. Small volume of air space
3. Security benefit
4. Simulation of air threats and ground threats, reduced need to allocate live ground and air threats in the training area as they can be simulated

The cost reduction is clear: it is cheaper to fight a virtual aircraft as you do not need to have a so-called red aircraft flying. The security benefit is clear

since any observers from the outside will not be clear what is being trained. When training for beyond-visual-range, normally the red aircraft is required at a good distance because of the range of modern missiles which is likely to increase with the range of radars and next-generation missiles. With virtual aircraft as the red aircraft, actual air space for the red aircraft is not required.

The difference between an embedded training system for a lead-in fighter trainer (LIFT) and an embedded training system for a combat aircraft is that the former can replicate all sensors of a combat aircraft. The latter has to co-operate with the avionics and sensor suite of combat aircraft such as radar, IFF, EW, RWR, datalink, etc. Taking into account the thought of integrating such a system on the F-35 Lightning II becomes an even bigger challenge due to bigger sensor suite than current inventory fighters – think of the EO-DAS and EOTS.



The Aero L-29 is possibly one of the oldest aircraft used for evaluating but it might be one of the cheaper aircraft to operate. (*ITPS via Panos Vitsas*)

The ETS developed by Dutch Space and NLR is hosted on the F-35's integrated core processor (ICP) and provides not only red aircraft but also simulation of friendly aircraft which would have to be taken into

consideration during the exercise such as threats from the ground such as surface-to-air missile launches. Even the ground-control-intercept communications with their updates were simulated by the system. The system can be prepared on the ground so that the instructor can set the scenario prior to the flight and the pilot can replay the situation after flying the mission and evaluate from the events and his actions, thus learning from his mistakes. To make the embedded training system effective there should be a broad database of different training scenarios for the pilot.

The F-35 ETS consists of a virtual training capability and a P5 combat training system. Furthermore, some details came out that the P5CTS was lacking its own global positioning system/inertial navigation system (GPS/INS). The P5CTS would get this information from the mother aircraft's systems. In its place another system found its way incorporating a National Security Agency (NSA)-certified Type-1 encryption unit for secure datalink communications.

Each fighter has a 30lb package of instruments installed which can be removed easily if required. The embedded system will allow the JSF to simulate training exercises even after the aircraft has been deployed to other air bases. The system can be activated by the pilot on the pilot vehicle interface, in other words on the head-down display, by selecting TRAIN mode. When TRAIN-mode is selected the aircraft can not only simulate weapons but also expandable countermeasures.

An off-board mission support environment (OMSE) used to create, edit, and store ETS Scenarios is then loaded into the portable maintenance device (PMD) and transferred to the aircraft as mission pilot-selectable data. These scenarios can be selected once the TRAIN-mode is selected. Here, however, there are multiple options available to the pilot who can select the Red-air scenario involving real aircraft as the opposing aircraft or the virtual threat scenario. The threat environment is generated by the on-board synthetic threat environment. Once the pilot selects a scenario he receives an aural confirmation of the selection made so that, if the input was wrong or for whatever other reason not entered correctly, the pilot can alter the input.

According to Dutch Space, the ETS is the cornerstone capability for live, virtual, constructive (LVC) training.

- Live: a platform or system as it is in actual use by military operators; this includes special training equipment like trainer and/or fighter aircraft.
- Virtual: an operator-in-the-loop simulation of a live platform or system.
- Constructive: a simulation of a live platform or system whereby the operator is also virtualised.

Within the concept of LVC training being explored by many air forces, the embedded ETS functionality in the F-35 provides a cornerstone capability. ETS provides the live and virtual threat environment as the constructive aspect of LVC. With ETS onboard, the fighter pilot can participate in mission-training sessions within the confines of a live, virtual, constructive range, and train anywhere, anytime, without the need of an instrumented training range.

In the US there were also several programmes to develop a LVC simulation. Lockheed Martin, Rockwell Collins and Cubic were all busy with developing such simulation capability. Rockwell Collins announced in January 2011 that it had performed LVC simulation demonstrations at the Inter-service/Industry Training, Simulation and Education Conference (I/ITSEC) in Orlando in December 2010. The demonstrations, led by representatives from Rockwell Collins' Advanced Technology Centre (ATC) and Simulation and Training Solutions (STS) organisation, included the following participants:



The L-29s from University of Iowa Operator Performance Laboratory that were available for the tests. These were also used later in support of the HMD for the F-35. (*Rockwell Collins*)

- A live Aero L-29 jet trainer operated by the University of Iowa Operator Performance Laboratory (OPL) in Iowa

- A pilot, operating as the wingman for the Aero L-29 pilot, in an F/A-18 simulator at the Naval Air Warfare Center (NAWC) exhibit also at Interservice/Industry Training, Simulation and Education Conference (I/ITSEC)
- A Joint Terminal Attack Controller (JTAC) in the Rockwell Collins booth at Interservice/Industry Training, Simulation and Education Conference (I/ITSEC)

Together, the participants collaborated in a CAS scenario in a virtual battle space near Solvang, California. The Aero L-29 pilot, while physically located in Iowa, flew with visual reference to the virtual environment in California. His Orlando-based wingman and the joint terminal attack controller (JTAC) also had displays that showed the virtual California scene.

Additionally, the Aero L-29 Delfin jet had an onboard flight simulator computer that augmented the scenario with the full spectrum of interactions that are typically available only in ground-based High Level Architecture (HLA) simulations. The Rockwell Collins' station featured an EPX-50 image generator that showed a very detailed photo-realistic view of the battle space, serving both the conference audience and providing situational awareness to the JTAC. To allow the Aero L-29 Delfin to participate, the cockpit had been retrofitted with two large glass displays so that the virtual scenarios could be displayed to the pilot. The University of Iowa Operator Performance Laboratory had two of these former Czechoslovak L-29 Delfins at their disposal.

'This was a collaborative effort between Rockwell Collins; ATC and STS organisations, and the University of Iowa and Naval Air Warfare Center (NAWC) that has the potential to deliver some real advantages for military training efforts,' stated John Borghese, vice president, Advanced Technology Center for Rockwell Collins. 'The valuable data that we collected during the exercise will be used in a variety of live, virtual, constructive (LVC) research projects underway.'

'The ability to join virtual and real worlds in a complex scenario like this one could one day truly advance warfare training to a whole new level,' said Ken Schreder, vice president and general manager, Simulation and Training Solutions for Rockwell Collins. The Office of Naval Research awarded a $2.9 million contract to Rockwell Collins. Rockwell Collins had

to research the effects of inserting virtual and constructive entities into live aircraft systems while maintaining safety during training scenarios. Working again with the University of Iowa Operator Performance Laboratory, Rockwell Collins was using advanced datalink and multi-level encryption technologies to inject computer-generated forces into pilots' displays in the university's L-29 jets in numerous air combat scenarios. Rockwell Collins also teamed with Embry Riddle Aeronautical University to conduct Cognitive Task Analysis on pilot responses, for requirements definition and verification.

Non-linear Dynamic Inversion Flight Control System

Non-linear Dynamic Inversion (NDI) was considered a success upon completion of the X-35 flight test programme, so much so that it was integrated on the F-35. The F-35 became the first production aircraft equipped with Non-linear Dynamic Inversion (NDI) control laws and was a step further than the X-35 in the sense that it also had weapons-carrying capability which would influence the model. The X-35 was a 7G-capable fighter design which was deemed sufficient by Paul Bevilaqua also for the operational stealthy aircraft. The F-35A, however, would be designed for 9G. This would come at a weight penalty and, according to the Perato principle that 20 per cent of the requirements cause 80 per cent of the structural weight, wind tunnel tests were helping create the on-board model for the F-35. In 2018 the F-35 on-board model (OBM) had approximately 3.5 million data points.

For the F-35's three versions the control surfaces differed which had an effect on the OBM.

Control surface (effectors) deflection limits

Surface	**CTOL and STOVL**	**CV**
Leading Edge Flaps	Upwards 3° downward 40°	Upwards 3° downward 36°
Trailing Edge Flaps	Upwards 30° downward 30°	Upwards 30° downward 30°
Horizontal tails	Upwards 30° downward 25°	Upwards 24° downward 27°

Rudder	±30°	±30°
Aileron		Upwards 30° downward 30°

The OBM has to exist in three variants and, as a result, is different for each variant. Although the movement of the horizontal tails is the same for the CTOL and the STOVL variant, the latter variant has a 9 per cent smaller surface than the CTOL variant. On the other hand, the F-35C or CV has larger vertical and horizontal tails. Since control surfaces are no longer operated by a hydraulic system as in previous generation fighters but through electro hydrostatics actuators (EHA), the non-linear dynamic inversion flight control system has to have good feedback on the status of the electro-hydrostatics actuators (EHA) and the primary control surfaces. The F-35C is the exception that the aileron was based on the conventional hydraulic system; basically the NDI flight control system for the F-35C has to communicate with a different system than the other two versions.

Another thing that complicated things a bit was that each aircraft had a different internal fuel system layout. To calculate everything correctly without the need for the pilot to take into account the fuel status, puts extreme demands on the fuel measurement system; the flight-control laws should have accurate information about eventual problems with fuel pumps or transfer system. Another difference among the variants is the weapon load since the F-35B has smaller weapon bays. The smaller weapon bay doors open and automatically close after weapon release; the different weapon-door sizes have differing aerodynamic influence on the flight-control system.

Crew Escape System

The US16E is made of the following sub-assemblies:

- A wide seat bucket within which is located the survival aids container, a backrest and under-seat rocket motor (USRM). The 19.5-inch-wide seat bucket is based on the one used for the NASA T-38N upgrade programme.
- A twin-tube catapult with integral penetrators. On the catapult structure are located: an energy absorbing head-pad a drogue parachute container, the main parachute container, an inertial retraction device and a third-generation commercial off-the-shelf (COTS) triple-redundant electronic sequencer.
- Side-mounted guide rails
- Fully-integrated life support and helmet-mounted-display (HMD) equipment

To give the third-generation COTS triple-redundant electronic sequencer an autonomic capability it is connected to thermal batteries mounted on the seat. In other words, the sequencer is independent of aircraft power supplies. The sequencer selects drogue, parachute and harness release times. The release times are dependent on the altitude and speed measurements of the sequencer. To reduce the effects of seat rotation on the speed sensor the sequencer had to be mounted near the centre of gravity, which was between the catapult tubes. The US16E would become the first ejection seat in US service that has HMD safety integrated from the outset. One of the differences between the previous generation seats and the US16E is that, in the previous generation, a booster cartridge was required in the gas system to initiate the USRM. Design changes allowed for the elimination of this booster cartridge in the US16E seat.



One of the early tests. Note that the Transparency Removal System splits the canopy in two pieces. The test was performed at 0 speed. (*Martin-Baker*)



The US16E seat under test. Note the airbags that hold the pilot's head and restrain it preventing neck injuries. (*Martin-baker*)

As an automatic ejection system (AES) was installed it was important that no delay with canopy removal be incurred. Normally, with current fast-jet fighter aircraft when the canopy has to be ejected the activation of the ejection seat procedure has a ~300msec delay, to allow the canopy to hinge/rotate upwards and clear the escape path before seat ejection can commence, thereby degrading safe terrain clearance performance. These ~300msecs can mean the difference between life and death in a situation where an aircraft can turn upside down in less than two seconds and the AES has only ~500msec to appraise the situation and initiate ejection. An example of a zero-time delay system is fragmentation (break through the canopy) recommended AES developer. A new system was developed by McCormick Selph Inc., a US company, called the transparency removal system (TRS). TRS is really from the same family as fragmentation, in that there is no dedicated seat time delay required, commonly known as 'zero time delay' systems; this maximises system safe terrain clearance performance and is required to provide equivalent 'best of legacy' performance, viz AV-8B, for the JSF STOVL variant. The TRS is used to split the transparency into two 'fly-away' panels which, when separated from the canopy frame, create a space through which the ejection seat will pass in the event an ejection is initiated. A flexible linear shaped charge is used to pyrotechnically cut the transparency into two clam-shell halves. An acrylic hinge system at the rear of the panels, in conjunction with the

inherent aerodynamic lifting moments acting on the panels, ensure safe escape path clearance is provided, and the hinges prevent the panels hitting the pilot in a later stage of the ejection process. The cutting cord in the TRS system goes through the middle of the canopy and can only be seen by the seated pilot. It is routed down the sides of the transparency from the centreline to the canopy side rails, aft of the ejection seat, but this is not within the pilot's field of view when looking at his six o'clock position.



From the ejection seat leaving the cockpit to parachute deployment. It is not supposed to be used often but every time someone requires it has to work perfectly. (*Martin-Baker*)



The Martin-Baker US16E seat. (*Martin-Baker*)

On the US16E seat, the auto-eject unit (AEU) that actually fires the seat is made by Martin-Baker but the signal comes from the ejection seat firing module (ESFM) which is provided by another company.

The seat is described as plug and play. When asked what was meant by this term in respect to the ejection seat the answer was that legacy seats are installed into the cockpit rails and locked into place. The pilot services are then normally connected separately between the seat and the structure. Examples of items connected in that space between the seat and the structure are oxygen, anti-G, arm-and leg-restraints anchors, seat-system initiation lanyards, etc. This, of course, has to be taken into account when designing the cockpit so that ground crew have access to make these connections or disconnections when it comes to maintenance. The US16E has been designed in such a manner that the pneumatic and electrical connections are automatically mated when the seat is installed into the aircraft.



Martin-Bakers programme badge. (*Martin-Baker*)

As Martin Baker also had problems qualifying their seats for the smaller anthropometric population with their JSF effort, they also contacted Survival Innovations Inc. to apply their system in connection with the US-16E. Martin Baker had experienced problems mainly with the anthropometric population below a weight of 150lbs. The US-16E had been qualified for people from 150lbs upwards. The problem was increased by the fact that HMD made the helmet carried by the pilots heavier and, therefore, forces on the head and neck during ejection are greater as well.

The auto-escape system includes flight-control algorithms in each triplex vehicle management computer (VMC) monitoring pitch, pitch rate, pitch acceleration, airspeed and weight-on-wheels information to determine if auto escape is enabled and if an auto escape is commanded. An off-seat escape system firing module (ESFM) device validates the ejection command (two of three voting) and completes the firing circuit, sending an electrical pulse to the seatmounted auto-escape explosive cartridge to initiate ejection.



0 speed 0 altitude ejection test 18 February 2016. (*Martin-Baker*)

Pure Power

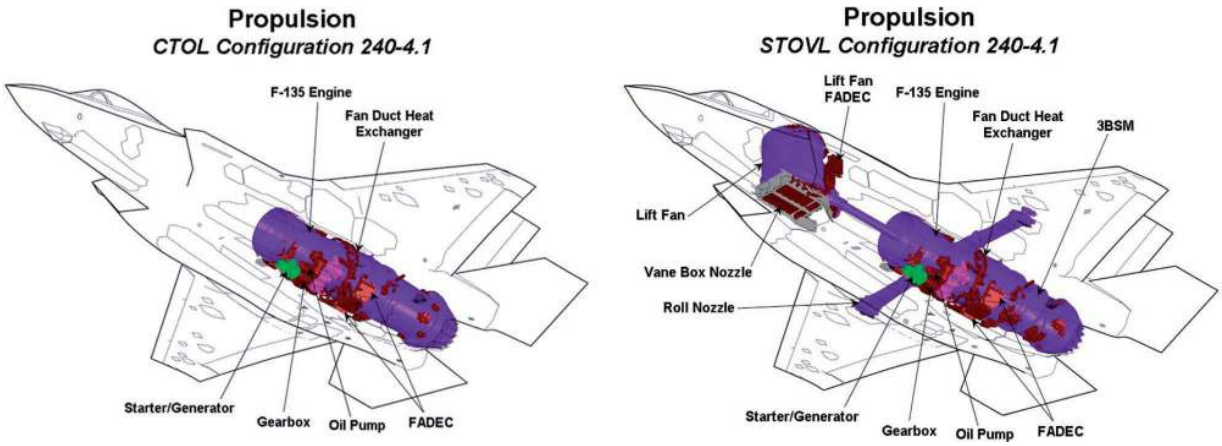
The Pratt & Whitney F135-100 was the designation for the CTOL version, the new F135-400 designation for the carrier version and the new F135-600 for the STOVL F-35B version. The F135-600 received enlarged roll posts so that the production F-35B would have increased stability during hover flight and increased effectiveness of modulation of the asymmetric loads. A limit that was set on engines was a not-to-exceed weight for the CTOL engine of 6500lbs.

The F135-100 engine provides 43,000lb of thrust with afterburner, which makes it the most powerful engine; to achieve this power, the inlet has a 43-inch diameter. Although the engine is a derivative of the F119, materials and parts had to be changed due to disclosure problems with certain technologies. The F135 has a three-stage fan, also known as a low-pressure compressor (LPC); the engine core includes the high-pressure compressor, high-pressure turbine (HPT) and combustor. Further, the F135 is equipped with a two-stage low-pressure turbine (LPT). The LPT is responsible for powering the lift-fan of the STOVL version. The afterburner is the last significant part of the engine. As previously stated the F135 engine is the most powerful, but that comes with a penalty of higher temperatures. The engine relies on nickel alloys, ceramic matrix composites and organic matrix composites and cooling for preventing the engine parts to melt.

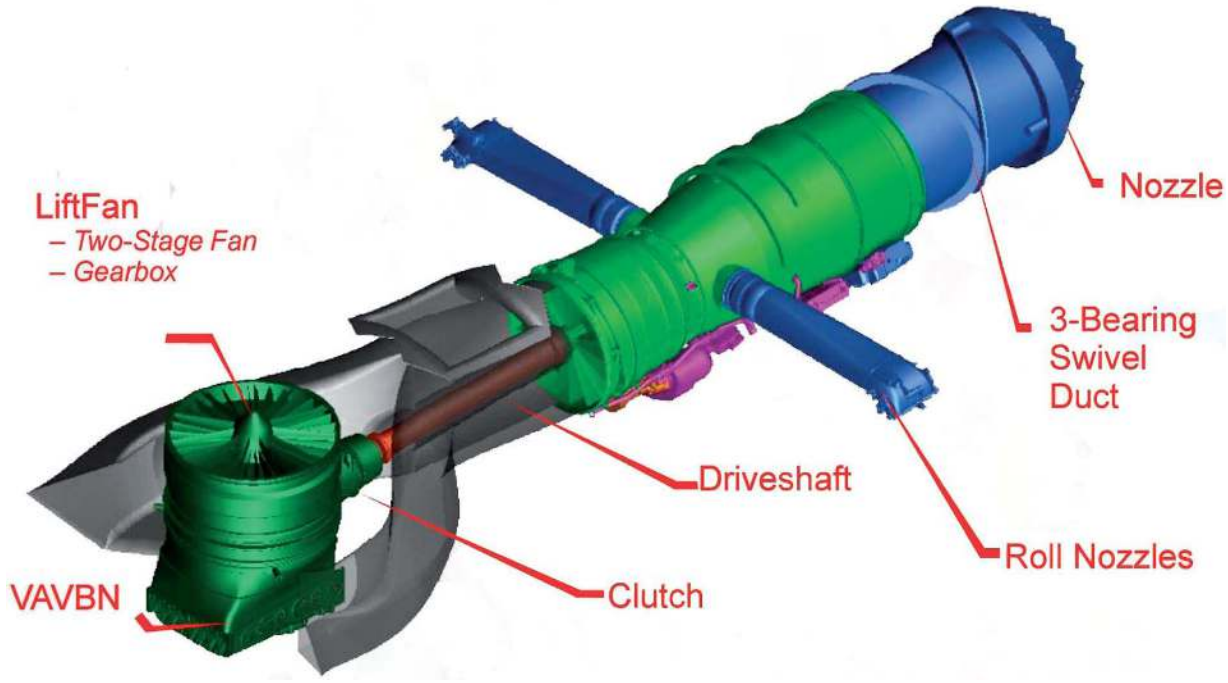
Ease of maintenance has been designed in from the outset and experience from the F119 and F100 engines has been utilised and improved on, so that the maintainer should be able to access all important subsystems from the bottom of the aircraft and, reportedly, requires only six tools. As the aircraft relies on a prognostic health management (PHM) system, so, too, does the engine to help the maintainer troubleshoot or indicate required maintenance action.

Although the three engine versions should be common to all versions, the STOVL propulsion system is more than just the F135 engine. The commonality factor is shown by the fact that the F135-100 and F135-400 are equipped with the same two-stage low-pressure turbine whereas a single stage for these two versions would be sufficient. The STOVL propulsion system can be divided into the following:

1. The lift fan
2. The driveshaft
3. Clutch
4. Accessory gearbox
5. Variable Area Vane Box Nozzle
6. Main engine (F135)
7. Three-bearing Swivel Nozzle
8. Roll post nozzles



A good comparison of the propulsion system integration for the different versions. (*TeamJSF*)



The VAVBN stands for the Variable Area Vane Box Nozzle which replaced the Baby Carriage Hood. The grey areas are the inlet ducts with the auxiliary Inlet graphically displayed on top. (*Pratt & Whitney*)

The STOVL engine provides 41,000lbs thrust with afterburner. However, in the hover it does not use its afterburner as the lift-fan provides the additional thrust required for hover. Dry power of the main engine is given at approximately 27,000lbs. The lift-fan provides the second main pillar of downward thrust.

The lift-fan has to provide 18,680lbs (83.1(kN) of cool downward thrust. The word 'cool' should be taken lightly since it could still burn your skin but compared to the exhaust of the F135 the description of cool fits. The driveshaft is powered by the two-stage low-pressure turbine of the F135 engine which, in turn, is connected to the lift-fan through the clutch and accessory gearbox. The driveshaft will rotate around its axis at about 8,000 rpm. As the clutch is located near the lift-fan, the driveshaft will continue to rotate even during normal flight when it will be disconnected from the lift-fan. The engagement of the clutch provides excessive heating and for this reason material similar to that used in carbon brakes is employed.



Clean off the production line. Note that all accessory boxes are below for easy maintenance. (*Pratt & Whitney*)

The variable area vane box nozzle (VAVBN) is capable of directing the 20,000lbs of thrust of the lift fan through 54 degrees in two seconds and has six vanes. The torque, or the force in the turning moment, on the vanes, is larger than the torque produced by a Cadillac engine. Of the VAVBN's six vanes, the first two are on one actuator, three are in the middle on one actuator and the last is actuated independently by itself. The VAVBN is a structural part of the F-35's middle fuselage and for this reason has to be delivered well in advance of the other propulsion parts.

In early 2012 a new science and technology development programme was initiated which immediately caused great consternation in Pratt & Whitney. The development programme was called adaptive engine technology demonstration (AETD) and aimed to reduce specific fuel consumption (SFC) rather drastically for the 2020 timeframe compared to the state of the art engines such as the F135. Specific fuel consumption improvement during cruise was targeted between 20 to 35 per cent and, during take-off, around 15 per cent. The potential for an adaptive, variable cycle engine is huge.


SR-16



A STOVL engine under test. Note that the exhaust of the lift fan is being removed to ensure this exhaust does not re-ingest. (*Pratt & Whitney*)



The first vertical landing of BF-1. A big propulsion system-related milestone that had been proven on the X-35B. (*Lockheed Martin*)

According to Pratt & Whitney, this looked like an attempt to revive the F136. Reduction of specific fuel consumption had two effects: first, cost would go down and, second, would improve the range of the F-35 or it could stay longer on station. The main aim is to ready technology that was proven during the adaptive versatile engine technology (ADVENT) programme run by the Air Force Research Laboratory (AFRL). The ADVENT programme had developed technologies for variable-cycle engines; the F136 was a variable-cycle engine while the F135 is not.

Phase 1 of the AETD programme, which ran through the mid-fiscal year 2015, included completing preliminary engine design, testing a full annular

combustor rig, high-pressure compressor rig and components using CMCs. Phase 2 of the programme, which will conclude in the fiscal year 2016, consists of fan-rig testing and a full engine-core test, allowing for a notional first full engine test as early as 2017. Both General Electric and Rolls Royce received funds for phase 2, leaving Pratt & Whitney out. Meanwhile General Electric was about to initiate core testing under the ADVENT programme. Full up testing under the programme was due in 2013.

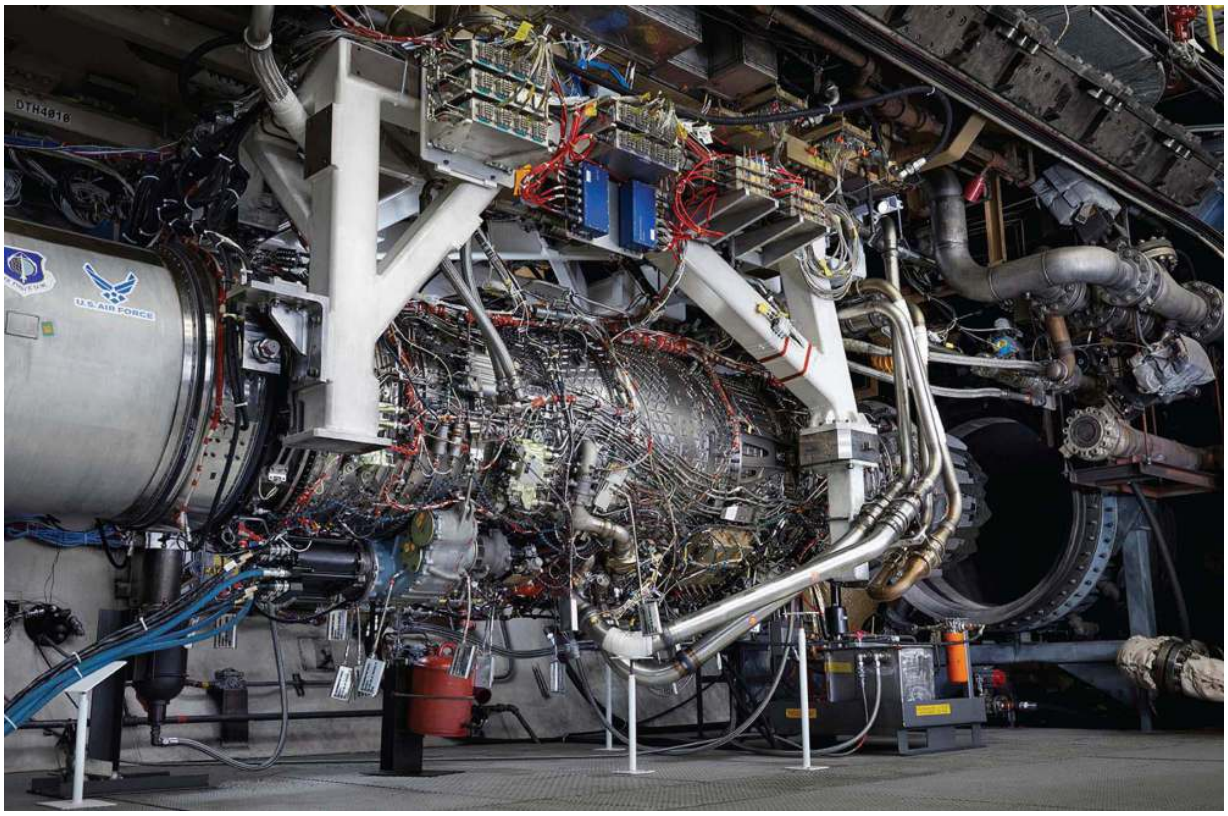
The adaptive engine technology demonstration (AETD) aimed to use the new technology around a core similarly sized for a propulsion system for a future bomber or any sixth-generation fighter, which is incidentally the same size as the F135. The congressman from Connecticut, Joseph Lieberman, one of the main opponents of the alternate engine, was, however, intent on making sure that this was not aimed at reviving an alternative engine. Although no contractor for the AETD programme had been selected, the war was on again. There were three bidders for the programme: General Electric, Pratt & Whitney and Rolls Royce. First engine to test (FETT) for the AETD is planned for 2016. By 17 September 2012, Pratt & Whitney and General Electric had been selected. That Rolls Royce lost out was a surprise to many observers since Rolls Royce was working under the Air Force Research Laboratory (AFRL) ADVENT programme. The selection of Pratt & Whitney, however, solved the tricky situation in Congress where some perceived the AETD programme as an effort to reinstate the alternate engine. Four days later General Electric was awarded the $394,747,900 contract for the AETD programme. The General Electric demonstrator was designated XA100 and the P&W engine was designated XA101. Both demonstrator engines should be in the 45,000lb-thrust class. Both demonstrators started running tests and set up a competition for the next generation engine and possibly opened the door for re-engining the F-35.



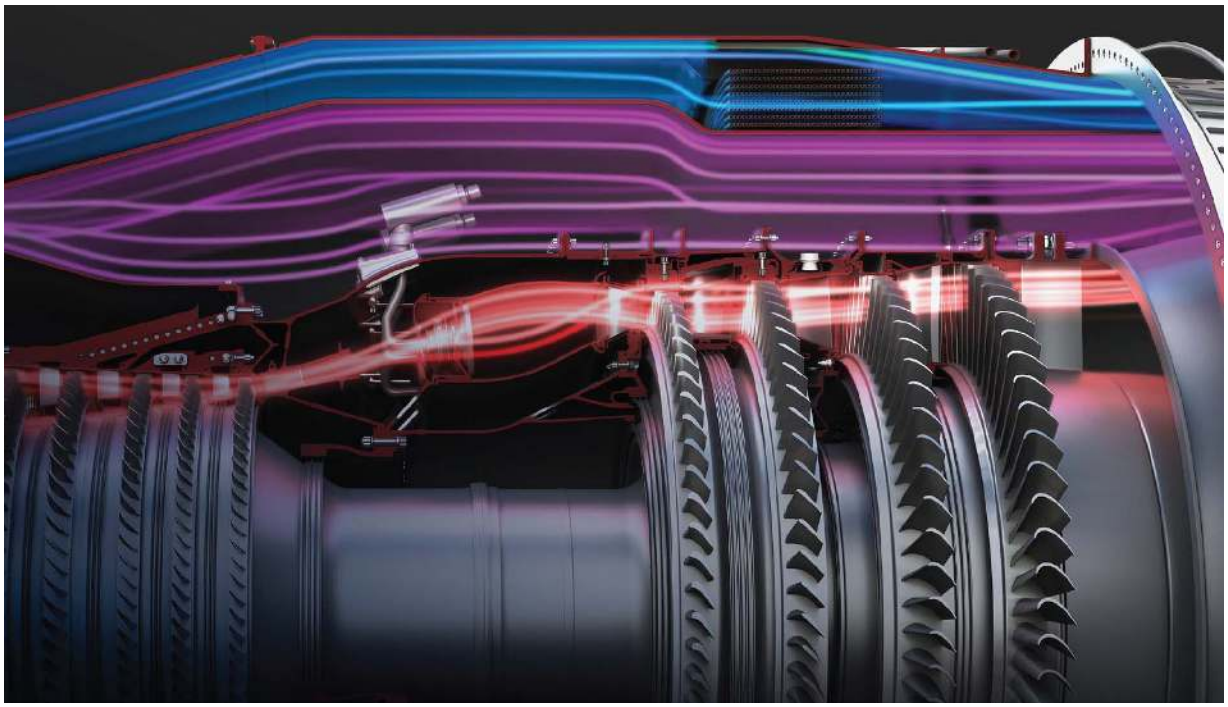
The light of the afterburner mixes nicely with the evening sky. (*Lockheed Martin*)

The third option is an upgrade of the existing F135 engine, which is called the F135 EEP Enhanced Engine Package.

Starting with the F135 EEP it is an engine that its upgrades would allow introductions in all three variants. The upgraded F135 offers a bigger than 10 percent increase of F-35 range, similarily thrust would be boosted by more than 10 percent, improve thermal management capacity by more than 50 percent, and the powered lift of the STOVL F-35B would grow by five percent. Cost of intergrating a new engine could be avoided – just remember the F-16 required a redesign of the inlet for the second engine. According to Pratt & Whitney F135 EEP can deliver the needed capability for Block 4 aircraft faster, cheaper, and with less risk than a new, unproven engine and can cover power and thermal management system growth to the maximum capability of the F-35. The disadvantages are that Pratt & Whitney would maintain its monopoly on the F135. As has been shown with the F-16 engine competition gives both manufacturers a bigger incentive to improve their engines in case of problems.



The actual General Electric XA100 test engine in the test cell in 2021. Pratt & Whitney is competing with the XA101 engine and offering an upgrade path to the F135 that would be cheaper. (*General Electric*)



A visualisation of the workings of the General Electrics XA100 engine. This might be something to be introduced in later block aircraft. (*General Electric*)

The Pratt & Whitney XA101 offering is mostly aimed at 6th generation fighter aircraft. The new technology with a third stream would only be possible for the F-35A. It has been reported that for the F-35C it would require a redesign for the F-35C tailhook location. Pratt & Whitney confirms that they met the targets set out by the AFRL.

Budget constraints still exist so only one of the AETP engines is likely to be selected for integration in the F-35 giving the newly selected engine a clear advantage and from that moment a very real advantage for the next generation fighter. So in the case of selection of a new engine Pratt & Whitney stands to lose the most. The General Electric XA100 is the second design under the AETP. So it is rather telling that the XA100 does fit both the F-35A and F-35C and does not require redesign of the tailhook. Besides all this the General Electric AETP engine offers 30 percent more range, twice the thermal management and due to lighter and more durable materials a larger than 20 percent acceleration.

The cost of integrating one of the AETP engines would mean that a total reduction of 70 F-35As would be required for the USAF to even out the budget. An interesting situation would unfold if one of the AETP designs was selected as the F-35B would miss out altogether and, considering that

shaft driven lift fan propulsion capability was the beginning of the winning Lockheed Martin design for the Joint Strike Fighter, this would be strange. The eventual engine upgrade for the F-35B and depending on engine choice F-35C operators would have to be considered separately and this would incur extra cost, the F135 EEP customized for the F-35B would become a major cost burden on the F-35B operators. Even the US Navy has balked about the USAF going it alone with a new propulsion system. A decision is due soon and politics will play a major part.

On 13 March 2023 US Air Force Secretary Frank Kendall made an announcement about the budget proposal for defence spending for fiscal year 2024. It lacked money for the further development of the AETP engines for the F-35. Stating that the USAF had decided for the Engine Core Upgrade (ECU) before known as the F135 EEP. The upgrade would be ready by 2028 and the idea was that by 2030 24 squadrons could be equipped with the F135 ECU. It was not sure if the US Congress would overturn this decision as funds for Next Generation Air Dominance (NGAD) advanced engine development – Next Generation Adaptive Propulsion (NGAP) – would receive $595 million in fiscal 2024. The political battle for the decision if there is supposed to be competition for the F-35 engine was still brewing.

On 13 June 2023 the proposed text of the House Armed Services Committee's proposed version of the 2024 National Defense Authorization Act (NDAA) revealed that both the General Electric XA100 and the Pratt & Whitney and the F135 ECU would be funded. Lockheed Martin's executive vice president of the Aeronautics business area, Greg Ulmer, threw fire on the discussion by reportedly stating that he would be advocating the AETP engines as they are a long-term solution angering Pratt & Whitney representatives in the process.

On July 27, 2023 General Electric announced the good news that the Senate Appropriations Committee included additional funding for adaptive engine development. A day later Pratt & Whitney announced that the same Senate Appropriations Committee had included the following items:

$497 million for the development of the F135 engine core upgrade (ECU), the DoD's chosen F-35 engine modernization effort.

$264 million above the President's budget request for F135 engine spares and repair parts.

A prohibition against integrating any alternate engine on any F-35 variant.

$280 million for the development of future engine technology that could be used on 6th generation tactical aircraft.

Pratt & Whitney was effectively handed a prolongation of its monopoly regarding the F-35 and the lessons of history with regrds to the F-16 were ignored. "I want to personally thank Senators Tester and Collins for their leadership on this effort, because it's essential to ensuring our limited DoD funds go to the most urgent, high-priority needs," said Jeff Shockey, senior vice president of RTX Global Government Relations,the parent company of Pratt & Whitney.

	P&W F135	
	CTOL/CV	**STOVL**
Maximum thrust	43000lbf / 191,3kN	41000lbf / 191,3kN
Short take off Thrust	N/A	38100 lbf/ 169.5kN
Hover thrust	N/A	39400 lbf/ 175.3kN
Main engine	N/A	15700 lbf
Lift fan	N/A	20000 lbf
Roll posts	N/A	3.700 lbf
Length	220 inches 5.59m	369 in/ 9.37m
Inlet diameter	43 inches 1,09	43 in/1,09m
Main engine	46inches 1.17m	46 in/1.17m
Lift fan	N/A	50 in/1.27m
Maximum diameter	51 inches 1.30m	51 in/1.30m
Bypass ratio		
Conventional	0.57	0.56
Powered lift	N/A	0.51

Overall Pressure Ratio		
Conventional	28	28
Powered lift	N/A	29

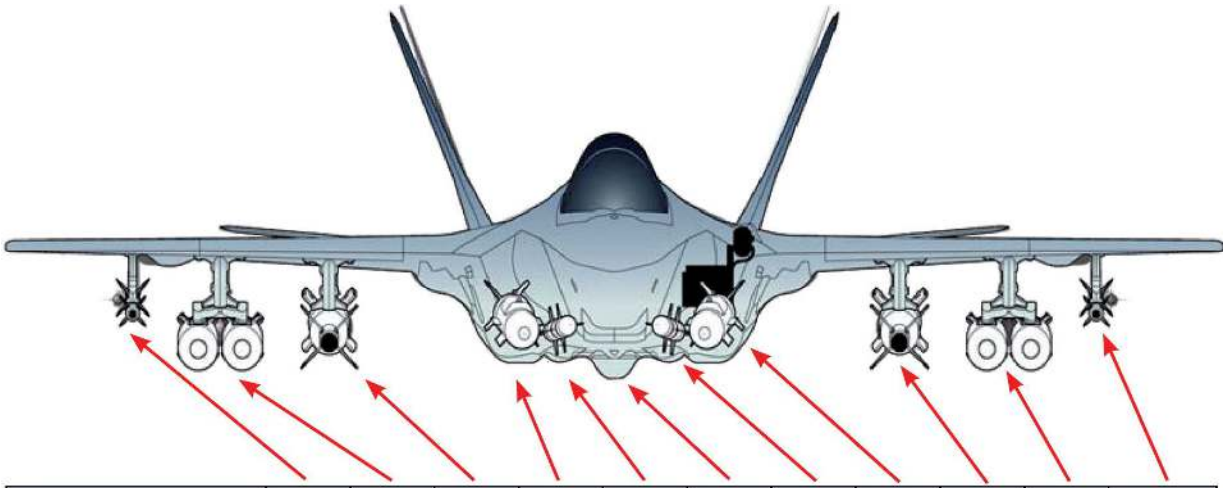
The Weapon Systems (The Lightning's Thunder)

As a result of the limited space in the internal bays, the F-35 was still equipped with underwing pylons, to be used when stealth was not so important or when air supremacy had been achieved and threats from ground-to-air weapons had diminished to ensure survivability. The F-35 would be equipped with a total of six under-wing weapon stations. According to one former Skunk Works employee, the requirement for under-wing pylons added weight and was detrimental to the quality of the aircraft. Payload was a major selling point.

Aircraft	**Payload**
F-35A	18000 lbs + internal cannon
F-35B	15000 lbs, no internal cannon
F-35C	18000 lbs, no internal cannon

As a result of the weight problems encountered early in the SDD phase the F-35B's weapon bays were reduced in size. However, this caused an increase in specific testing for the STOVL version as there would be different doors and lighter mechanism to open the doors. Extra flight test time had to be allocated to test the new aerodynamic situation although, up to a point, this could be done in wind tunnels.

F-35 weapon stations and their weight limit



Station	1	2	3	4	5	6	7	8	9	10	11
F-35A weight (lb)	300	2500	5000	2500	350	1000	350	2500	5000	2500	300
F-35B weight (lb)	300	1500	5000	1500	350	1000	350	1500	5000	1500	300
F-35C Weight (lb)	300	2500	5000	2500	350	1000	350	2500	5000	2500	300



The F-117 return from a mission. See the weapon bay doors are open. One bomb per bay was the weapons load, but the fact that it could go where no other aircraft could go it made it a very effective strike aircraft. (*USAF*)

All stations with the exception of station 6, the external centre-fuselage station, would be qualified for air-to-air weaponry. With the exceptions of external stations 1 and 11 and internal stations 5 and 7, all stations would be

qualified for air-to-surface weaponry. Furthermore, besides the internal weapon-bay size reduction of the F-35B which caused the loads of station 4 and eight to be reduced by 1000lb, the centre under-wing station carriage capability was reduced in similar fashion. An important factor for ship-based aircraft is the bring-back load capability. The F-18C/D, for example, had to dump some of its unused weapons in the sea prior to landing. This was one of the reasons why the F-14 Tomcat remained the weapon system of choice even when its replacement was in the arena. The F-14 Tomcat never needed to dump any weaponry because it had no problems with bringing its weapons back to the ship. The F-35B had to bring back a load of 5000 lb, which meant that the internal stores could be brought back at all times and a fully loaded F-35B could not land vertically. For this reason an evaluation of a ship-borne short rolling vertical landing (SRVL) was conducted.

An important feature for the stealth element of the F-35 was the internal weapon bays. A disadvantage of weapon bays is that they need to be more voluminous than the actual weapons and increase the cross section of the aircraft disproportional to the weapon load. The space required for the weapons to leave the bay also had to be taken into account. The weapons should be able to leave the bay cleanly without interfering with other weapons or tubing and plumbing passing through the weapon bay. This is made more difficult by turbulence, flow-field effects, rolling and manoeuvring of the aircraft while weapons are being released. The internal weapon-bay volume also includes the space required for maintenance access with weapons installed. Experience and lessons learned from the F-22, F-117 and even the F-111, and new technologies such as real-time motion capture (RTMC) and real-time immersive simulation (RTIS) were important for this.

Suspension and Release Equipment

Generally speaking, there are two ways of stores separation: an ejector rack which pushes stores forcefully away from the aircraft or a rail launcher which also pushes stores away. Store separation is evaluated already in wind tunnels as a part of the modelling and simulation. For each safe store separation the basic information that should be available is:

- Store mass properties – the weight and measure of the store to be separated
- Store ejector performance
- Store aerodynamics

- Aircraft manoeuvre, Mach, altitude, KCAS, angle of attack, angle of sideslip, roll, yaw pitch rates.

Another relative novelty to be introduced on the F-35 was the launch of weapons using non-pyro technology. In the previous generations small detonations were used to release weapons from their pylons but the pyro technology involved required a lot of maintenance and was therefore a major financial burden on operations. Only the F-22 Raptor was equipped with this new technology in the shape of the LAU-142/A AMRAAM vertical ejection launcher (AVEL). However, the new technology was test flown on the Raptor from 1999 onwards.

In early January 2002 EDO was rewarded for all its efforts, receiving a contract valued at $24.8 million from Lockheed Martin to develop pneumatic weapon suspension and release equipment. EDO initiated development of its 30-inch (75cm) pneumatic bomb rack unit (BRU)-68, a launcher AAM unit (LAU-147 launcher) and a pneumatic dual-piston AIM-120 launcher. The LAU-147 was for internal use in the weapon bays and another launcher, designated LAU-148, was developed for the under-wing pylons. This one is mainly used to carry the short-range air-to-air missiles but can also launch the AMRAAM. The STOVL weight attack team (SWAT) caused the internal weapon bay to be reduced, prompting the requirement for a smaller version of the BRU-68; that became the 14-inch (35cm) pneumatic bomb rack unit (BRU)-67. The specification life for both BRUs was thirty years, 8,000 flight hours or 500 shots; the specification life for LAU-147 is thirty years, 8,000 flight hours or fifty shots. The BRU-67 is designed to carry and eject weapons of 500lbs up to 1,000 lbs and would fit in the smaller weapon bay of the F-35B; the BRU-68 is designed to carry and eject the same stores plus heavier and larger stores up to 2,000lbs and fits in the larger weapon bay of the F-35A and F-35C. The BRU-67 is planned to be used mainly for internal weapons carriage while the BRU-68 is planned for under-wing pylon use. Both the BRU-67 and BRU-68 will be integrated into suitable pylons. As the small diameter bomb became available, and more could be carried on one pylon, the bomb rack unit-61A (BRU-61/A) was developed for both internal and external under-wing carriage. The BRU-61/A is a common carriage assembly, derived from a unit used on the F-15 Strike Eagle.

Another novelty to be introduced on the F-35 was the universal armament interface (UAI). The UAI is a US DOD and NATO initiative to develop standardised functional interfaces in aircraft, weapons and mission planning to

support integration of future weapons independent of aircraft operational flight programme (OFP) cycles. A major problem noted in the conflict over Libya was weapon stockpiles and therefore the ability to maintain operations. Operations could have continued apace if weapon stockpiles could have been shared on different platforms, but that would require integration of weapons and, according to Lynda Rutledge from the Air Armament Centre (AAC), in 2005 each weapon has its own unique interface requirements and its own interface control document (ICD) while weapon integration activities are tied to platform pre-planned operational flight programme (OFP) update schedules. Besides hardware, the software of the weapon interfaces and the aircraft OFPs are drivers of integration schedule and cost. The universal armament interface (UAI) was integrated in the BRU-61 which could carry four GBU-53/B SDB IIs. The GBU-53B was the first weapon on the F-35 to make active use of the UAI and would be introduced in Block 4. The BRU-61/A will probably also be used for the SPEAR that is planned for integration.

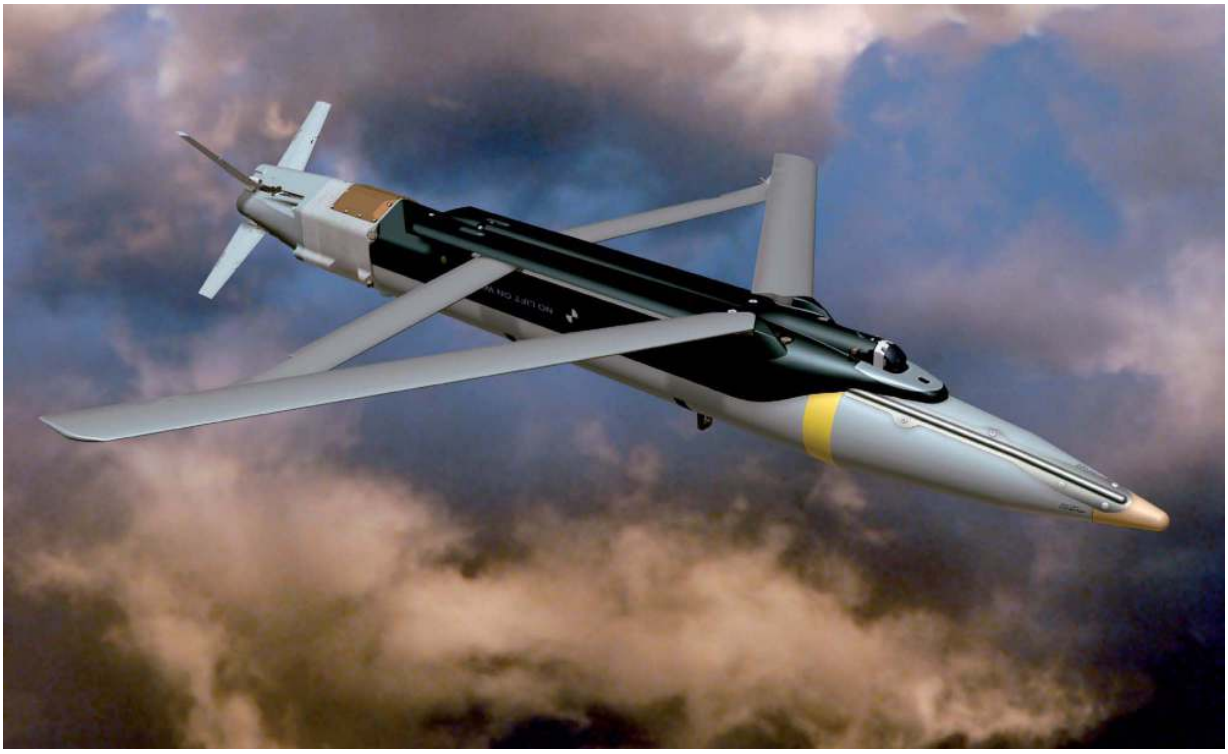
Small Diameter Bomb (SDB)

The problem with a single-engine strike fighter is that it is relatively small. The fuselage space had to be shared by the engine, fuel tanks, air intakes, aircraft systems and internal weapon bays: quite a challenge. For the STOVL version this was likely to be worse since STOVL-specific technology would also require some space. It was for this reason that the industry was requested to look into stealthy weapon systems so that either no weapon bays were required making the aircraft lighter, or more weapons could be carried without affecting the radar cross section (RCS).

The industry came back, however, saying that it would be financially cheaper to develop smaller weapon systems so that more weapons could be carried in the same weapon bay and multiple targets destroyed during the same mission. Development of the small diameter bomb (SDB) was born. On 29 June 2001 a request for proposals was issued by the SDB programme office Eglin AFB. Initial operational capability (IOC) was aimed to be achieved somewhere in fiscal year 2006/2007. By the autumn of 2001 two contractors, Lockheed Martin and Boeing, were provided with contracts for the system design and development (SDD), each worth US $47 million. Each team was to design and develop two versions, with one version equipped with inertial navigation system/global positioning system (INS/GPS) and the other with an additional terminal seeker automatic target recognition (ATR)



The SDB in the wind tunnel exiting the weapon bay of the F-35 at Arnold Engineering Development Centre. (*AEDC*)



The SDB in detail, the folding wings apparent. Boeing.

As the name SDB indicates, it is a small diameter bomb of 18.75cm, a length of 177.5cm and a weight of 250 pounds. The warhead case is made from steel for penetration purposes. In fact the SDB should be able to penetrate six feet of reinforced concrete or more than three feet of steel-reinforced concrete and the damage should be done by 50lbs of high explosives. SDB has a stand-off range of sixty nautical miles which should be increased somewhat if launched supersonically from any aircraft, but in particular from the F-22 which has super-cruise capability. The weapon would be guided to its fixed target by a guidance differential GPS/INS and is off course autonomous and with an all-weather capability.

SDB was a strike weapon and it was therefore normal that the F-15E Strike Eagle was chosen to perform the weapon qualification trials since it was also a Boeing aircraft. The first flight test with the SDB took place on 25 February 2003 below an F-15E which became the test vehicle for the entire programme. Soon afterwards, on 13 July 2003, followed a test flight with SDB accuracy support infrastructure using wide area differential GPS.

For the JSF programme, now the F-35, the JDAM had been selected as the preferred weapon. The SDB is complementing and might even replace JDAM as, on 28 April 2006, a contract modification was awarded to Lockheed Martin to integrate the SDB onto the F-35A CTOL version, giving the SDB a bright future. The contract, however, also had some side effects, one of which was that the programme to integrate the wind-corrected munitions dispenser (WCMD) was eliminated from the F-35A CTOL version integration effort. The SDB reached initial operational capability on the F-15 on 6 October 2006. Not long after this, the first use in combat occurred in Operation ENDURING FREEDOM on 11 November 2006. Boeing, or its subsidiary McDonnell Douglas, received a contract on 15 December 2006 to deliver test assets for the SDB integration on the F-22A and the F-16 Block 30,40 and 50. The F-22A, because of its relevance of integration into weapon bays, is a small step in the direction of integration of the GBU-39 onto the F-35. The first wind-tunnel tests with an F-35A model and the GBU-39 SDB model were evaluated in the AEDC 4T wind tunnel in 2007.

A milestone that went almost unnoticed, which is rather strange for a programme in dire need of good news, was that on 23 October 2013 the first ground separation test with a GBU-39 over a pit took place from an F-35A, AF-1, with US government pilot Vince Caterina in the cockpit. The first separation test was announced only as an afterthought by the programme office as the programme was facing some criticism about the pace of weapons

integration. First separation test of a GBU-39 SDB took place on 21 October 2014, followed by a multi-separation test on 20 November 2014.

SDB II

The competition to the Boeing/Lockheed team, however, sprang a surprise when Raytheon was selected for the development of the GBU-53/B SDB II on 10 August 2010. Raytheon announced on 22 January 2013 that it had performed fit check out with its SDB II on the F-35 at Eglin AFB, that is on operational fighters with no combat capability. At the time the fit check was more important for Raytheon than for the SDD or Joint Programme Office. Integration of the SDB II delayed. During the test, four GBU-53/B SDB II shapes were loaded into an F-35 weapon bay alongside an AMRAAM. Sweeps of the inboard and outboard bay doors verified there was adequate clearance between the two weapons. The fit trial was performed on a F-35A which would be able to carry them with ease as it featured a bigger weapon bay and there was a requirement that the F-35B should carry four GBU-53/B SDB IIs in each weapon bay alongside the AMRAAM. The SDB II threshold aircraft for the USAF was the F-15E; for the US Navy the threshold aircraft were the F-35B and F-35C.



The SDB II also known as the GBU-53/B Stormbreaker launched from an F-15 during a test trial. (*Raytheon*)



A computer drawing of multiple Raytheon Stormbreaker taking out their targets. (*Raytheon*)

'Completion of the fit check is critical because it further validates GBU-53/B Small Diameter Bomb II's (SDB II) compatibility with the F-35 and keeps GBU-53/B SDB II on track for a smooth transition to production,' said Harry Schulte, Raytheon Missile Systems' vice president of Air Warfare Systems. 'Once fielded, GBU-53/B SDB II will provide the warfighter with an unprecedented capability to precisely strike moving targets in adverse weather conditions and through battlefield obscurants.'

SDB II's integrated tri-mode seeker, which is built in Raytheon's automated tri-mode seeker factory, fuses millimetre-wave radar, uncooled imaging infra-red and semi-active laser sensors on a single gimbal, which enables the weapon to seek and destroy targets despite weather conditions. SDB II will hit moving targets in adverse weather from stand-off ranges. A fourth targeting mode is provided by a GPS receiver on the GBU-53/B

The plan was to have this weapon introduced on the F-35 with Block 4 software. For the F-35A and the F-35C this was not going to be a problem. However, the Joint Programme Office acknowledged early in March 2015 that the weapon bay of the F-35B proved to be a problem and a redesign would be required. The redesign was estimated to be required by 2022. This would

mean that early production F-35B model would not be able to carry four GBU-53/B SDB IIs in each weapon bay or it would have to undergo an expensive upgrade. This would mean a second redesign regarding the weapon bay as, due to weight problems, the original larger-sized weapon bays were given up and replaced by smaller ones. The requirement to redesign the weapon bay might put export customers on hold to wait and see, and get the redesigned weapon bays. Countries that had expressed an interest were Italy and the UK. The extent of the redesign was detailed and put into perspective by the deputy programme manager at the precision strike association conference on 17 March 2015. 'SDB II will fit in the F-35B,' Rear Admiral Mahr said. 'We have to move one hydraulic line and one wire bundle about a half-inch each to make it fit.'



BF-3 from the VX-23 Salty Dogs performing a test weapon separation with a GBU-53B Stormbreaker over a test range near NAS Patuxent River. (*Lockheed Martin*)



The four Stormbreakers snugly fit into the weapon bay of the F-35A and F-35C. The AMRAAM also visible will not get into the way. The Stormbreakers are due to be integrated in block 4A by 2021. (*Raytheon*)

It took a while. There was a long silence from the programme office and Lockheed Martin, but the silence was broken by a contract announcement regarding the SDB II integration, weapons capabilities technology maturation and risk reduction pre-engineering, manufacturing and development activities for dual-capability F-35 Lightning II Joint Strike Fighter aircraft and small-diameter bomb 2 (SDB-II) in support of the Marine Corps and Air Force. The contract was to be completed by July 2018. Raytheon announced 19 September 2022 that it had completed two of the last of seven trials of one development stage during one flight on the Lockheed Martin F-35.

Spear – Selective Precision Effects at Range

Selective precision effects at range (SPEAR) is the United Kingdom's Ministry of Defence (MoD) research and development request for highly accurate, beyond visual range re-targetable weapons which can receive target information updates over a data-link (network) in near real time as part of the UK's network-enabled capability (NEC).

SPEAR evolved into three capabilities:

- SPEAR Capability 1: Paveway Guided Bomb
- SPEAR Capability 2: Powered Missile (Brimstone)
- SPEAR Capability 3: Requirement for retargeting via data links.

The MBDA SPEAR draws its name from the UK MoD's selected precision effects at range capability requirements and specifically the Capability 3 requirement. SPEAR is managed as part of the interim portfolio management agreement (PMA-I) that was signed between MBDA and the UK MoD in March 2010. MBDA released a computer rendering of the SPEAR being launched from an F-35. It was at Farnborough 2014 that MBDA showed off a model of the F-35 equipped with two Meteor missiles and eight SPEAR missiles divided over the two weapon bays.

Cannon

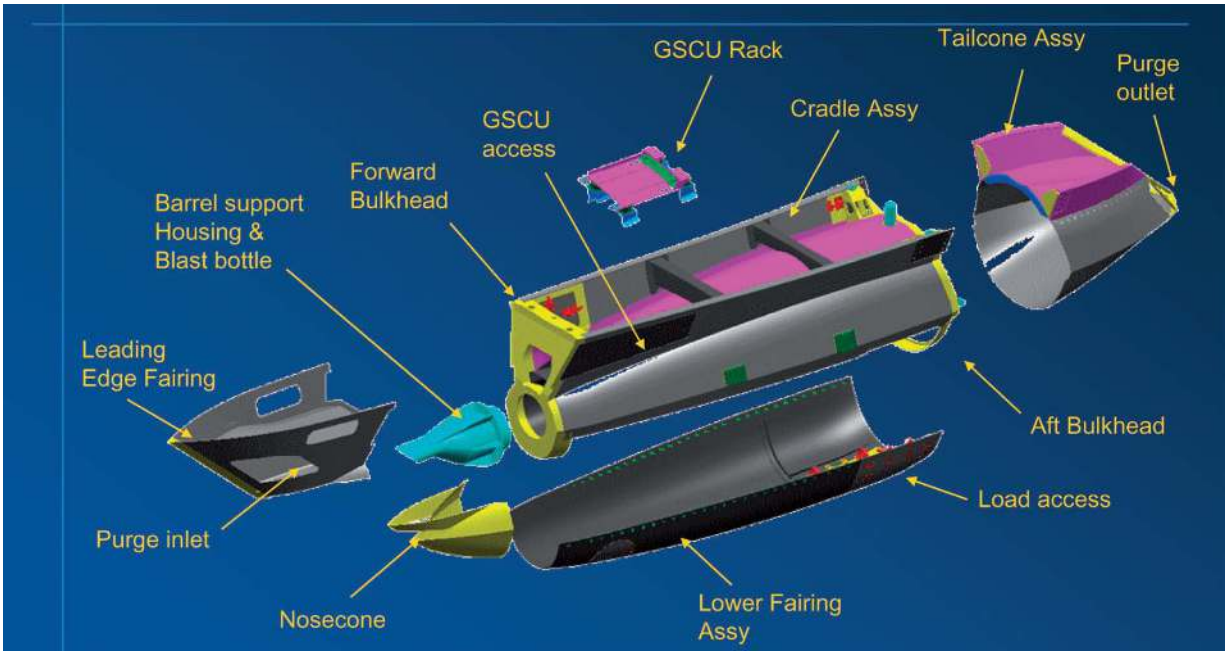
Lockheed Martin announced on 25 September 2002 that it had selected General Dynamics Armament and Technical Products to supply a derivative of the GAU-12/U.

The most major change for the modified GAU-12/U 25 mm gun was that instead of the four barrels it would be equipped with five barrels. Other design changes involved the loading drive, the transfer unit, recoil spindles, remote safing, firing/safing cam assembly, rear cover, the muzzle clamp and the mid barrel clamp. The last two were of course required because of the amount of barrels that had changed. The GAU-12 was supported at the mid-barrel clamp while the 5-barrel derivative would be supported at the muzzle. The gun system control unit (GSCU) would be new and was to not only control gun functions but also operation of doors in front of the muzzle. The GSCU was supplied by Hamilton Sundstrand. The requirement of the ammunition capacity for the CTOL version was exceeded by two, for a total of 182, this was later reduced to 181. Compared to the F-16 this was a huge reduction as the F-16 was capable of carrying 510 ammunition rounds internally and against the F-18 the comparison was even worse as the F-18 carried 578 rounds internally, while the predecessor of the F-18, Vought A-7 Corsair II, was a dedicated strike aircraft with an internal capacity of 1000 rounds. The F-35 had to fulfil a requirement which called for 181 rounds to be sufficient for three effective gun employments. Lockheed Martin hoped that with the aid of an advanced avionics system this requirement could be fulfilled. The requirement for the STOVL and CV version was met exactly at 220 rounds. The amount of ammunition was a reason for criticism due to the amount of ammunition carried by previous generation fighter aircraft.

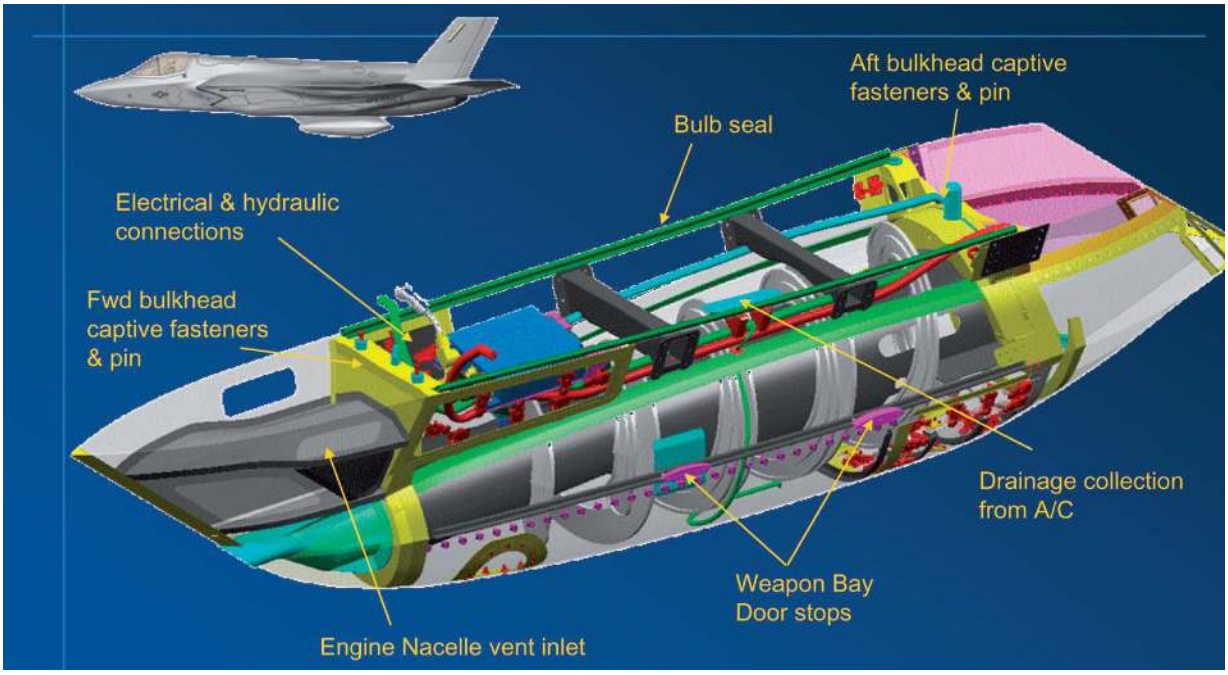




MBDA had this vision in 2017 for the F-35, a load out of 8 SPEARs, two Meteors and two ASRAAMs under the wings. (*Gérard Keijsper*)



An exploded view of the Missionized gun pod structure. (*GDATP*)



The Missionized Gun System for the STOVL and CV version. They are not interchangeable. (*GDATP*)

According to Douglas Parker design/test engineer JSF gun system with General Dynamics Armament and Technical Products the MGS was made from five subassemblies:

1. the pod
2. the GAU-22
3. the 220 round helical linear link-less ammunition handling system
4. Gun System Control unit
5. Hydraulic system

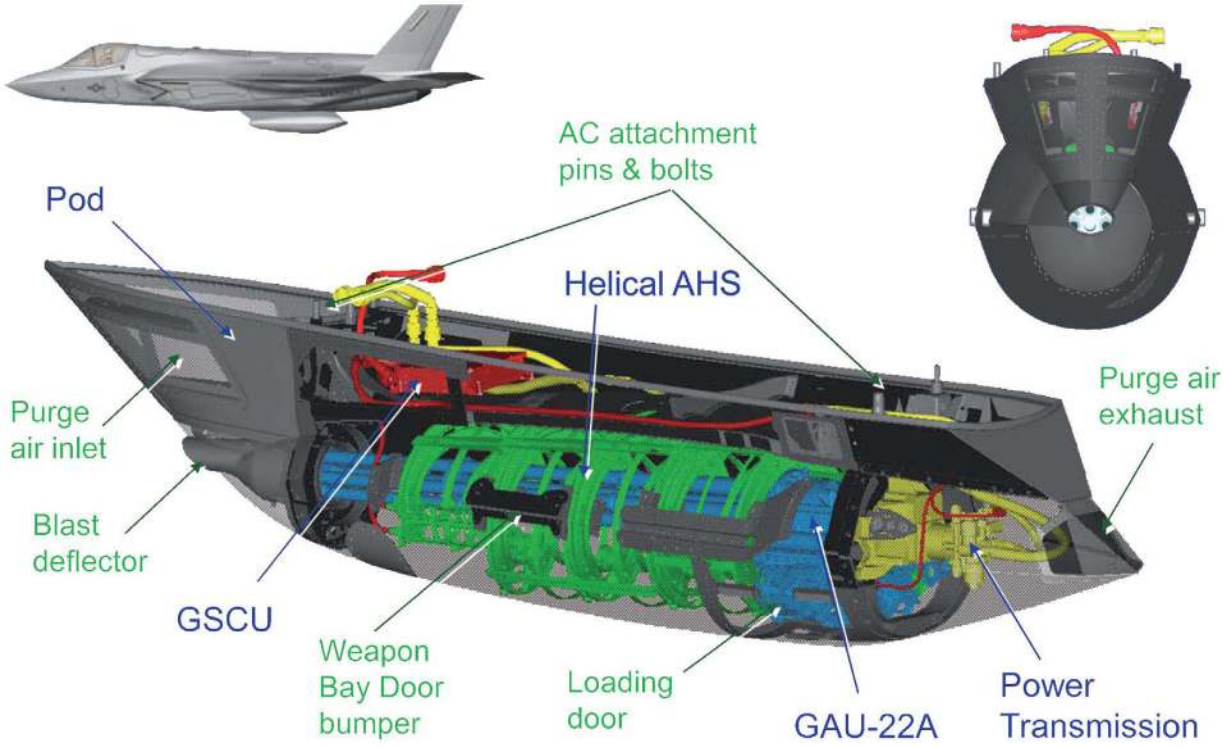
The weight of the entire missionised gun system (MGS), that is the five subassemblies, is 1.017lb fully loaded. Measurements of the MGS are 27-inches wide, 32-inches high, 146-inches long. Further the GAU-22 for the MGS is 85 per cent common with the CTOL gun system. By the summer of 2010 the GAU-22 was qualified with two types of ammunition, projectile gun unit-20/U (PGU-20/U) and PGU-23 TP.

The MGS required its own support equipment. The support equipment was also developed by General Dynamics Armament and Technical Products. Six pieces of support equipment were developed. These were a trolley which was called the ground handling adapter, an ammunition loader, gun mounting adapter, a hoisting beam, a gun transfer adapter and a mount rail. The ground handling adapter would be used to place the MGS under the centreline of the

fuselage of the F-35. Design requirements on the ground handling adapter were quite severe as it would be used only on the F-35B and F-35C. This would mean mainly on ships and forward operating bases. The ship environment had a lot to with the design for example the conditions under which the ground handling equipment should be able to be used on board ships was under sea state 6.



The BF-3 with the Missionized Gun System undergoing Ground Vibration Tests. (*GDATP*)



The key components of the Missionized Gun System. (*GDATP*)



The BF-1 here used for developmental test of the Missionized Gun System. (*USMC*)


A F-35A from the 4th Fighter Squadron on the first strafing run August 2018. (*USAF*)

For the MGSystem the low rate initial production was as follows:

LRIP II – 3 STOVL systems, due for delivery by August 2011
LRIP III – 4 STOVL systems, due for delivery by December 2011
LRIP IV – 7 STOVL & 2 CV systems, due for delivery by June 2012

This was the first time that the Missionised Gun System was differentiated between a STOVL and a CV system. The reason was that due to differences in the Outer Mold Lines (OML) of the F-35B and the F-35C the two systems are not interchangeable.



The AF-02 during the first firing of the gun in the air. (*Lockheed Martin*)

SRAAM (Within Visual Range WVR)

The AIM-9X Sidewinder as was realised by Lockheed Martin and Raytheon with the F-22, the internal weapon bays made lock on after launch (LOAL) capability for the short range air to air missiles (SRAAM) an imperative. With the F-35 this LOAL capability would have to be achieved by the AIM-9X Sidewinder and other SRAAM missiles such as the ASRAAM in the English inventory or the IRIS-T that was in development for numerous air forces in Europe. The ASRAAM was from the outset a requirement for the UK as the IRIS-T was a requirement from the outset for both Norway and Italy. The ASRAAM was a weapon that was set for integration in the Block 3 development programme. It was unclear in which development block integration of the IRIS-T missile would take place. The AIM-9X was, however, selected only as a weapon for carriage on the underwing pylon making the LOAL capability a nice feature but not a requirement.

USAF test pilot, Major Raven LeClair, fired an AIM-9X missile from an F-35A's external wing pylon against an aerial drone target in restricted

military sea test range airspace on 28 July 2016. Test data and observers confirmed the F-35 identified and targeted the drone with its mission systems sensors, passed the target 'track' information to the missile, enabled the pilot to verify targeting information using the high off-boresight capability of the helmet-mounted display (HMD) and launched the AIM-9X from the aircraft to engage the target drone. After launch, the missile successfully acquired the target and followed an intercept flight profile before destroying the drone, achieving the first F-35 Air-to-Air kill.

Immediately prior to launching the AIM-9X, Major LeClair shot an internally carried AIM-120C missile against another target drone. This target was beyond visual range and the AIM-120C was given a successful self-destruct signal right before target impact.



The AIM-9X fired from the F-35 during the SDD. This inverted launch was probably one of the most extreme looking launch positions. (*Lockheed Martin*)



The AF-1 with the AIM-9X under its wings during a test flight. The white marks are there for the evaluation of the separation sequence. (*Lockheed Martin*)

The AIM-9X is a short-range heat-seeking missile with an off-boresight capability for accuracy and features thrust-vectoring controls for increased turn capability. The F-35 can carry two AIM-9X missiles on its wings.

During previous test shots a self-destruct signal had been sent to the missile prior to it hitting the target. The initial firings of the ASRAAM were announced by MBDA on 15 March 2017, although no dates were given. One of the trials was performed from BF-17 from the 461 FTS Deadly Jesters. The AIM-9X was to be carried on the outer pylon and on the F-35C a structural problem was found as loads from missile and pylon on the outboard structure exceeded the design limits. In 2017 the new outboard wing structure had to go through buffet and loads testing to ensure that the new design had solved the problem. For the time being the AIM-9X was only carried on underwing pylons and not internally. The same was true for the ASRAAM missile and no plans existed for integration the internal weapon bays.

Beyond Visual Range (BVR)

If more than 30 per cent of air combat ends up in close-in combat then more then 60 per cent ends already in the BVR (beyond visual range). The

reliability and effectiveness of the BVR weaponry had increased and was not going to diminish. In fact, from the outset when the key performance parameters were set, the AMRAAM missile was set to be carried internally on the JSF.

The dimensions of the Raytheon AIM-120/AMRAAM missile are:

Length:	365 cm
Max span:	63.5 cm
Body diameter:	17.8 cm
Launch weight:	156.8-kg/345 lb.

The AMRAAM selected was the AIM-120C. the two weapon bays were volume wise small and would hold initially two weapons in each weapon bay an air to ground weapon deep in the bay and the AIM-120C below it attached to the weapon bay door. For the AMRAAM not to block the operation of the air to ground weapon it was decided for safe operations that the AIM-120C would be attached to the inner weapon bay door. The AIM-120C would rotate out of the way with the door of the free fall trajectory of other munitions in the weapon bay. As part of the structural ground tests two AMRAAMS were loaded onto the A-1 on 25 March 2006. An interesting feature of the weapon system is that the pilot can mark aircraft on the display outside the AMRAAMS range. Once the target aircraft enters the missiles range the pilot can see that on his tactical display. The pilot will launch the missile. On the display the missile is connected with its target by a line plus the amount of seconds that the missile requires to get to the target. Once the target is destroyed the pilot gets confirmation through its EO-DAS and EOTS systems that will have noticed the heat flare up of the explosion.





A sequence of the firing of the AMRAAM from AF-6, the official first production aircraft heavily used in developmental testing. (*Lockheed Martin*)

Although the obvious weapon of choice for the services that had bought the AMRAAM for their current fighter aircraft, there were nations such as the UK that wanted to develop their own air to air BVR missile. The UK's Defence Procurement Agency selected the European-developed Meteor missile in December 2002 and did so on behalf of the European partner countries, Italy, Germany, Spain and Sweden.

The F-35 could carry four AMRAAMs internally giving up space for the JDAM. Although a drawing of an F-35 with six AMRAAMs internally had been going around this had not as yet been requested by any of the customers and the required SR&E technology had not been identified as yet.

Moving into the active phase of weapons test is another large step toward delivering Block 2B software capability that will enable initial combat deployment. 'We've spent years working on the design of the aircraft, and many months ensuring that weapons could be contained within the aircraft and dropped as designed. This event is the result of tremendous effort and collaboration in the F-35 enterprise, and marks a turning point in F-35 capabilities; the AIM-120 launch is one small but critical increment toward proving combat capability,' said Charlie Wagner, F-35 Weapons Director.

The development first live firing of an AMRAAM took place on 30 October 2013. The missile was fired from AF-6 piloted by USAF Captain Logan Lamping. Test data and observers confirmed the F-35 identified and targeted the drone with its mission systems sensors, passed the target 'track' information to the missile, and launched the AIM-120 from the aircraft to engage the target drone. After launch, the missile successfully acquired the

target and followed an intercept flight profile. Moments before the missile was about to destroy the target, a self-destruct signal was sent to the AIM-120 in order to preserve the aerial drone for use in future tests. This weapons delivery accuracy (WDA) test and the second which followed on 15 November 2013 were done with undefined work arounds that are not acceptable during operational service or operational test according to the Director of Operational Test and Evaluation (DOT&E). Final inert store separation took place from the F-35C with an inert AMRAAM on 19 September 2015. Prior to that inert shots had also been performed from internal weapon bay stations 4 and 8 from the F-35B, which up till then had been used for air to ground weapons. Integration of the Meteor missile is planned for October 2022 according to MBDA. The wings of the Meteor missile had to be reduced in size to fit in the weapon bay similar to the AMRAAM.

JDAM Joint Direct Attack Munition

Lethality was a major cornerstone in the JAST programme. Experience from the Gulf War in 1991 and target engagement analysis showed a requirement for rapid targeting and engagement of mobile targets, such as tanks, armoured vehicles, artillery and ships, and fixed tactical targets, such as airfields, supply depots and communication centres. The most effective weapon against these targets was a variety of 1000lb weapons according to an analysis done for the JAST programme office. That is how the requirement for the JDAM came into existence.

As the SDD phase was initiated there were several versions of the JDAM available and three versions were to be integrated during the initial block of the SDD phase. A fourth version would be integrated at a later stage. The three versions that were to be integrated during the SDD were the GBU-31 JDAM 2,000-lb (MK-84 warhead), GBU-31 JDAM 2,000-lb (BLU-109 Warhead) and the GBU-32 JDAM 1,000-lb (MK-83/BLU-110 warhead). The fourth on the wish list, but not fitting in the budget, was the GBU-38 JDAM 500-lb (MK-82 warhead).

	GBU-31 Mk-83	GBU-32	GBU-38
Length (JDAM and warhead)	387,9 cm (152.7 inches)	303,5 cm (119,5 inches)	235,2 cm (92,6 inches)
Launch weight	925,4 kg (2,036 pounds)	460,5 kg (1,013 pounds)	253,6 kg (558 pounds)
Wingspan	63,5 cm (25 inches)	49.8 cm (19.6 inches)	35.6 cm (14 inches)

As the ultimate strike weapon at least from the outset JDAM was tried out during the ground tests. Two inert JDAM were loaded on to the A-1 prototype on 25 March 2006, one JDAM in each weapon bay together with an AMRAAM missile in each weapon bay. If a group of F-35s would fly during a mission the F-35 Lightning II weapon system would allow the leader to assign targets not only to his own JDAM weaponry but also to his wingman and all this without voice communication but with the help of the data-link systems. For the first flight test with JDAM the services had to wait some time; the closest to actual JDAM carriage occurred on 16 September 2008. Two JDAM mock-ups were carried in flight by AA-1 in the internal weapon bays plus the mock-ups of two AMRAAMs. The mock-ups were representative in weight (2000lb) and dimensions.

The first pit drop of an inert GBU-32 JDAM was performed by US Navy test pilot Lieutenant Christopher Tabert. This was followed a couple of months later by the first weapon drop over the ocean on a test range near Patuxent River by BF-3 on 9 August 2012. Both the aircraft and the JDAM were equipped with reference dots so that the inert weapon drop could be evaluated and compared with predictions. It was at this time that again some bad news about the weapon bays was released; doubts existed that the weapon bays could retain the thermal conditions at such levels that weapons such as JDAM could be carried safely, especially when the exhaust plume of an AMRAAM would be heating the confines of the weapon bay. The second JDAM drop was performed over the test range of NAS China Lake. This test was performed from AF-1 flown by USAF test pilot Major Eric Schultz. The inert JDAM dropped was an instrumented 2,000lb GBU-31. During the flight AF-1 carried on each outboard station an additional AIM-9X Sidewinder-shaped store with cameras inside, used for catching the test on film. The first development weapon delivery accuracy (WDA) test was performed with a GBU-32 on 6 December 2013 with the work-arounds that were needed similar to the AMRAAM WDA tests. The GBU-38 is a smaller version of the JDAM

with a weight of only 500lbs. Integration is part of block 4 upgrade. The GBU-54 is a version of the GBU-38 500lb precision weapon, equipped with a special targeting system that uses a combination of the Global Position System and laser guidance to accurately engage and destroy moving targets. The laser guidance would be provided by the EOTS.

Advanced Interdiction Weapon System or the AGM-154 Joint Stand Off Weapon (JSOW)

Even though the F-35 had stealth features and would be able to evade radar, for some areas it was still considered better to have a stand-off weapon. The Raytheon (earlier Texas Instruments) AGM-154 JSOW was the natural choice as it was a recently developed weapon when the SDD of the JSF programme was initiated. The Raytheon AGM-154 JSOW was to be integrated both on the internal and external hardpoints. The JSOW existed in several versions and had been selected for integration during the SDD phase. During SDD it would only be integrated on the internal weapon bay points. The AGM-154 is a modular weapon and three versions existed.

The AGM-154A is the baseline version. 145 BLU-97/B combined effects munition (CEM) bomblets shape the warhead of the AGM-154A which are dispensed by a cluster bomb dispenser. The bomblets can defeat armour, have incendiary effects and a fragmenting case so that they cause a lot of material damage. The AGM-154B was designed with 6 BLU-108/B SFM (sensor-fused munition) dispensers, each of which can release four Skeet terminally guided anti-tank sub-munitions. The third version was developed for the US Navy only. It was equipped with BROACH multi-stage penetrator warhead. Furthermore, the AGM-154C was equipped with an imaging infra-red seeker and an autonomous target-acquisition system. The autonomous target acquisition system compares the images of the imaging infra-red seeker with a pre-set reference image to identify the target. The autonomous target acquisition system replaces a two-way data-link which was originally planned for this weapon.

The AGM-154 is a glide weapon with a range depending on launch height and speed, range varying from fifteen nautical miles (low-altitude launch) to forty nautical miles (high-altitude launch). As can be deducted, AGM-154 depends on kinetic energy and no booster and for this reason is relatively cheap. The way that AGM-154 achieves this range is with wings that unfold shortly after launch. The AGM-154 JSOW is guided to the target by a global positioning system (GPS)/inertial navigation system (INS) that works

independently from launch, which means that it is a fire-and-forget weapon. For homing and navigation the AGM-154 employs the prior mentioned GPS/INS but also uses imaging infra-red (IIR) and data-link. The all-weather capability increases the flexibility.



CF-5 dropping the first JSOW for the qualification on the F-35 piloted by Cmdr. Ted Dyckman. (*Divids*)



An F-35C from the 461st FTS releases a GBU-12 Paveway II. The inert bomb tracked a moving pickup truck on the ground at NAWS China Lake. The F-35C was flown by Col. Scott Cain, 412th OG commander. (*Darin Russell/ Lockheed Martin*)



Fit checking the Raytheon JSOW on the F-35. (*Lockheed Martin*)

Raytheon announced in November 2011 that the JSOW AGM-154 C-1 would fit in the weapon bay of the F-35 without specifying the type and or if it was in combination with other munitions. It took a little over four years before the AGM-154 was dropped from an internal bay. Commander Ted Dyckman was the pilot during the 180th flight of CF-5 on 23 March 2016.

The GBU-12 Paveway II

The GBU-12 was determined as one of the first weapons that was to be carried in the internal weapon bays besides JDAM and AMRAAM.

The memo from the Director of Operational Test and Evaluation, which was leaked, followed the IOC announcement by the USAF that the F-35 had limited capability to engage moving targets. Even though the Block 3i F-35A does not have a functioning gun, it can carry the GBU-12 laser-guided bomb which can be used against moving targets. However, Block 3i does not have

an automated targeting function with lead-laser guidance (i.e., automatically computing and positioning the laser spot proportionately in front of the moving target to increase the likelihood of hitting the target) to engage moving targets with the GBU-12, like most legacy aircraft that currently fly close air support (CAS) missions. Lead-laser guidance is currently not planned for Block 3F. Instead, F-35 pilots can only use basic rules-of-thumb when attempting to engage moving targets with the GBU-12, resulting in very limited effectiveness. Also, limitations with cockpit controls and displays have caused the pilots to primarily use two-ship 'buddy lasering' for GBU-12 employment, which isn't always possible during extended CAS engagements when one of the aircraft has to leave to refuel on a tanker.





A sequence of early operational USMC aircraft that drops a GBU-12 Paveway II from internal weapon bay. Lockheed Martin 2x





Several releases of the GBU-12, the top two releases were developmental tests from the underwing stations. (*Lockheed Martin*)



The devastating result of a GBU-12 striking its target after being launched from BF-17 piloted by Maj. Richard Rusnok.

During Block 2B and 3i testing the GBU-12 was only dropped from internal weapon point from the weapon bay; in Block 3F this was extended to include use of the underwing pylons.

GBU-49 Enhanced Paveway II

Even before the Block 3F testing had been concluded it was recognised that the F-35 lacked a weapon for moving targets. A quick solution was required and there existed only one such solution; that was the GBU-49 – BLU-133, a 500 lb (227 kg) bomb. Raytheon's enhanced dual-mode GPS and laser-guided bomb (LGB) version of the laser-only GBU-12. The interfaces of the GBU-49 are similar to another version, the Paveway IV, which was being integrated F-35B for the UK. The size and the weight of the GBU-49 is similar to the GBU-12; as such, integration work could be carried out within a couple of months.



The crew loading GBU-49s on the F-35B. The F-35B belonged to the 'Avengers' of Marine Fighter Attack Squadron (VMFA) 211. (*USMC*)



The F-35B seen here with two underwing mounted GBU-49s on the USS *Essex* December 2018. (*USMC*)

The first use of the GBU-49 for an operational unit was with the 34th Fighter Squadron during a Combat Hammer exercise on 7 November 2018. 'It's a really flexible weapon. It was reliable, accurate, and effective,' said Lieutenant Colonel Matthew Johnston, 34th Fighter Squadron commander. 'Like any new weapon, what we learned, and what we will learn as we continue to train with the GBU-49, will directly impact our tactics and will make the F-35A even more lethal.'

Paveway IV

The United Kingdom had in its inventory the Paveway precision-guided bomb (PGB) and it was only natural that it was also to be integrated on the F-35. A request was issued on 10 March 2005 for a proposal regarding the integration and the certification of Paveway IV onto the JSF. The baseline of the proposal was for the integration of Paveway IV on the internal weapon bays. An estimate or priori rough order of magnitude (ROM) for the integration and certification on external stations was required by 15 April 2005. The proposal was for integration and certification on the internal stations by 30 June 2005.

For this reason the Lockheed Martin weapons integration team invited the Raytheon team responsible for Paveway IV to receive a technical briefing about the design and integration requirements. This briefing took place on 7 April 2005 so that Lockheed Martin could prepare a proposal for the integration/certification of the Raytheon Paveway IV for the UK. Initial Paveway IV flutter flight testing was started on 13 November 2014 and was completed on the 21st. Separation testing of Paveway IV continued through 2016 from internal and external weapon stations.

HARM

Although initially eliminated from the list as obsolete weapons, the US Navy wanted to upgrade the missile. The US Navy initiated an upgrade programme for its AGM-88 high-speed anti-radiation missile (HARM) by the end of 2002. A new rocket, a variable flow ducted rocket (VFDR), ram-jet engine provided by Atlantic Research Corporation should increase the missile's range from 80 to 100 miles and increase its speed from approximately Mach 2 to Mach 3.5. Furthermore the HARM missile should be prepared for internal carriage. The fins of the HARM do not fold, so just like AMRAAM it should be adapted in a similar way (AMRAAM fins were clipped for use in F-22). The upgrade eventually selected by the US Navy and the Italian Air Force looked a bit different but gained the designation AGM-88E, advanced anti-radiation guided missile (AARGM). Development was initiated in 2005 and completed in 2012. While in development, it was made compatible with the weapon bays of the F-35. The modification included a new guidance section, and modified the existing control section, which are coupled with the legacy HARM rocket motor and warhead section, wings and fins. In fiscal year 2016 the US Navy initiated the advanced anti-radiation guided missile – extended range (AARGM ER); it was foreseen for carriage on the F/A-18E/F and EA-18G. There was no mention of F-35 in this case, although this changed relatively quickly in fiscal year 2018 when the first money was allocated. Orbital ATK, a company that had taken over Atlantic Research Corporation, received a contract for development of the AARGM-ER in January 2018. The budget proposal noted that the F-35 was the USAF threshold programme and required a weapon capability that it called stand in attack weapon (SiAW) that could provide strike capability to defeat rapidly relocatable targets that create the anti-access/area denial (A2/AD) environment. Although the AARGM-ER was not mentioned at first as the missile of choice to fulfil this requirement. Northrop Grumman Innovation Systems, the new owner of Orbital ATK,

received a contract for engineering and manufacturing development (EMD) of the AGM-88G, also known as the AAGM-ER on 7 March 2019. The EMD effort includes the design, integration and test of a new solid rocket motor for the AARGM-ER for use on the F/A-18E/F, EA-18G and F-35A/C aircraft. Changes from the AGM-88E to the AGM-88G were:

– A new rocket motor providing increased range
– A new control actuation system (CAS)
– A different warhead and fuse

The USAF selected the US Navy AARGM-ER as its weapon of choice for the SiAW. As the AARGM-ER was a new missile, it had to be tested on the Super Hornet as well. The first captive test of the AARGM-ER on the Boeing F-18E Super Hornet was performed by the VX-23 'Salty Dogs' on 3 June 2020. The AARGM ER was considered a US Navy weapon but integration was aimed first at the F-35A and F-35C variants. On 23 November 2020 Lockheed received a sole source contract from the Air Force Life Cycle Management Centre at Eglin AFB for test and evaluation.

JSM

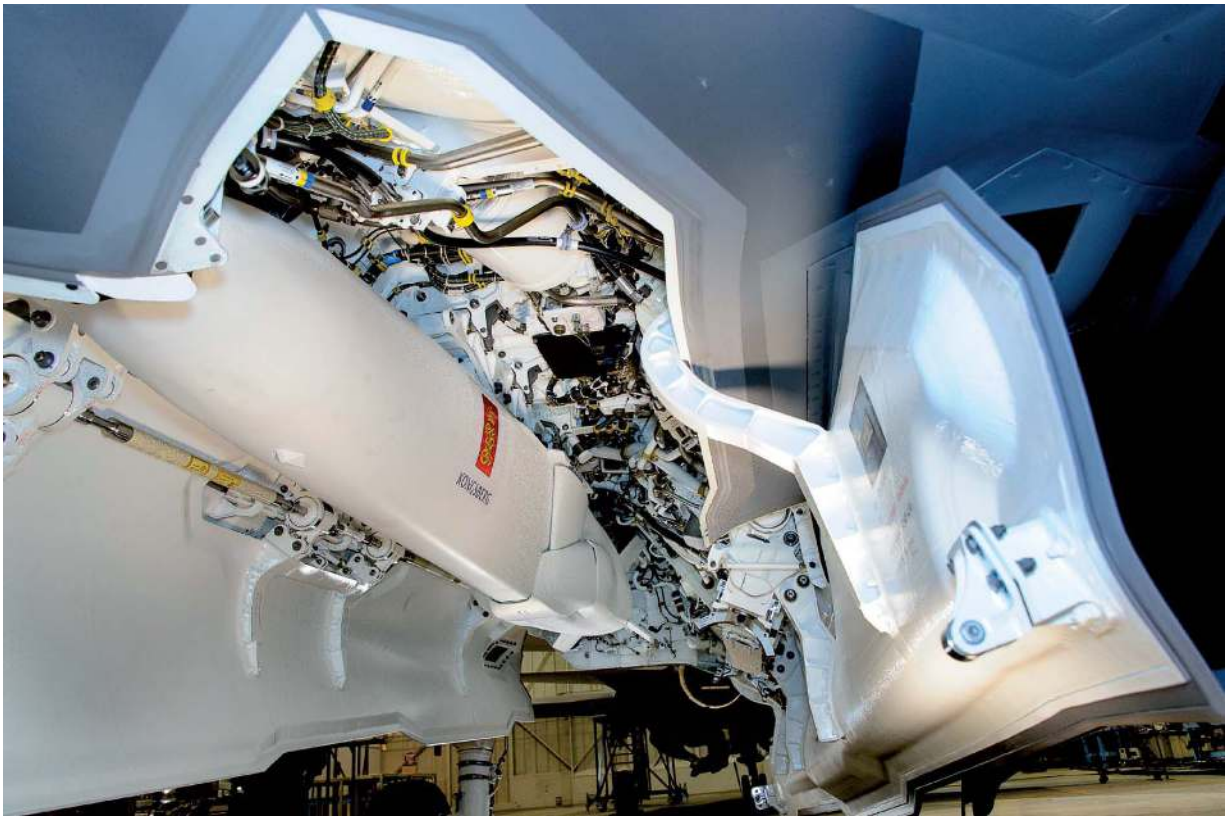
The joint strike missile (JSM) was a derivative of the naval strike missile under development in Norway, development of the JSM anti-ship missile having been initiated by Kongsberg in 2008. One of Norway's requests was for support for its JSM. This support was more or less promised by Lockheed Martin. The Norwegian government supported Kongsberg in its initiative by financing the first phase of the programme through the Norwegian Defence Logistics Organisation in 2009. The value of the development contract for the first phase was NOK166 million (Norwegian kronor). According to Kongsberg, the company responsible for the development of the JSM, there was a need for the F-35 weapon system. No other anti-ship missile was on offer for it. For Lockheed Martin it provided an opportunity of offering some form of high-tech off-set to Norway. The JSM was to be sized so that it could be carried in the internal weapon bay of the F-35A and F-35C versions. Preliminary design review was completed in 2010, although major design changes were still possible and occurring at the time. Automatic target recognition modes are a standard feature of the JSM.

The JSM was not to be integrated on the F-35 during the SDD, that is during the first three software blocks. Kongsberg and the Norwegian government counted on the JSM being available for the Block 4-software-

equipped aircraft, to which Norway expected to buy in. It was on 12 April 2011 that the Norwegian government made known its decision to support the second phase of development of the JSM. The missile was to be further developed to technology readiness level (TRL) 6, which would include the critical design review. The aim of the Norwegian government and Kongsberg was to have the JSM available and integrated from the moment Norwegian F-35s became operational, which was then planned to be 2018/2019. Because the financial burden of developing a missile like the JSM was too high for Norway by itself, Norway tried to attract partners to its project. Australia was such a partner with common interest in such a missile and participated in the cost of integrating JSM on the F-35 during the first phase. The JSM phase-two contract was to be completed in 2013 and a follow-up phase was required to put the JSM up for flight test. Flight test initiation of the JSM would depend on F-35 aircraft availability which could become a problem due to development delays.



The Kongsberg Joint Strike Missile (JSM) fitted to the F-16. Even though the F-16 would be retired from the Norwegian Air Force there would still be a substantial market of F-16 operators. (*Raytheon*)



The fit check in the weapon bay of the F-35. Note that this time the AMRAAM was left out. (*Raytheon*)



The JSM was also tried out on the underwing pylon of the F-35. (*Raytheon*)



A computer presentation with the F-35 employing the JSM. Kongsberg hoped that it would be a success on the F-35. (*Raytheon*)

A contract modification was announced on 31 May 2012 which involved a study on the integration of the JSM on the F-35. The work would involve a risk reduction study for the Norwegian Ministry of Defence: aspects included physical fit checks, wind-tunnel tests, engineering analysis and designing and building of an emulator and adapter to determine next steps in integrating the JSM into the F-35. Work was to be performed in Fort Worth, Texas, Arnold Air Force Base and by Kongsberg in Norway. The study was expected to be completed in May 2014 and was financed by the Norwegian Ministry of Defence. The first physical fit check was done on the outboard underwing station of BF-24 on 27 February 2013 and, about a month later, also in the internal weapon bay of an F-35A. The JSM was confirmed to be a part of Block-4 development plans, similar to the brakechute requirement for the Royal Norwegian Air Force. Flight testing was initiated by the 416th Flight Test Squadron under the lead of James Cook, 416th FLTS JSM programme manager. Along with James Cook, the JSM team consisted of test pilots Major John Trombetta and Major Jameel Janjua (Royal Canadian Air Force), flight-test engineers Eric Biesen and Tom Smeeks and Collin Drake, project engineer. It was Major Janjua who flew the USAF F-16 Block 40A 87-0352 to launch the JSM, its release point being above the Utah Test and Training Range west of Salt Lake City, Utah in November 2016. The flight testing of

the JSM was completed on the F-16 on 15 June 2018. Testing would then proceed to the F-35 as the JSM had been qualified, but also had to be qualified on the F-35. This was followed by some more good news on 11 March 2019: Japan joined Norway and signed up for the JSM. The biggest customer to sign up was the USA on May 31, 2024 all deliveries under this production lot 1 contract were due by August 31, 2026.

Cyberstrike pod

At the precision strike association conference 2015 held in Springfield, Virginia the deputy commander of the joint programme office, Rear Admiral Randy Mahr, revealed that an as-yet unidentified industry partner, not Lockheed Martin, was working on a stealthy pod with a cyber strike capability. Since the F-35 was touted as having an inherent cyber-attack capability this was rather a surprising announcement. The pod was in the prototyping stage.

On 21 July 2015 a solicitation was published for a study and analysis of the effect of a weapon on the radar cross section of the F-35 on the Federal Business Opportunities website. The weapon was not identified; however, it was clear that it could not fit in the weapon bays as it would not affect the RCS if it did. The business opportunity was sole sourced to Lockheed Martin and the contract award was expected no later than 30 September 2015. It was during the Air Force Association exhibition in 2020 that Raytheon showed an F-35 model with a stealthy pod, which was said to be a generic model.

Dual Capable Aircraft (DCA)

The phrase dual capable aircraft could mean anything but the real meaning is that the aircraft involved can also carry nuclear bombs. Countries other than the USA with such a capability were Belgium, Germany, Italy, the Netherlands and Turkey. The capability was receiving diminishing attention since the break-up of the Soviet Union and was seen as out of date by the general public which made it not a very popular investment. The DCA was performed by either the Panavia Tornado or the F-16 for the above-mentioned countries. General Bogdan testified on 23 March 2016 that in summer 2015 a series of test flights had been conducted to assess the vibration, acoustic and thermal environments of the F-35A weapons bay with the B61-12 weapon. Nuclear certification planning efforts were initiated as part of the Block 4 contracting activity in anticipation of beginning of B61-12 integration on the F-35A in 2018.



Dual Capability Aircraft is terminology for an aircraft that is also capable of dropping nuclear bombs. This is one task that the F-16 had performed for NATO. It is normal that the F-35 would get this capability. (*DoD via David Cenciotti*)



Belgium wanted a nuclear capability and made it a requirement for the tender. Belgium's first aircraft should be delivered to Luke AFB in 2023. This test took place in June 2020. (*DoD via David Cenciotti*)



Another safe Dual Capability separation performed February 2020 flown by test pilot Major Rachael 'Banshee' Winiecki. (*DoD via David Cenciotti*)

The USA, however, wanted this capability integrated on the F-35 in Block 4. When the Block 4 negotiations started and the House Armed Services Committee showed an interest in the capability, they wanted to secure its future by separating the funds for the DCA from the remainder of the Block 4 development cost in an effort to protect the further development of this capability. US$77 was allocated to enable Lockheed Martin to continue development from the preliminary design review (PDR) to critical design review (CDR).

The B61-12 will be approximately 12 feet long and weigh approximately 825 pounds. The first safe separation took place with test pilot Jason Shulze at the controls of AF-1 on 27 June 2019. By the end of the year 2019 the team managed to complete a total of 7 separation flight tests. The first supersonic test took place 25.8.2020 and from launch to impact on the desert ground took 42 seconds. It was confirmed on March 8, 2024 that B61-12 had been qualified on the F-35A and had been since October 12, 2023. The Royal Netherlands Air Force was the second nation to become operational with dual

capability when transferring the responsibility from the F-16 to the F-35 on June 1, 2024.

The Range of the JSF

One of the design changes to the preferred weapon system concept (PWSC) implemented by Lockheed Martin during the SDD phase was the raising of the top surface of the aircraft along its centreline, thereby increasing fuel capacity by 300 pounds. The range increase compared with fighters the F-35 was to replace was quite big; however, later block F-16s equipped with conformal fuel tanks would have a range similar to the F-35. The penalties of having conformal fuel tanks would be in manouvrability and a reduction in load capability.

Aircraft	KPP Combat Range	Internal Fuel	Nr. Fuel Tanks
F-35A CTOL	590 NM	18498 lbs	
F-35B STOVL	450 NM	13326 lbs	11 fuel tanks
F-35C CV	600 NM	19624 lbs	

All services, however, did not want to be depending on internal capacity and so required the additional capability that was and is standard in the other fighters the F-35 was due to replace – aerial refuelling. Besides the advantage for the services it can also have advantages for test reasons as it can extend time available during one test sortie, the importance of which is noted in earlier chapters.

The fuel system is important for the range of an aircraft and here there were three versions of an aircraft with each requiring its specific fuel system. Commonality was a major point when the SDD was initiated and for that reason maximum commonality in the fuel system was also aimed for. The weight question that was recognised in 2004 caused a re-design of the fuel system as well. As at this time AA-1 was already in production the fuel system was unchanged, but for the follow-on aircraft the fuel system had to be adapted to the new weight requirement and optimised for each variant. This meant that the fuel system of AA-1 was unique. BAE Systems,

who are responsible for the system, had to go back to the drawing board for three different optimised systems. The system included wetpoints under the wing for external fuel drop tank carriage and a refuelling and fuel-dumping system. The system is divided over the centre fuselage and wings and the feed tank which feeds fuel to the engine and is located in centre fuselage.

In the request for binding information response to the Royal Norwegian Ministry of Defence regarding programme 7600 future combat aircraft (FCA) it was confirmed that the F-35A exceeded the key performance parameter (KPP) of combat range by twenty nautical miles.

Another way to increase range is to use external fuel tanks, a normal procedure for ferrying aircraft. Range could be extended and the tanks dropped prior to entering enemy air space allowing the aircraft to return on internal fuel and still be stealthy during the main part of the operation. This is important when tanker aircraft are in short supply. From the outset the requirement existed for external fuel tanks for all three versions. The USAF, however, cancelled the integration of external fuel tanks in a contract modification on 28 April 2006. The increase of internal fuel compared to the fighters the F-35 was replacing meant that the range was sufficient. Integration of the external fuel tanks could always be done later; some future export customer might have the requirement and be willing to pay for it or at least share the cost. However, there were not many air forces that required such force projection as the USAF. One advantage of external fuel tanks over internal fuel tanks is that they do not need to be cleared for the entire flight envelope or the 8,000 or 16,000 hours of durability testing.



AA-1 was also quickly qualified on the tanker aircraft. Here it is seen behind a KC-135. (*Lockheed Martin*)



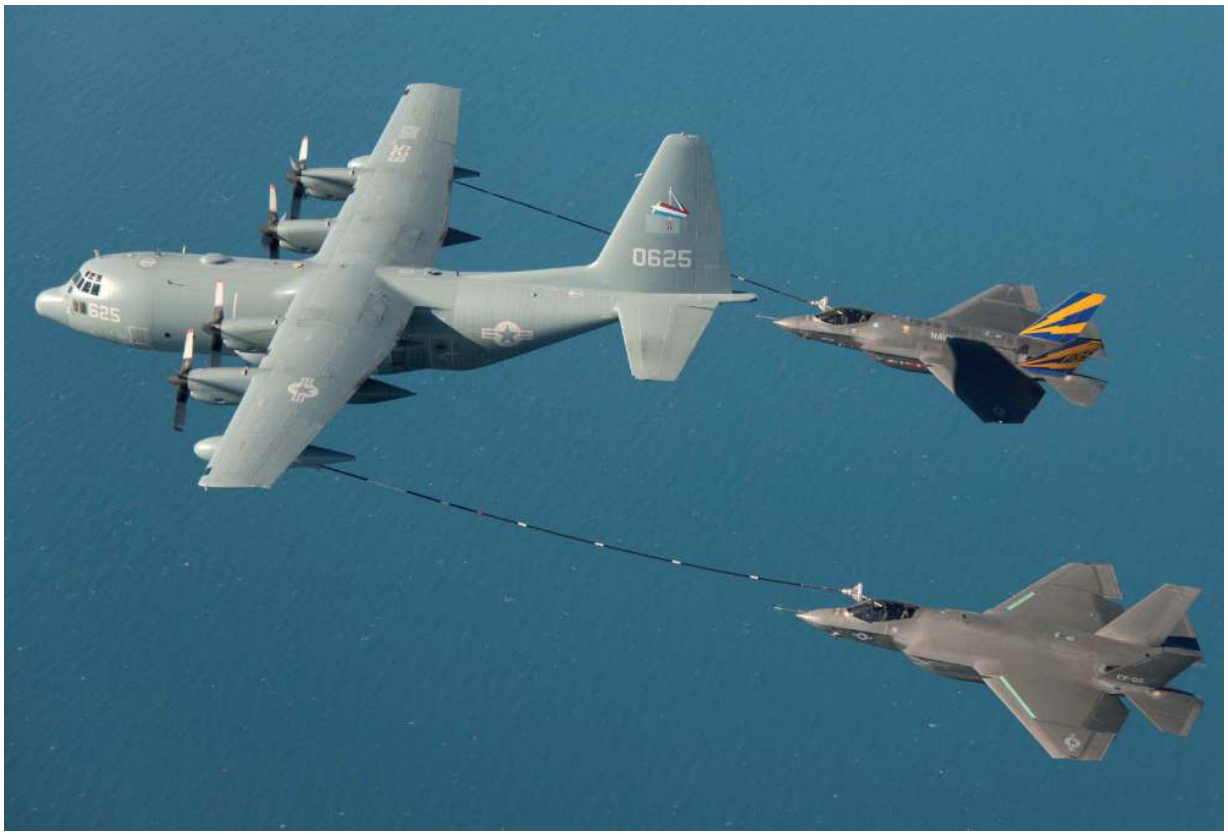
The KC-135 playing an active part during the SDD phase. The Royal Air Force sent its A330 MRTT Voyager for tanker qualification. (*Crown copyright*)

Fuel can also prevent an aircraft from landing if it is too heavy, especially for carrier landings which was the reason for the installation of a fuel-dump system. The system was mainly required for the US Navy; in Jon Beesley's words it was a way of life for the navy guys. The fuel-dumping system was tested on AA-1 so that it would not become a show-stopper later in the programme when it could have more serious effects. Furthermore the critical design review of the carrier version was planned for June 2007. On the sixth flight of AA-1, when Jon Beesley closed the valve for fuel dumping, fuel still came out slowly and in small amounts and continued along the wings towards the fuselage. So when the aircraft was down the valve was replaced by a better one and some foam was installed to give a different direction to the flow. On flight 18 the test was repeated, the valve closed the flow almost immediately and was found suitable for the carrier version. Fuel dumping is done rather safely because the pilot indicates the threshold amount of fuel that has to remain in the aircraft and the aircraft will not allow the fuel dump to be extended more than required. Another piece of information given by Jon Beesley at le Bourget in Paris 2007 was that AA-1 had a small problem with its fuel system and had not

used its full fuel capacity of 18498 lbs. The longest flight of AA-1 was about 1.5 hours. Beesley estimated that, with the full fuel tank, an easy two hours of flight could be achieved without air-to-air refuelling. On 12 April the first step towards air refuelling was taken when Jon Beesley opened the refuelling door for the first time. After this the continuation of in-flight refuelling was delayed by technical problems.



The F-35B being refuelled by C-130 tanker. The US Marines had modernised heavily and were probably the envy for any western air force. (*Lockheed Martin*)



The CF-2 Flight 158 with Mr. Dan Canin and CF-1 Flight 189 with Lt Chris Tabert on 18 January 2013. First dual refuelling of F-35C on KC-130 tanker. (*Lockheed Martin*)



A STOVL version from the SDD fleet plugged in to an KC-130 tanker. (*Lockheed Martin*)

In a briefing by Major 'Digger' Davis from Air Combat Command (ACC) each version was compared to the aircraft it was replacing in the US services. The F-35A was supposed to have 2.5 times the range of the F-16; the F-35B was planned to have 1.8 times the range of the AV-8B Harrier; the F-35C is supposed to have double the range of the F-18C. It was almost a year later that the first major milestone in aerial refuelling took place. On the thirty-fourth flight Jon Beesley hooked up with a KC-135R from Edwards. Although he did hook up several times during this flight no fuel was transferred. To facilitate these tests the KC-135R was based at NAS Fort Worth; it belonged to 445th Flight Test Squadron from 412th Test Wing. Two days later USAF test pilot James Kromberg performed some testing behind the tanker but, again, no fuel was passed on. That occurred two flights later with Jon Beesley back at the controls on 21 March 2008, again with a KC-135. This third flight with the tanker also set the record for flight duration at three hours. This was the last flight for aerial refuelling prior to the F-35 being grounded again after its fortieth flight for a flight test upgrade. The flight refuelling trials were important as they would allow the aircraft to transfer to Edwards AFB. The actual transfer to Edwards

occurred on 1 October 2008; it was then the longest flight in the programme.



The italian KC-767 was the first foreign tanker to be qualified for refuelling the F-35. (*USAF*)



The interface of the boom operator on the Italian KC-767. Note the headwear of the operator. (*USAF*)

The F-35 had to maintain a minimum amount of fuel for landing, as is normal with all fighters in case things go wrong. However the F-35 is a stealth aircraft with limited air cooling (ram-air limitations) compared to non-stealthy fighters. More electric systems produce heat that needs to transfer elsewhere for cooling. This heat is transferred to the fuel which is no problem early in the flight when tanks are full, but, when the fuel is burned and fuel load is reduced, the heat cannot be transferred. In other words, the F-35 needs to land without overheating its systems which demands more fuel for its landing the previous generation fighters with fewer electrical systems. It was not clear how much this affected the F-35, but it was considered a problem which made it into the media. The fact that that the power and thermal management system (PTMS) was due to be improved in Block 4 made it clear that the margins were considered small and that there was room for improvement. However, Lockheed Martin's Steve O'Bryan, vice president of F-35 business development, called that a red herring at le Bourget in 2009 saying that the thermal requirement was

the toughest of any fighter aircraft ever built. The unique feature of the stealth aircraft also means that it is all very tightly packed with no natural gaps or spaces through which air cooling can be applied. According to him, the fuel system is a natural heat exchanger. The only time when there is a thermal 'issue' (he did not want to call it a problem) was with the STOVL aircraft at 90 degrees Fahrenheit. All three versions are thermal compliant with the requirements. As an example of the thermal requirement, O'Bryan described the following situation: an F-35 tanked with fuel with a temperature of 120 degrees Fahrenheit is standing on the tarmac with engine and all other systems running. It goes on low-level flight mission at an outside 120 degrees temperature in, for example, the middle of the Saudi desert, comes back and sits on the ground again for an hour before refuelling it again. 'We are passing that specification quite comfortably even when performing a vertical landing.'



Australian KC-30A over the USA. Australia well ahead of the time qualified their KC-30 for when they required it for transit. the first transit of F-35s was for a visit to an Australian air show. (*USAF*)



For the evaluation of the F-35B refuelling capability, Lockheed Martin had to wait longer than it liked and expected. First steps were made in the autumn of 2008 when the retractable probe was extended from the aircraft during flight. After this had been successfully tested on BF-1, the STOVL aircraft was grounded in preparation for the hover pit tests and engine modification qualification. It was only in summer 2009 that the second STOVL prototype, BF-2, resumed test flying and the aerial refuelling testing trials were resumed when initial flight qualification flights were complete.



The Dutch sent one of their KDC-10's over for the qualification. The KDC-10 has since been retired by the Royal Netherlands Air Force. (*USAF*)



The UK was the first export country or partner country that qualified the STOVL version on their tanker and the KC30 became the first aircraft to be qualified to fuel the F-35A and F-35B. (*Crown copyright*)

When BF-2 was transferred from Fort Worth to Patuxent River the aircraft was refuelled by a Lockheed Martin KC-130 Hercules from the US Navy VX-20 and returned with the crew that had performed the initial refuelling trials from Fort Worth. The first refuelling mission by this unit included Steve Angay, Craig Homer, Josh Iyenour, Jeff Kosich, Chris Loftis and Bill Smith. The VX-20 is normally at home at Patuxent River, just like the VX-23 that is also supporting the JSF programme.

The aerial refuelling tests, although already initiated on AA-1, were resumed on AF-1 on 21 April 2010. AF-1 was flown by chief test pilot Beesley. During the 2.5-hour flight, a KC-135 transferred 4,300 pounds of fuel. Both aerial-refuelling systems, the drogue-and-probe and the boom, were to be installed on Canadian aircraft. As there would be a requirement to select a certain system the avionics system would have to be adapted

slightly so that the pilot can select the right refuelling option. Another option was to let the system open both at once although this might cause a problem in the plumbing system.

Aerial refuelling had become part and parcel of flight testing and every SDD aircraft transferred from Lockheed Martin Fort Worth to Patuxent River was refuelled during flight. This was done as a safety precaution so that the pilot could select other bases to land at in case of having to divert and land somewhere else.

During aerial refuelling of the F-35A, connect-and-disconnect problems were encountered during 2012. These required an evaluation of the cause. Evaluation and remedy took some time. AF-1 flew with the solution two flights to see if the problem had been solved. Those flights occurred on 12 and 14 December 2012 and during them, 174 connects/disconnects were performed with an instrumented tanker; no delays were registered. The next phase of in-flight refuelling evaluation was initiated in 2012. The aircraft at this time was already qualified for day time but, since night time flying had begun, it was important to keep the aircraft airborne and one of the first tests was nocturnal in-flight refuelling. The first such refuelling occurred with a KC-135 Stratotanker and AF-4 was flown by USAF test pilot Lieutenant Colonel Peter Vitt from Edwards AFB. That this milestone was advertised showed that the need for good news was immense; every milestone that could be milked was so. The next milestone in flight-refuelling was the first operational flight refuelling from Eglin AFB which marked an expansion of the training syllabus ahead of the operational utility evaluation, a milestone that offered more confidence in the system and a sign that operational capability was expanding.



The F-35 was not the only delayed programme. The KC-46 also had a very rocky development. The two met for the first time in 2019. (*Lockheed Martin*)

Testing of the probe-and-drogue system continued with the first double refuelling of two F-35Cs achieved on 17 January 2013. F-35B, BF-2, flown by USMC test pilot, Lieutenant Colonel Matt Kelly as part of strategic tanker testing, performed aerial refuelling operations with an air force KC-10 tanker on 19 June 2013. This was followed by qualification test flights with a KC-135 equipped with a drogue with the F-35C. USMC test pilot Lieutenant Colonel Patrick Moran flew CF-1 for its 217th flight on 20 August 2013, during which he connected with the KC-135 for refuelling. This milestone meant that all three F-35 versions were qualified to take fuel from the KC-135.

Airframe wetting during fuel-dump operations was still a problem and a solution was to be selected by March 2013.

Problems with the fuel system continued to surface during development. The latest problem exposed by Dr J. Michael Gilmore, Director of Operational Test & Evaluation, in early 2016 was that all Block 2B aircraft were limited to a maximum of 3G in symmetric manoeuvres when fully

fuelled in order to avoid exceeding the allowable pressure in the siphon fuel tanks. As soon as fuel levels decreased limits of g loads were lifted. Dr Gilmore noted that a hardware solution for the problem had been designed and tested for the F-35B and retrofit packages were in production so that they could be sent to the units in the field. The new hardware would be installed on the production line from LRIP 8. Once this modification was installed the manoeuvre limitation on the flight envelope was removed. The solutions for the F-35A and the F-35C were still in the pipeline.

Not even three months later Dr Gilmore stated before the House Armed Services Committee that the F-35 fuel-burn rate is very high compared to legacy strike fighters – at least 60 per cent higher than the F-16C, and 180 per cent higher than the A-10. This creates a burden on the air-refuelling resources if used to increase F-35 time on station. The higher fuel burn rate is off set in the F-35A and F-35C with more internal fuel; this, however, equals each other out.

Partner nation qualifications

The partner nations with an air-to-air refuelling capability had different aircraft from the USAF. The air forces from these partner nations sent their refuelling aircraft one by one to the US to qualify them to refuel the F-35.

The first nation to send their air-refuelling assets to the US for tanker qualification was the *Aeronautica Militare* (Italian Air Force) which has four KC-767s in its inventory. The reason for Italy's hurry was that their F-35s were due to roll off the production line in Cameri. Pilot training was to take place at Luke AFB and the first F-35s had to transfer to the US to support pilot and maintainer qualification. One of the four, a KC-767A belonging to 8° *Gruppo* (squadron) of 14° *Stormo* (wing) from Pratica di Mare airbase flew to Edwards AFB. The actual flight test phase took place from 22 July to 6 August when the KC-767 was qualified. The qualification first transfer of fuel took place on 29 July with twenty-five boom contacts and 16000lb (7259 kg) transferred during the flight. A total of twenty-four flights took place, during which 655 contacts were made and a total of 330000lb of fuel transferred.

The second nation to send an aircraft for aerial refuelling was the Royal Australian Air Force (RAAF) which was the first country to come with a tanker aircraft produced outside the USA. The KC-30A, a variant of the Airbus A-330, is equipped with a boom and wing-mounted hose-and-

drogue systems. The KC-30A flew just like the Italians with aircraft from Edwards AFB. The trials started on 23 September 2015 and lasted until 26 October 2015. Twelve sorties were flown altogether with KC-30A using the 18-metre-long advanced refuelling boom system and an F-35A. During those twelve flights a of 479 dry and twenty-four wet contacts were made with the refuelling receptacle of the F-35A. The F-35A was also flown with external stores and linked up with the tanker. The KC-30A was operated by a crew from No. 33 Squadron.



The future of airpower together in 2019. (*Lockheed Martin*)

The third nation to do so was the Netherlands which sent over its KDC-10. The main difference between the KC-10 and the KDC-10 was the boom operator's view over the receiving aircraft. In the KC-10 the boom operator has a large window with a good view over the aircraft it is refuelling. The KDC-10, however, lacks this large window. Instead the KDC-10 boom operator is reliant on five displays from the tanker remote vision system (TRVS). The images on the five displays are provided by three cameras that provide more than 180-degrees horizontal field of view between both KDC-

10 wingtips in the aft direction. Two other cameras from the stereoscopic vision system aimed at the refuelling boom tip provide the other images. The other difference between the KC-10 and the KDC-10 is the fuel-loading capacity.

The RNLAF deployed one (T-264) of its two KDC-10 aircraft to Edwards AFB to perform the air-refuelling trials. The RNLAF was the first to use their own F-35A aircraft and their own pilot, Majoor Laurens Jan Vijge. Only one pilot was used because of the ease of briefings. Qualification was completed by 31 March 2016. The Netherlands was, however, investing in new tankers to replace the KDC-10, the replacement being the A-330MRTT.

Rather surprisingly because of its status within the programme, the next partner nation was 'only' the fourth to send its tanker for flight qualifications. The United Kingdom deployed one of its nine A-330-200 Voyager multi-role tanker-transports (MRTT), also known as a KC-30, from Brize Norton on 15 April 2016 to NAS Patuxent River. The UK was the first country to send its aircraft to NAS Patuxent River and to qualify its refuelling aircraft on the F-35B. The Voyager was essentially the same aircraft as the Australian KC-30 but this time the qualification trials had to do work with the hose-and-drogue system. The first flight test where contact was made with BF-4 was on 19 April. As of 20 May five flights had been flown of twenty planned. The reason for qualification had nothing to do with the imminent deployment to the UK for the Royal International Air Tattoo and Farnborough but with the deployment of 617 Squadron, the Dambusters, to RAF Marham in 2018 at which time ten aircraft were supposed to deploy to their new home base.

After the SDD was completed it was the turn of the KC-46 to be tested with the F-35. The Boeing KC-46 Pegasus was the future of the USAF aerial refuelling capability and therefore it was only logical that on 22 January 2019 the F-35 hooked up to the KC-46, another step in providing future force projection.

Unmanned aircraft were considered the future and for this reason the US Navy had initiated several programmes to prove that drones could land on an aircraft carrier. Once this was proven by the Northrop-Grumman X-47B in 2013, the next step was to evaluate what would be the first drone to operate from their ships and from several unmanned UAVs proposed the MQ-25 as the first serious looking acquisition programme for an aircraft-

carrier-based UAV. For the MQ-25 Boeing was selected and the first flight of the prototype took place on 19 September 2019. The flight-test programme started gaining in significance when the MQ-25 Stingray refuelled a Boeing F-18F from VX-23 ‘Salty Dogs‘. The second type refuelled by the MQ-25 Stingray was the E-2D. The next step was the F-35C. CF-5 was the F-35C used and was flown by Commander Andy (Bosco) McKee during this first flight. He stated that he had to fly 750 miles to the test site, execute the test and return. It was a first step in getting this capability to the fleet but the capability would allow the US Navy to increase the range of the F-35C. The first flight with F-35C hooking up to the Boeing MQ-25 Stingray took place on September 13, 2021 and was a possible sign of things to come for the US Navy.

Radar System

A novelty for the new generation of fighters was that the radar would be on the basis of the active-electronically-scanned-array (AESA) technology. The technology was from the outset a new technology for the advanced tactical fighter (ATF). In the west the technology had been introduced for the first time in McDonnell Douglas F-15 Eagles based in Alaska. The next step was the F-18E/Fs introduced into service with the US Navy shortly after. The F-22 Raptor followed suit in 2005.

The AESA radar system had several advantages, the most important one being that it could be used for multiple tasks, the second the fact that it gave the radar a low probability of intercept (LPI). AESA was not only a radar, but the system could be used for other purposes, and; those functions and capabilities had to be explored. The new functions and advantages would be:

- Data communication and data linking
- Jamming
- Jammer nulling through beam agility
- directed energy weapon

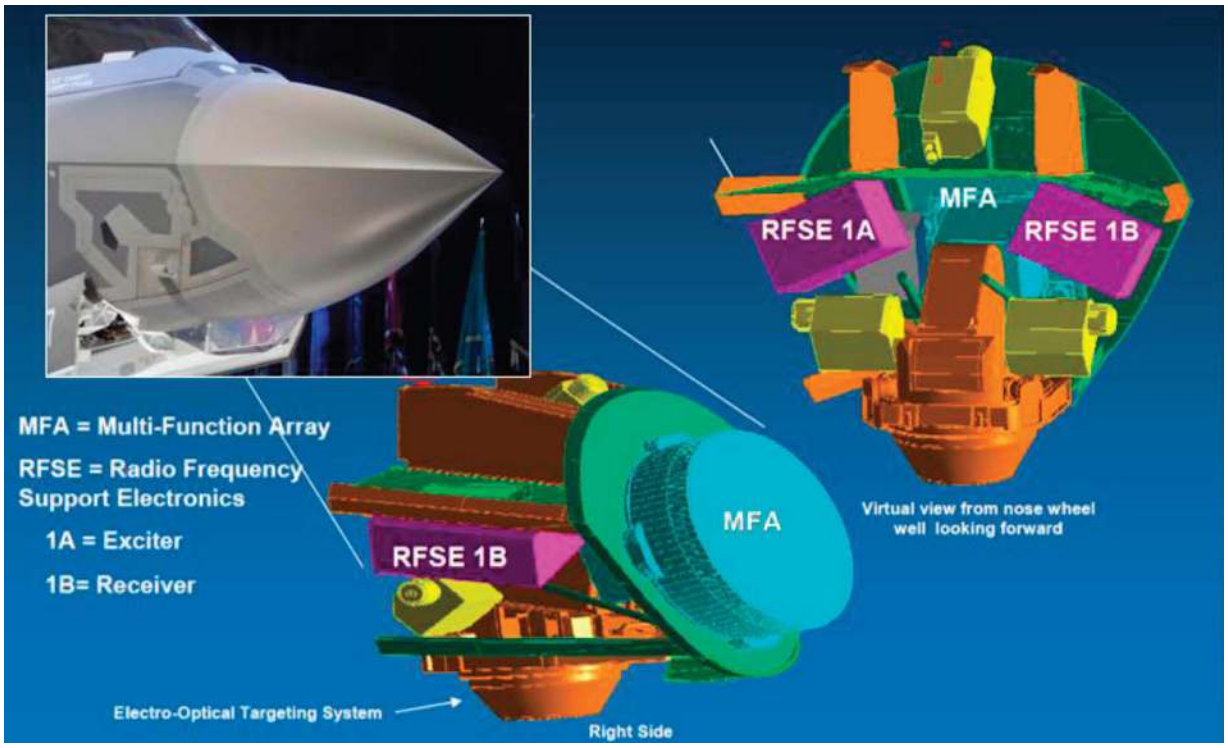


The F-35 APG-81 was integrated not only in the avionics but it was an integral part of the Electronic Warfare system as well. (*Lockheed Martin*)

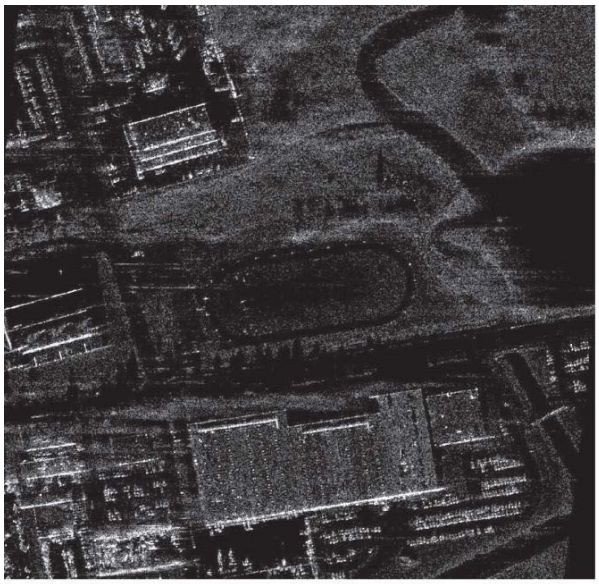
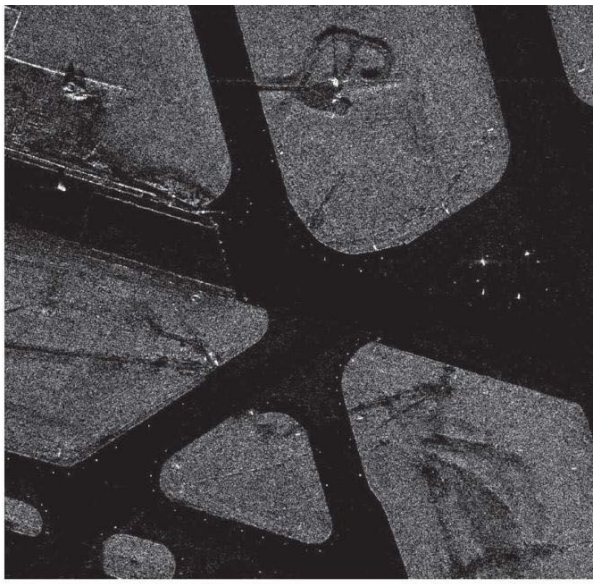
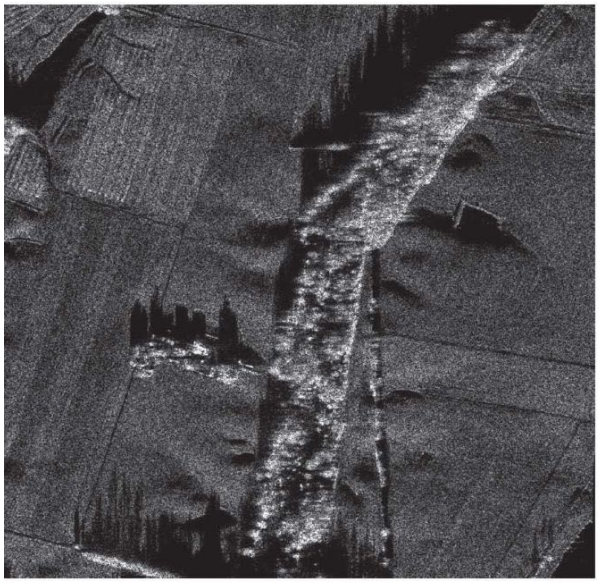


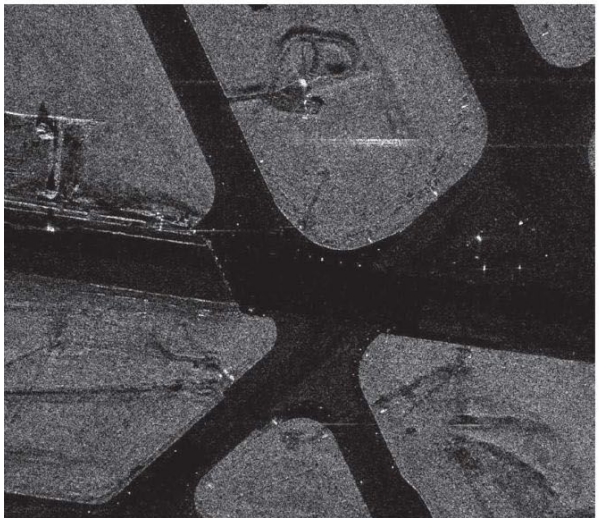
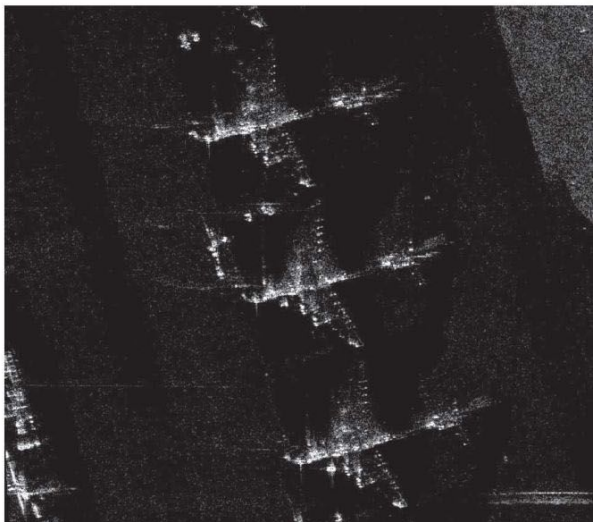
The quality of the radar in combination with stealth makes the AWACs superfluous. (*Lockheed Martin*)

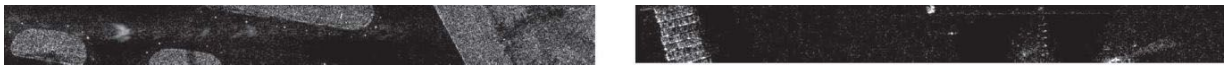
As the last radar developed for any US fighter was the AN/APG-80 for the F-16E/F for the United Arab Emirates, the new designation for the radar for the F-35 was the logical follow up: AN/APG-81. According to the US Army Navy (AN) electronic equipment identification system, the system was for a manned aircraft (A), the type of system was radar (P) and the main function was fire control (G). In other words, the radar for the APG-81 was the eighty-first radar produced for integration into manned aircraft.



The tightly packed nose cone does not only house the radar but as this image shows it houses the EOTS, and the three yellow boxes are three of the six EO-DAS sensors. (*Lockheed Martin*)



These are images from the APG-81 radar taken with the Synthetic Aperture Radar. The images can be called up later or forwarded to other players in the area or the pilot can act upon this detailed information himself. (*Northrop Grumman*)

As with the APG-77 used in the Raptor, AN/APG-81 is installed in a canted position to reduce possible reflection. The reflection from the radar dish will be upward away from the radar wave source, increasing the stealthiness, and thus survivability, of the F-35.

The AN/APG-81 has over 1,000 T/R modules and if one would fail it would not be repaired but the radar would function by graceful degradation. The plan was just as former JPD Mike Hough hoped for: that the antenna unit would not be repaired but be a sealed unit with 'do not tamper with' technology. Upgrades would be through software or replacing the antenna with a new unit. During a briefing by Northrop Grumman's Mark Gaertner, at le Bourget 2009, the capability of AN/APG-81 was demonstrated on video. The video reminded the viewer that the radar had no moving parts and that the transmitter/receiver modules were electronically steered. There were twenty-three targets within 100 miles during one flight test to be detected in the area and the radar managed to target and track nineteen of them under three seconds and had detected all and kept track of them within nine seconds while searching for more. This is important from a survivability point of view: the faster a radar or any sensor for that matter can find the target or any danger for the aircraft the faster the target or the danger can be destroyed.

The military Exercise NORTHERN EDGE 2009, held in Alaska, was an opportunity to test AN/APG-81 radar in an operational environment as ground-and air-to-air and even maritime electronic attacks on the functioning radar had to be countered. NORTHERN EDGE was held from 15 to 26 June. Northrop Grumman took the opportunity and send its BAC 1-11 equipped with AN/APG-81 radar to Elmendorf AFB, Alaska. There it participated in the exercise and had to counter these electronic attacks on AN/APG-81 to demonstrate the electronic protection capability of the radar in this highly representative environment. Electronic attacks applied to the radar were intended to either degrade, neutralize, or destroy the combat capability. Teri Marconi from Northrop Grumman explained:

We spent the last several years in the laboratory testing environment on the ground and in the air validating the maturity of the software for electronic protection. We were pleased with the results, so when NORTHERN EDGE 2008 was completed, we started to socialize the idea, through the F-35 Joint Program Office (JPO) and the Joint Electronic Protection for Air Combat (JEPAC), of the BAC 1-11 equipped with an APG-81 participating in Northern Edge 2009 in order to further validate in an operational environment, what we already established in the laboratory.

We laid out our test objectives for electronic protection and planned to achieve them over seven to ten days of flights. We were quite pleased that we finished all our objectives for electronic protection in 3.5 days. The NORTHERN EDGE 2009 exercise was highly co-ordinated, with up to a hundred aircraft participating at any given time, as well as a Naval carrier battle group. The BAC 1-11 took part in both scripted and unscripted portions of the exercise. During the scripted portions of the exercise, the BAC 1-11 team pursued and successfully met a specific series of test objectives for the radar.

From a testing standpoint, there were no special test cases or software specifically modified for this exercise. The radar software was used in the same way it would be employed in an operational F-35, concluded Teri Marconi. Electronic protection is a shorter term for electronic counter-counter-measures (ECCM). The design of the radar and its effectiveness depends heavily on its capability to continue to function withstanding these electronic counter-measures (ECM) from opposition forces.

‘Exercise NORTHERN EDGE presented a rare and valuable opportunity to observe the performance of the F-35 Joint Strike Fighter’s APG-81 radar inanoperational environment,’ said Michael Solomon, a representative from Resources and Experimentation, US Pacific Command. The exact capabilities of the radar remain secret but Lockheed Martin test pilot Billie Flynn has stated that the range of the radar is well over 200 miles. The Northrop Grumman AN/APG-81 has been the only radar for the F-35 from the outset. The technology of the antenna had been tested for robustness and as such was deemed not to require any maintenance over the life of the F-35. It came more or less out of the blue when the story broke that the AN/APG-85 radar had been in development for a while. The change was deemed necessary for two reasons: there is never enough capability, and

secondly a big problem for stealth aircraft is cooling. The transmitter/receiver in the AN/APG-81 have Gallium Arsenide semiconductors in the 1,676 transmitter/ receiver modules whereas the AN/APG-85 has Gallium Nitride semiconductors in the probably 1,676 transmitter/receiver modules instead. Gallium Nitride has a significantly better heat dispersal ability. This results in either more power available for increasing the detection range or decreasing the cooling requirements and maintaining the same level of capabilities or a combination of both.

Air to air	Air to surface	Electronic Warfare	Navigation support	Other
Autonomous search	Ground map	Electronic attack	Weather	Automatic target cueing
Sector search	Ground moving targets identification	Electronic Protection	Navigation updates	System Health and calibration
Passive search	Surface emitter			Communication
Cued search	Air to ground ranging			Data link
Air Combat mode				
Multi-target track				
Air target identification				
AMRAAM support				

Working with/around the F-35

Flying and maintaining are the two words that come to mind when talking about working the F-35. The flying was to be done by one pilot, which was decided early on in the programme. The maintaining and sustaining of the F-35 was supposed to be less work intensive so that the cost of operations would go down. Sustainability of the aircraft was one of the four pillars of the JSF programme. One of the ways of getting maintenance hours down was making the maintenance work less intensive. Some key performance parameters (KPP) were:

- 97.8 per cent mission reliability
- 30 per cent increased sortie generation rate
- 21 per cent sustainment cost reduction

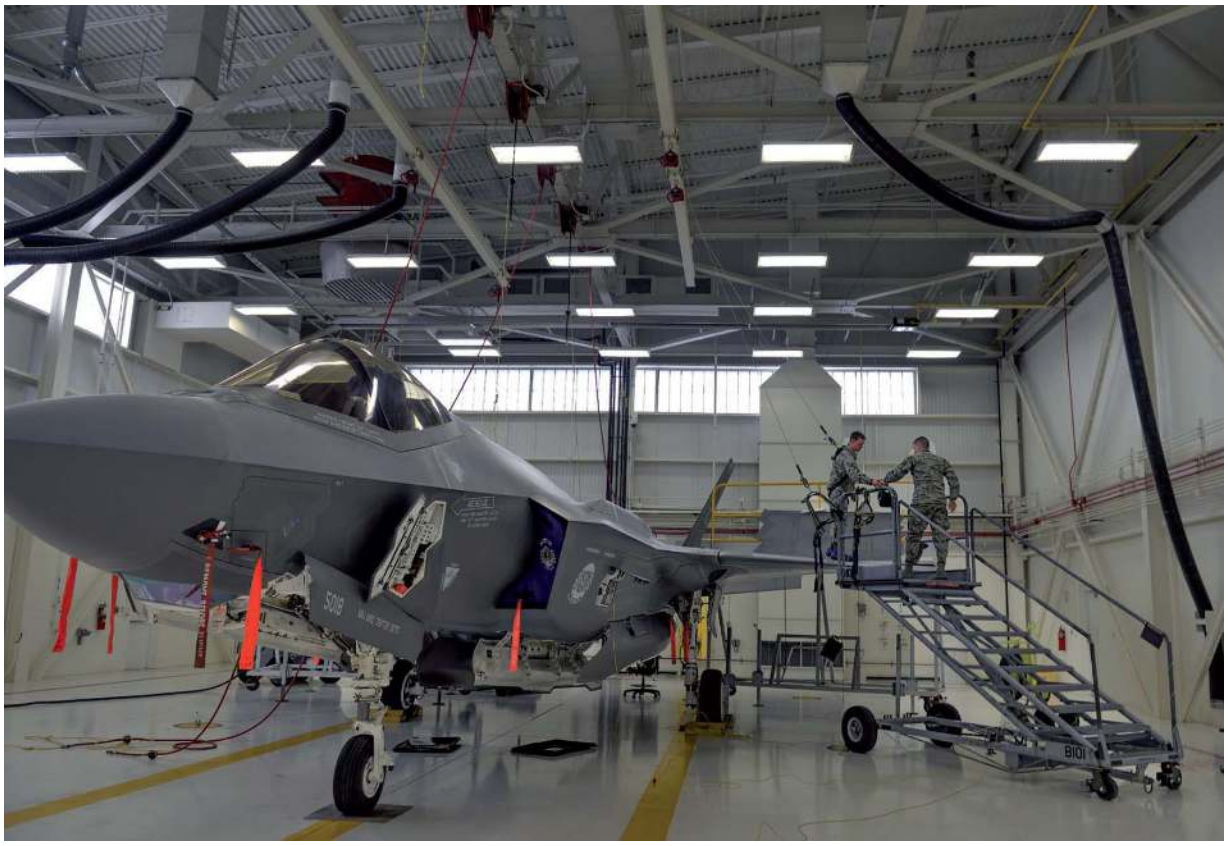
In a presentation from Lockheed Martin for the JSF Canadian Sustainment Conference it was stated that the CTOL version was to give the USAF a 35 per cent reduction in maintenance manpower over the F-16 or A-10 which the F-35A was to replace. The US Navy and the USMC were supposed to be able to reduce their maintenance manpower by about 40 per cent. Maintenance levels were to be achieved by one of the main features of the F-35 system, the autonomic logistics information system (ALIS). Each F-35 unit is connected to ALIS through standard operating units (SOU). ALIS is available 365 days per year 24/7 because it is connected to an uninterruptable power supply (UPS).



The HMS *Queen Elizabeth* has been designed around the F-35B and as such there is a spacious feel in the hangar under the main deck, the space above the aircraft is important for lift fan removal and installation. (*Royal Navy*)



Fire drills are an important part of being ready and as the F-35B was a new aircraft these drills had to be done relatively early to train the firefighters here seen on the USS *America*. (*USMC*)



The F-35A at Eglin would be maintained in newly built facilities. The maintainer suspension system is to avoid injury and damage if the maintainer should slip and fall. (*USAF*)

The importance of ALIS can be explained by a short explanation that the air system (AS) exists out of the air vehicle and autonomic logistics (AL). The air vehicle can be divided into five subgroups: the airframe, the vehicle systems, the mission systems, propulsion and PHM system. The autonomic logistics can be divided into three parts: ALIS, support systems and training systems. ALIS is an eighth of the entire AS.

ALIS subsystems (Hardware)

Equipment	Notional Beddown	Function	
Autonomic Logistic Operating Unit (ALOA)	Lockheed Martin Fort Worth	Supports all ALIS functions Central repository for logistics, maintenance, mission planning, vehicle status and fleet health data	Classified and unclassified
Central Point of Entry (CPE)	1 per country	National information aggregation Allows nations some data flow control to and from ALOA Provides linkage between commercial and military equipment	Classified and unclassified
Standard Operating Unit (SOU)	1 per squadron	Unit level data storage Information exchange with CPE	Classified and unclassified
Offboard Mission Support Work Station (OMS WS)	Multiple per squadron, number depends on customer preference	Display workstations for data stored in SOU Support mission planning and debriefing	
Portable Maintenance Aid (PMA)	2 per aircraft	Ruggedised computer used by maintainers to connect to F-35 for health and maintenance data Used to track aircraft status, order parts, log maintenance tasks and display technical data.	unclassified
Portable Classified Aid (PCA)	1 per aircraft	Classified version of PMA	Classified
Low Observable Health Assessment System (LOHAS)	1 per squadron	Classified system that supports maintenance of F-35 low-observable condition and repair	Classified



Maintenance on top of the F-35, the maintainer is secured from the top. Note that the he has special covers over his boots to protect the coatings. (*USAF*)



The Portable Maintenance Aid (PMA) was a notebook. In 2018 an additional tablet was introduced. (*USAF*)

A little talked about feature of the autonomic logistic operating unit (ALOA) was that the functions of two given were not as simple as they seemed. It does more than just support all ALIS functions but besides being a central repository for logistics, maintenance, mission planning, vehicle status and fleet health data, the fleet health data is evaluated by a structures life management (SLM) cell. An SLM cell is supposed to be set up in the USA and the UK, functioning on identical software. The SLM cell is going to monitor actual aircraft use. Things such as flight control effector movements, loads experienced during flight, the data collected including Mach, angle of attack (AoA), angle of sideslip, accelerations, stores and fuel carriage, will be checked against data gained from durability tests and as such compared. This will provide the industry with data but also the operators as the information is fed back through ALIS. The amount of information being sent back is the most contentious part of the system for partner and export nations.

The first version of ALIS was put into use by October 2009. The designation was ALIS 0.1.5. It took only nine months before a new version, ALIS 1.0.2 was put into operation by June 2010, the year that the version of ALIS should be able to support the entire developmental testing for the F-35. ALIS 1.0.2 introduced capabilities such as supply management, mission planning and maintenance management. ALIS proved to be a bigger problem than was anticipated and the joint programme office (JPO) was unhappy about the progress made and wanted to gain input from other people or companies to ensure that ALIS would not hold them in custody for the remainder of the lifetime of the programme. That was the reason why, in 2012, the JPO organised a sustainment industry day which took place on 14 November 2012. Lockheed delivered a new version of ALIS with designation 1.0.3 by December 2012 and supplied more integration of the previous capabilities. The next version to be implemented was ALIS 2.0, a little over two years later in January 2015. ALIS 2.0 brought central point of entry reporting capabilities. This was followed by the decision to introduce small software fixes in between major upgrades as the end user was not happy with the performance of ALIS.



The cleaning of the F-35 is not an easy task. As can be seen the canopy received a special cover. (*USAF*)

By 2016 two different versions of the standard operating unit (SOU) existed. The first one was SOU V1, SOU V1 was housed in two 1,600-pound server racks and was mainly used at texting sites. The second version SOU V2 was designed to have its components fit into transit cases that are two-man portable, each weighing approximately 200 pounds according to a GAO report. The obvious advantage of SOU V2 is its deployability.

The SOUs were based as follows, equipped with ALIS 2.0.1:

Base	**Amount**	**Proposed Software 2.0.2. Upgrade**
Fort Worth	1 SOU V1 2 SOU V2	July 2016
Edwards AFB	4 SOU V1	October 2016

NAS Patuxent River	No information	
Eglin AFB	3 SOU V1	August 2016
Nellis AFB	2 SOU V1 1 SOU V2	October 2016
MCAS Yuma	1 SOU V1 2 SOU V2	September 2016
Ogden Logistics Center depot	1 SOU V1	September 2016
Luke AFB	5 SOU V1	November 2016
MCAS Beaufort	2 SOU V1	August 2016
Cherry point depot	1 SOU V1	September 2016
Hill AFB	1 SOU V1	July 2016
USS Wasp	1 SOU V1	November 2016

ALIS was considered one of the biggest risks because of the software. ALIS had a lot of programmes or applications as programmes were being called. Of the nine applications of ALIS, two were reported to have no problems, five were reported to have minor problems and the remaining two were reported as having major problems. The nine applications were:

1. Joint technical data (JTD) is a technical, interactive electronic publication used to assist in repairing the aircraft. It can display the appropriate information based on aircraft variant.
2. Computerised maintenance management system (CMMS) is used to initiate and track maintenance actions, schedule of work, aircraft and support equipment status, access the joint technical data (JTD) and provide traceability to ‘as built’ and ‘as maintained’ configuration data.
3. Supply chain management (SCM) is used to provide near real-time responsiveness for all activities that directly or indirectly support the sortie generation cycle.
4. Low observable health assessment system (LOHAS) is used to manage the radio frequency signature health of the aircraft. Software provides the user a range of analytical and data management capabilities to identify damage and repairs needed.

5. Maintenance vehicle interface (MVI) provides an interface to the aircraft for the portable maintenance aid (PMA), allowing the maintainer to operate aircraft subsystems, and retrieve and display aircraft status including fuel levels, pump status and weapon status.
6. Off-board mission support (OMS) is used to conduct mission planning, generating information on the mission area and uploading it onto the aircraft, and mission debrief.
7. Air vehicle data/health (AVD/H) decodes prognostic health management (PHM) data. It also collects, filters, and correlates downloaded system generated and manually raised health reporting codes and converts them into working orders. It extracts PHM data and provides them to the computerised maintenance management system (CMMS). It also assesses the mission capability of the aircraft based on the health and the status information available.
8. Propulsion processes the data downloaded from the aircraft, including propulsion health reporting codes (HRC) as a basis for ADV/H to generate work orders that are passed to the CMMS.
9. Training management system (TMS) is used for programme administration, planning, scheduling, and collecting actual events from training, and ad-hoc reporting. Based on permissions granted, it provides access to specifically authorised courseware.



It was feared early in the programme that a supersonic STOVL fighter would cause equipment and staff to be blown of the deck like confetti. It was unfounded but a certain respect is required as can be seen with the F-35B on approach to the USS *Makin Island*. (*USMC*)



The tablet that was added was easier to take along to the flight line. (*USAF*)



The first aircraft arriving at the depot at HILL AFB, Ogden Logistics Center (OLC). The learning curve and therefore the modernisations required were not all known at the time. (*USAF*)



The USMC shortly after also sent its aircraft to Ogden. These are the two first examples on arrival. (*USAF*)



Working beneath the F-35 means loading the weaponry onto the F-35B. In normal circumstances a tight working space, at sea this can be confounded by the sea state. (*USMC*)



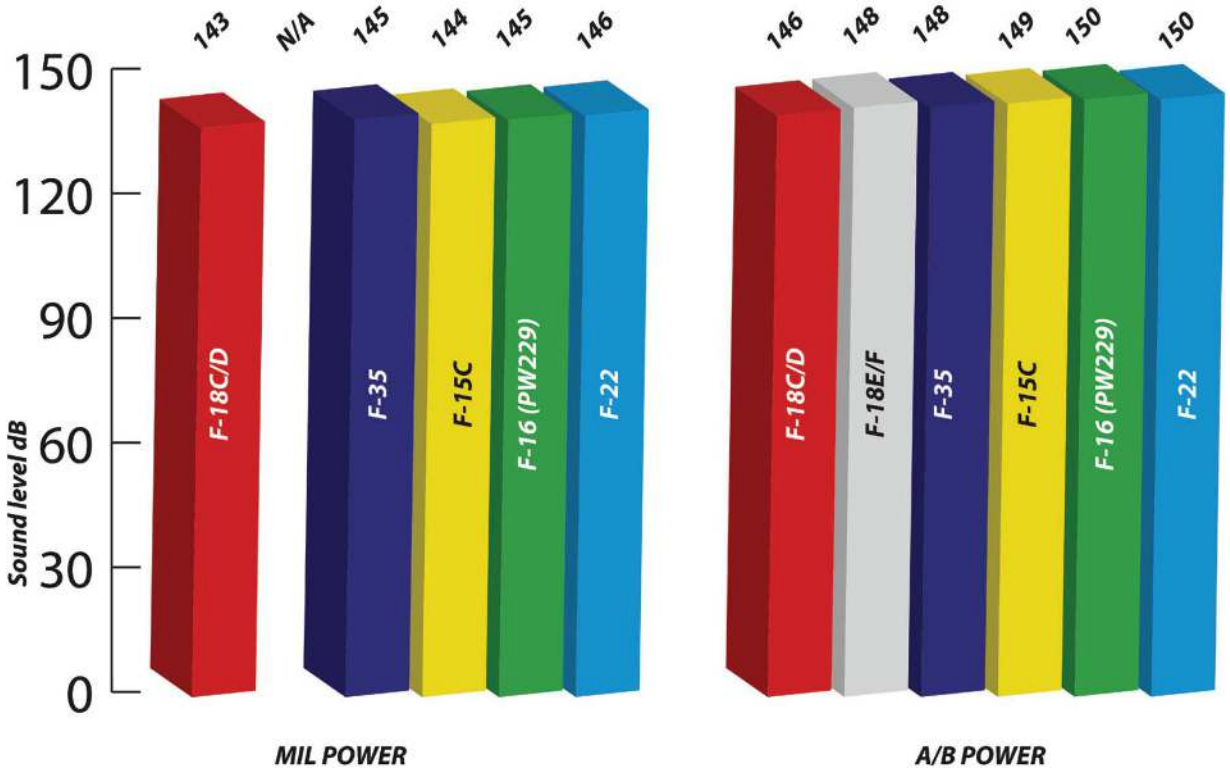
A rare look inside the depot at MCAS Cherry Point. Six aircraft in different stages of work. (*USMC*)



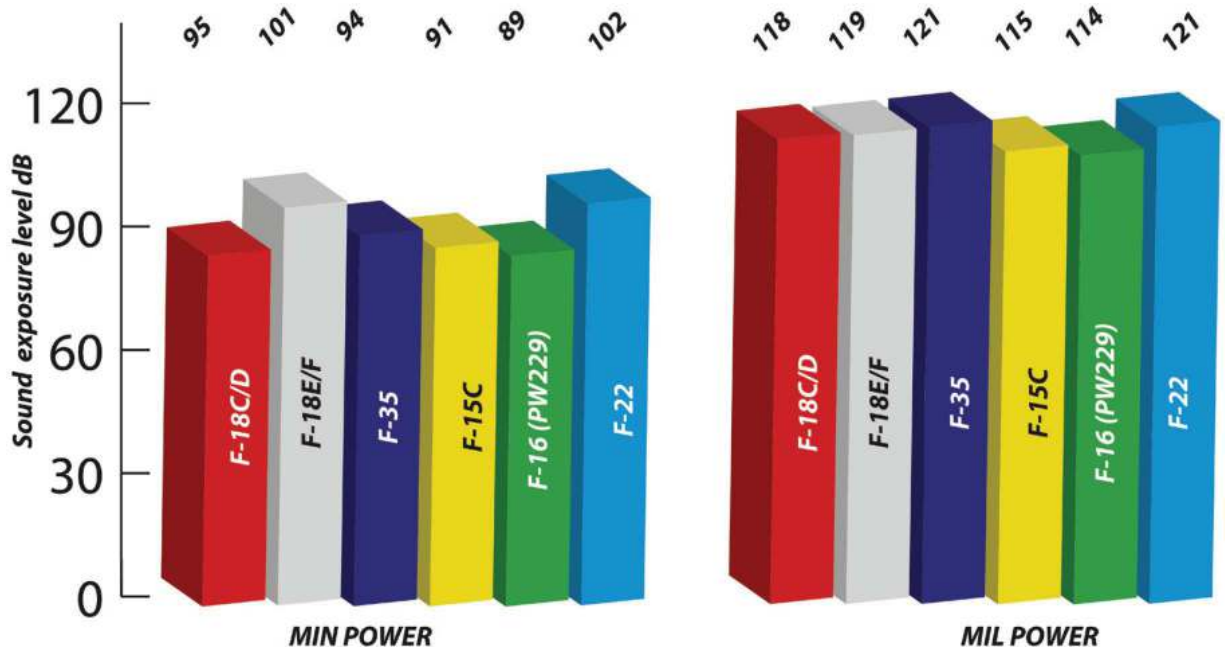
The first F-35B to be sent to a depot seen here after arrival at MCAS Cherry Point Fleet Readiness Center east on 9 July 2013. Cherry Point had to wait till 2020 to receive its first active F-35 unit. (*DoD*)



The F-35B had to operate in all kinds of environments and new materials had to be found to protect that environment. The amount of energy that went into development of new materials would surprise some. (*USMC*)



Measured worst case aircraft sound levels at 50ft distance. These measurements were made in 2009 for maintenance and operations personnel evaluation. F-18E/F data in military power were not available.



The sound predicted at 1000 ft height at minimal power and military power at Edwards AFB. These figures were important for people living around airbases.



Acoustic tests or noise evaluations were also performed in a Hardened Air Shelter (HAS) at Leeuwarden AFB, the Netherlands. These tests were performed in the Netherlands to convince the general public. (*USAF*)



The OBIGGS makes operations in bad weather near storms possible. It has to work properly and faults have been swiftly rectified. As of September 2021, a solution was still being sought for the last problem. (*Lockheed Martin*)



OBOGS were systems introduced in the fourth generation fighters and as such also used in fifth generation fighters. The Martin Baker seat was equipped with an alternative system to help the pilot survive. (*USAF*)



Both fifth generation fighters had episodes of hypoxia-like problems, which seemed to be a fifth generation issue. (*USAF*)



The hypoxia-like experience was confined luckily to Luke AFB. The problem seems to have disappeared. (*USAF*)



The F-35C in non chromatic primer. The F-35C and F-35B is the most vulnerable to corrosion due to operations at sea. (*Lockheed Martin*)



Jon Beesley returning from an early test flight in CF-1. (*Lockheed Martin*)



CF-1 just rolled out after receiving its first paint job. Note the landing gear is retracted during the paint process. (*Lockheed Martin*)



The F-35B BF-5 in primer. Note that panels and doors mostly have received their paint job. (*Lockheed Martin*)



F-35B operations at sea with a Sea Hawk following everything from the air. (*Lockheed Martin*)



It was not only the US Marines and US Navy that were having to battle corrosion. Partner nations Norway, the United Kingdom and the Netherlands have some pretty wet weather. The first arrival in the UK at Fairford in 2016 was a case in point. (*USAF*)



For the USAF the real corrosion test came with the arrival of operational F-35s at Eielson AFB. (*USAF*)



Initial Operational Test and Evaluation brought this VX-9 Vampire F-35C to Eielson AFB, Alaska in 2018. (*USAF*)



The F-35B, BF-5, here seen in the McKinley climatic facility at Eglin AFB. An ice cloud is being blown on to the F-35B – one of the many different weather types being evaluated. (*Lockheed Martin*)



Snow and icy conditions are corrosion conductive. USAF Airman 1st Class Jose Miguel Tam. (*USAF*)



Test at Edwards – cleaning after chemical contamination. (*Edwards AFB*)



Tina Slade and Jennifer Tanyatanaboon, microbiologists with Battelle, the lead contractor for the JSF decontamination project, prepare an F-16 for a biological (simulant) contamination trial. (*USAF*)



The F-35B during decontamination testing in its deployable housing. (*AFRL*)



The sheer size of the decontamination shelter is impressive. (*USAF*)



The interior of the decontamination shelter. These tests at Edwards were more successful than those a decade before. (*USAF*)



The F-35B being prepared for decontamination tests. Note the open lift fan door of the F-35B. (*AFRL*)



The F-35 being lifted by inflating airbags. (*USAF*)



Recovery testing taking place on the fourth CTOL F-35. (*Department of Defense*)



Royal Navy Culdrose, the only place where you can find these hand on trainers for aircraft handlers. (*Crown Copyright*)



These hands-on training devices can be filled with water to change the weight of the device to make training more realistic. (*Crown Copyright*)

For the Senate Armed Service Committee on 26 April 2016 General Bogdan stated that the IOC date for the USAF was planned for 1 August 2016 and had a threshold date of December 2016; the only thing that would be problematic to deliver in time was ALIS. ALIS had a sixty-day delay which he was positive about because it was within the threshold date. There was margin for bigger delays.

In the GAO report the following risks were mentioned as they were perceived by the actual operators of the ALIS.

Deployability of ALIS

Users were concerned about ALIS's ability to deploy in operational environments because of the large standard operating unit (SOU) server size and connectivity requirements. The Marine Corps, which often deploys to austere locations, declared initial operational capability in July 2015

without conducting deployability tests of ALIS. Although a more deployable version of ALIS was put into operation in the summer of 2015, the Department of Defense (DoD) has not yet completed comprehensive deployability tests.

No redundancy in its infrastructure

Users were concerned that ALIS's current design results in all F-35 data produced across the fleet to be routed to the central point of entry and then to the autonomic logistics operating unit, with no back-up system or redundancy. If either of these fail, it could take the entire F-35 fleet offline.

Ability to communicate with legacy systems

Users were concerned that ALIS does not have much interoperability with legacy systems. The services will continue using legacy systems for other weapon systems, and some of these data must be shared with ALIS. Because ALIS currently has little interoperability with legacy systems, some of this information is currently being tracked manually outside ALIS, which is inefficient and could result in data not being populated back into the system.

Action Request (AR) process is inefficient and problematic

Users reported that the then current AR process did not provide transparency of all ARs submitted across F-35 sites, and placed responsibility for resolving the requests primarily on the contractor.

Data accuracy and accessibility issues

Users reported concerns about data that reside within ALIS, including errors related to missing or inaccurate information about parts and not being able to extract raw data to generate needed reports.

Off-board mission support (OMS) and training management system (TMS) are immature

Users reported that both ALIS applications were important to their day-to-day operations but were immature and did not function as intended. OMS was a key application used by pilots to conduct mission planning and debriefing. TMS was used by pilots and maintainers to track training qualifications. Describing the problem during questions and answers for the House Armed Services Committee in March 2018, JPD Mathias Winter

explained that the true issues were in the underlying commercial off the shelf (COTS) products, based upon a 1995 architecture that causes unacceptable usability and interface concerns but that the design team was on track to assess the re-architecture plan to address all of those usability issues encountered and stabilise the software while continuing to work with the maintainers to ensure that ALIS would be scaleable and flexible for the distant future.

Going into a little bit more detail during follow-on questions he stated that after landing and bringing out the portable maintenance device (PMD), the data cartridge, there was initially an older generation of data recorder transfer that was just completely unacceptable; it was one to fifteen, one to twenty. ‘We are now on the third generation and having designed the fourth generation that’s now near real time and so that is good but even in downloading that our debrief mission planning system is not up to snuff and so we need to work on that along with that integration to ALIS so that all of that data can then provide the health and status and prognostic look-ahead for that individual aircraft.’ On 5 October 2018 it was announced by the USAF that a new tool had been put to work in conjunction with the PMD; the new tool was a ruggedised tablet. The original portable maintenance device or portable maintenance aid as it is also known is not WIFI-enabled, and does not allow for real-time information sharing.

The PMD units are also bulky and heavy and must be manually updated with tech data and other information. Any changes to a jet’s status also required maintainers to leave the flight line to log into ALIS. Now, maintainers and their tablets will be networked together to update work orders and other information immediately, moving from jet to jet much more quickly.

‘If we have an issue with a jet and need to ground abort, a pilot will be able to sign out a spare right on the line and step to that jet. We can do that right on the flight line without having to call the flight ops desk for a backup,’ said First Lieutenant Eric Dolan, 388th Maintenance Squadron Aerospace Ground Equipment Flight commander. Eventually 388th Maintenance Group will have nearly 200 of the handheld tablets which will help maintainers generate sorties quicker and more efficiently.

The PMD is a tool for downloading details of the flight. Data from the aircraft includes over 150 parameter time histories captured by the tool. Examples include air data system parameters such as angle of attack, Mach

number, altitude, control surface deflections, stores configurations and masses per station, accelerations (rotational and translational), velocities and rates (rotational and translational), individual fuel-tank states, miscellaneous discrete parameters such as weight-on-wheels, door positions and measurements from strain gauges, corrosion sensors that are part of the prognostic health management (PHM) system. There are also the engine parameters that are downloaded during the same process. This data is transferred to the squadron operating unit (SOU). The SOU provides the analysis of the data to the maintainer, or SOU operator. The data on the SOU will be sent on to the central point of entry (CPE).

The autonomic logistics information system (ALIS) had come under so much criticism that one could not be blamed for thinking that it was the Achilles heel of the F-35 programme. That ALIS was not performing as advertised had become clear even to Lockheed Martin and from 2017 they initiated an independent research and development (IRAD) looking into Cloud-based applications with the ability to perform tasks with the current ALIS applications and some new ones. One of the problems of ALIS was that since development started again computer technology had jumped forward and the interface was already aged by the time it was deployed. Besides the operational problems crews were also dogged by proprietary information problems related to ALIS.

On 29 September 2020, Marines at US Marine Corps Air Station (MCAS) Yuma, Arizona, completed the loading of a single squadron of F-35Bs on new modernized ODIN hardware. Later that day, the USMC flew the first flight supported by the new hardware with four more flights the following day. The new hardware is running the most current version of ALIS and is designed to host future ODIN applications. Successful operation at MCAS Yuma validates the next-generation servers as a viable successor to the aging ALIS system and provides a significant performance upgrade to F-35 units.

‘The Integrated Test Force at Edwards Air Force Base, California, and Naval Air Station Patuxent River, Maryland, were part of the Logistics Test and Evaluation (LT&E) event for the ODIN Base Kit (OBK) executed at Patuxent NAS during August 31-September 10 before the OBK was shipped to Yuma MCAS for operational testing,’ explained Mary Parker, Deputy Director for Logistics, F-35 ITF.

‘The OBK hardware, with currently fielded ALIS Release 3.5.2.2 software, supported two weeks of live flight test operations with superb supportability evaluation results,’ Parker added. ‘There was positive feedback from the maintainers on the flight line for the system speed of all ALIS applications.’

ODIN is the planned replacement for ALIS. ODIN is a cloud-native system that incorporates a new integrated data environment and a new suite of user-centred applications; it will be a significant step forward to improve the F-35 fleet’s sustainment and readiness performance. ODIN is being designed to substantially decrease F-35 administrator and maintainer workload, increase mission capability rates for all F-35 variants, and allow software engineers to rapidly develop and deploy updates in response to emerging warfighter requirements.

‘Different from ALIS, ODIN is an F-35 joint programme office-led effort leveraging government and industry partners such as Kessel Run, the 309th Software Engineering Group, Naval Information Warfare Center, Lockheed Martin, and Pratt and Whitney,’ said Lieutenant General Eric Fick, F-35 Programme Executive Officer. ‘ODIN will leverage the agile software development and delivery practices piloted by Kessel Run and investments by Lockheed Martin to better posture our F-35 fleet to increase and maintain a high readiness rate in order to meet its operational requirements.’

ODIN’s new hardware brings numerous improvements to ALIS. Immediately obvious is its reduced size. While existing ALIS servers comprise a full-person-height rack of electronics and require additional back-up power modules, the ODIN-enabled hardware fits within two transportable cases – roughly the size of two pieces of carry-on luggage. This smaller ‘footprint’ also brings significant weight reduction – from more than 800lbs for an ALIS server, to two modules each weighing under 70lbs for ODIN.

ODIN hardware also brings significant performance improvements while running ALIS. Performance testing of ODIN showed a reduction in the administrative workload and significantly reduced processing times compared to fielded ALIS servers (> 50 per cent decrease) – reducing the maintainers’ workload by making system interactions quicker. The testing

also demonstrated a significant reduction in the time required to configure the system for use in a new environment and transfer aircraft.

'The portable memory device (PMD) debrief time was twice as fast as the PMD Debrief on the ALIS deployable squadron operating unit (SOUv2-unclassified – aka the ALIS server). There was a significant reduction in OBK hardware logistics footprint, with the OBK being one-quarter the size of the SOUv2-U,' Parker said. 'There were favourable supportability results for the integrated product support (IPS) measures. Overall, the limited developmental test and evaluation (DT&E) of the OBK with one aircraft at PAX was very successful.' It was announced in January 2022 that all SOU V1s had been replaced by the ODIN unit.

Maintenance levels

If one looks at the current practice, maintenance was divided over several so-called levels. There are generally four levels:

- Organisational Level (O-Level)
- Intermediate Level (I-Level)
- Depot Level (D-Level)
- At the original equipment manufacturer or licensed service provider

Organisational Level (O-Level)

This level is performed on aircraft at the flight-line and includes servicing of the aircraft and maintenance by exchange of line-replaceable units (LRU).

The post-flight maintenance process includes three phases:

- Download for maintenance information is accomplished via a portable memory device (PMD).
- Download for data from the exceedance management system (EMS)
- Checking for nuisance health reporting codes and generating a list of maintenance actions.

During the operational utility evaluation (OUE) these phases were measured as to their suitability for initial training. The first phase measured download times were ranging from the optimum two minutes to the extreme of 109 minutes with an average of just over twenty-four minutes. The second phase ranged from fifteen minutes to 134 minutes with an average

download time of 31.6 minutes. The third phase ranged from two to 247 minutes. On average the three phases lasted 82.5 minutes; at best one could say that the three phases could last just nineteen minutes but in a worst case scenario 490 minutes. One other problem was that personnel could only log on to ALIS at a time, even though they could manage downloads from multiple PMDs simultaneously because of the wait times involved in each phase of data processing.

In the report about the operational utility evaluation, the following information was given:

Aircraft release is more difficult with ALIS as the time required to sign off maintenance tasks can be lengthy due to the way the process is mechanised. Work packages take a minimum of thirty minutes to sign off. In one instance, a 'parent' task had eighteen sub-tasks, each of which required a signature in the maintenance event field. Additionally, Lockheed Martin and Pratt and Whitney representatives must sign off on some of the tasks. Flight-line personnel must co-ordinate to get these individual tasks performed and signed off before the work package can be completed. Even a highly recurrent task such as aircraft refuelling requires three different signatures in ALIS. The fact that refuelling required three different signatures seems very bureaucratic, especially in wartime.

JSF Block II aircraft will be equipped with prognostic health management (PHM) wireless down-link capability in support of mission sortie generation/readiness objectives. Downloaded parameters will include fuel state, ammunition state, expendables state, and component conditions requiring maintenance in order to minimize turn-round time. For the JSF, wireless digital transmission will eliminate the need for additional classified handling equipment, avoid potential loss of data fidelity during manual transfer, and enable maintainers to monitor airframe parameters that could prevent mishaps.

Flight-line servicing exist out of:

A before operations servicing (BOS) inspection is a flight preparedness inspection performed by maintenance personnel and must be completed prior to aircraft flight. A foreign object damage (FOD) inlet inspection as well as a visual inspection of the engine's first stage components in the fan module and engine exhaust are incorporated into the BOS inspection. The BOS inspection was valid for twenty-four hours.

A post-operations servicing (POS) inspection is an after-flight inspection performed by maintenance personnel and is valid for seventy-two hours once completed. A POS is required after the last flight of the day or after a period of extensive maintenance operations and includes inspection of the engine.

Intermediate Level (I-Level)
This level of maintenance is performed at the shop at the unit's base. In general, the defective line replaceable units (LRU) are restored by exchange of (shop replaceable units and minor scheduled inspections as well as minor repairs of the structure are performed here.

Depot Level (D-Level)
This level is performed at a central depot operated by the Air Force. Depending on the skills and capacity available at the depot, repair of SRUs, major (depot) inspections and major repair of the structure are performed here. It was at this level that F-35s were upgraded to higher block levels to reach the required levels for both the USMC and, later, the USAF IOC.

At the original equipment manufacturer or licensed service provider (Industry)
At industry the repair of SRI beyond the skills and/or capacity at the military-operated depot is performed. Furthermore, the following large-scale tasks are performed:

- overhaul of equipment
- major repair of the structure
- modification of equipment
- modification of structure

The advantage was that most maintenance could be performed at the unit's base but much ground and support equipment to maintain the aircraft had to be bought for every unit. This increases cost but also increases independence on industry. Cost, however, was now a major factor and for this reason the Joint Strike Fighter programme was looking to change the system. In the meanwhile the German Air Force changed its system from a four-level to a two-level one.

The US services were looking at depot-level maintenance. It was clear that not all depots in service would retain their function. It was therefore a point of contention which depot would survive. Getting Joint Strike Fighter depot work ensured the future of the depot. On 16 September the US Navy and the USAF announced that they had come to agreement on allocating work to different depots. The agreement covered 80 per cent of the aircraft systems. The remaining systems, mostly regarding software and avionics, were to be decided by a team of service representatives.

The depots selected were:
Ogden Air Logistics Centre (ALC)
Oklahoma City Air Logistics Centre (ALC)
Warner-Robins Air Logistics Centre (ALC)
Fleet Readiness Centre (FRC) Northwest Whidbey Island
Fleet Readiness Centre (FRC) West Lemoore
Fleet Readiness Centre (FRC) West Pac (Atsugi, Japan)
Fleet Readiness Centre (FRC) Southwest North Island
Fleet Readiness Centre (FRC) Southeast Jacksonville
Fleet Readiness Centre (FRC) East Cherry Point
Fleet Readiness Centre (FRC) MID Atlantic Oceana
Fleet Readiness Centre (FRC) SEFAC Solomon's Island

The first depot to set up was Ogden Air Logistics Centre (ALC) at Hill Air Force Base, followed shortly by the Fleet Readiness Centre (FRC) East at Cherry Point Marine Corps Air Station (MCAS). Both will be doing work on the airframe and engine, associated doors, panels, covers and control surfaces. Although second to set up, Cherry Point became the first depot to receive an F-35B for depot work. Lieutenant Colonel Steve C. Gillette flew the F-35 from Eglin Air Force Base to Cherry Point on 9 July 2013, landing at 10.00am, marking the first F-35 arrival at the base. After an official ceremony the depot work could start. Part of the work includes reinforcing hinges on doors that allow the F-35B model to take off and land vertically.

Nickel-free Conductive Fillers
Environmental safety and health (ESH) considerations have been a major part of the development for the JSF. These new requirements have caused new research efforts to be initiated to fulfil new regulations. Some of the

considerations have not been required by law but came about due to cost-reduction efforts. It is clear that some of the new technologies do have an impact on the environmental safety and health of crew in and around the aircraft. During development regulations were introduced in different countries with which the JSF programme had to comply. European regulations mainly had an effect on materials that could be used on the aircraft. One regulation that came into effect was the European Community Regulation on chemicals and their safe use, called REACH (Registration, Evaluation, Authorisation and restriction of Chemical substances). The law was enacted from 1 June 2007. However, it would be modified by industry manufacturers; importers are required to gather information on the properties of their chemical substances, which will allow their safe handling, and to register the information in a central database run by the European Chemicals Agency. These regulations often posed a technological risk and induced cost, as alternatives to existing solutions had to be found.

Nickel was considered a hazardous material that had been identified for removal to the widest extent possible due to its environmental, safety and health (ESH) concerns. It was mainly connected with low observables (LO). The Air Force Research Laboratory (AFRL) issued small business innovation research (SBIR) for nickel-free conductive fillers in 2007. The problem statement was as follows:

Current fighter aircraft incorporate conductive materials to control the radar signature of the vehicle. Many of these materials employ the use of nickel or nickel-coated fillers to provide the corrosion resistance necessary for the aircraft's various operational environments. Unfortunately, nickel is a hazardous material and requires additional health and safety handling procedures during many steps in the installation process. Environmental, safety and health regulatory impacts include limitations on application equipment and controls as well as allowable worker exposure. Elimination of nickel used in gap fillers, fastener fillers, and non-woven mat materials, and identification of filler and/or conductive filler coatings that will meet signature and corrosion resistance requirements would provide the aircraft program with cost affordability through environmentally friendly material.

The SBIR was anticipated to have two phases:

PHASE I: The objective of this task is to identify alternative nickel candidate materials and conduct preliminary feasibility screening tests. The identified tests will be performed, resulting in no more than two candidate materials for formulation and further material characterisation. The materials being looked at were plies of nickel-coated carbon fibres in epoxy resins, mats of short nickel-coated fibres in epoxy resins and chopped nickel-coated fibres in thermoplastic resins. The areas to be filled or repaired were not considered as important as the replacing of nickel coating on the carbon fibre.

PHASE II: The objective of this phase is to formulate and optimize a material (fastener fill, gap filler or nonwoven mat) with the candidates identified in task 2 and perform detailed material characterization to determine if the candidate material is suitable for use in low observables (LO) materials. The material characterization shall include chemical, mechanical, corrosion and electrical property evaluation.

Noise levels

There are environmental areas where the JSF programme has not succeeded in reducing the danger to crews. It is also one of the things most commonly complained about, although not by the crews. People living around air bases often complain about the noise levels and the disturbance this causes to the population in the area although civil airports encounter the same problem.

The noise level is important as noise-induced hearing loss is the Number One US DoD disability. The F135 engine noise level measured at 50 feet radius 135 degrees of the nose centreline was at military power 148 decibels and, with afterburner, 152 decibels. This does not constitute a major increase but as stated is important, especially on US Navy ship decks where people stand within the immediate vicinity of the aircraft when it takes off with afterburner on. The most important thing to take into account is that acceptable noise level is up to 85 decibels for an eight-hour working day. US Navy safe noise exposure limit is less stringent than DoD, Air Force, and Army limits which are set at 85 dBA for an eight-hour-time-weighted average with a 3 dBA doubling rate. The US Navy has 4 dBA doubling rate which would mean that for every four DBA extra the working time should be halved. At 89 dBA the working day should last only four hours; the safe number of jet launches per day that some close-in US Navy

or USMC crews can be exposed to is not enough to prevent hearing damage with current hearing protection. This is rather inconvenient on aircraft carriers where space is rather limited; to house the extra required crews would require the carriers to be at least twice the size and probably more. Earplugs attenuate up to 6 dB depending on how they are worn. Cranial protection regularly worn by US crew provide 21 decibels attenuation. Poor fit or wrong cranial protection would reduce the effectiveness by 3 to 15 decibels. A total of 30 decibels attenuation can be achieved by wearing double protection correctly. Double hearing is required from 104 dBA.

Big level increase or not it does, however, worry F-16 operators, especially Norway. The F-16 equipped with a Pratt and Whitney -229 engine has, according to an Air Force Research Laboratory document, a near field noise level of slightly over 140 decibels in military power and just under 150 decibels in full afterburner. However, environmental issues are something that have become more important and laws about noise emissions have become stricter. The other problem is that even with ear protection at noise levels of 150 decibels, that ground crew have problems, hearing communication (speech) through their headsets. The personal protective equipment (PPE) is currently only good enough to reduce noise levels by about 30 decibels and that is if double protection is worn. This is not a new problem; however, the military do accept more noisier aircraft. The reason the DoD has done very little about noise-induced hearing loss is because the US Department of Veteran Affairs have picked up the bill, not the military. The cost of hearing loss for all veterans from 1977 to 2006 totalled $8,385,892,465. As worries were shared among partner nations and the communities around Eglin AFB, the first USAF base to receive several operational aircraft, it was important to do some thorough noise measurements. These were done at Edwards AFB during the first visit of the prototype, AA-1. Noise measurements were taken while the F-35 was on the ground and when it was flying. Reports from those noise measurements were used to calm down the reactions around the world, but scepticism remained among the population surrounding the future bases. A lot of noise critics in the Netherlands, for example, would rather the Royal Netherlands Air Force (RNlAF) would acquire the next-generation Gripen aircraft, because of the lower noise level, saying they would prefer the acquisition of the Gripen E because that uses the same engine as the F-18E/F since the Gripen E has only one engine as opposed to the F-18E/F

Super Hornet and would therefor produce only half of the noise. This unfortunately is not true; the effect of one engine compared to two engines only influences the sound level by a couple of decibels. The *Koninklijke Luchtmacht* (KLu) or Royal Netherlands Air Force (RNLAF) sent its two first F-35s to the Netherlands to let the public do a comparison of noise levels and experience the differences between the two aircraft prior to permanent basing. The bases involved were Leeuwarden and Volkel.

Exhaust speed and heat

Reducing or minimalizing exhaust speed and heat would play a big part in making working around the aircraft safe. As could be seen from the above, noise was a major contributor for health risk but the F-35B brought a completely new risk. As the Harrier pointed its nozzle down, the exhaust speed was not that high nor was the temperature as high as with the F-35B. That was already anticipated and evaluated early in the programme. As early as 1995 when the Lockheed X-32 large scale powered model was tested at the NASA outdoor aerodynamic research facility (OARF) ground environment studies were performed. Walking through the fountain was accomplished with some difficulty at a radius of thirty feet; on board a ship this is quite some space. Considering that a less powerful engine than the F135, which would become the standard engine, was used at the time, it is questionable if thirty feet would be sufficient. Later in the programme it was also evaluated in the UK in wind tunnels but by 2009 the issue of exhaust speed and temperature had not been totally resolved.

That it was more demanding was also recognised by the US Navy in a report dated December 2009 on the unified facilities criteria. In that report the landing pads were discussed and it was stated that these pads will to be exposed to 1,700˚ Fahrenheit and exhaust speed of approximately Mach 1. The exhaust will melt the top surface of asphalt pavements and will highly probably just splinter the surface of standard airfield concrete pavements on the first vertical landing. Therefore high-heat-resistant materials are required for the pavement and for the joint sealants. At the present time there are no identified sealants that can survive a significant amount of vertical landings, continued the report. This was a cause of concern because vertical landings were the immediate target of the F-35B after arrival at Patuxent River. The trials there were expected to start in earnest in January

2010 when the report was published. The pads will be constructed from continuously reinforced concrete sized 100 x 100 feet

Reducing handling hazardous material

During the lifetime of a fighter aircraft many hazardous materials are used and have to be disposed of. Besides the disposing of these hazardous materials there is also the health hazard for people working on these aircraft. The environment plays a more important part in daily life and this reality had come home as well to the Department of Defense (DoD). So when the JSF programme was initiated several projects were initiated to remove these hazardous materials from the JSF aircraft. This was called design for environment (DfE). On the other hand one of the main pillars of the JSF programme, low cost, had to be maintained as well. Low cost, however, was now not only measured in acquisition cost but also in life cycle cost (LCC).

One way of looking at it was with fasteners; thousands of fasteners are used in any aircraft and the JSF is no exemption. The fasteners have cadmium plating, which provides corrosion protection and lubricity. The environmental disadvantage is that cadmium is removed during the paint-removal process as the paint is grinded off. This has health risks for maintenance staff during the process. The solution has been to install more expensive titanium or stainless-steel fasteners; the connected LCC are lower, so in the end the solution is more environment friendly and cheaper as well. In the LCC are also calculated that the requirement for personal protective equipment (PPE) is reduced; there are some positions (three) where the cadmium fasteners are maintained in the F-35. The three locations are the gun, QAD and SFD.

Vulnerability of aircraft is reduced by filling empty fuel tanks with halon 1301 as an inert gas is required to prevent explosion or fire from bullets or shrapnel. With halon 1301 used in all aircraft stockpiles of halon 1301 were required for wartime inerting. A replacement was found in the on board inert gas generation system (OBIGGS) which functions on the principle that ambient air is used to filter oxygen to form nitrogen enriched air suitable for fuel tanks, with the same safety effect. OBIGGS makes the wartime stock piles of halon 1301 redundant with no negative effect on the survivability of the aircraft. OBIGGS failed to inert the fuel-tank ullage spaces throughout the combat flight envelopes evaluated during the live fire test and

evaluation tests. (Ullage is defined as the vapour space above the fuel within the enclosed tank that contains a mixture of fuel vapour and air.) The director of operational test and evaluation recommended a redesign of OBIGGS so that the system would maintain oxygen concentration levels below those that would sustain fire and or explosions.

If one combines this with the fact that the F-35 uses an active lightning protection system, which according to the quick look review report, presents challenges to certification to a more conventional passive system, if the F-35 Lightning II is parked, it means that the fuel tanks are not inerted and are without lightning protection. Improvements to OBIGGS are in the pipeline and other changes include fuel-vent valve redesign. At the time there were restrictions on dive rate and, if or when the F-35 fleet at Eglin AFB would commence flight training, there were limitations on flights in proximity of thunderstorms. The report anticipated that this would reduce the amount of possible training missions by approximately 25 to 50 per cent at Eglin AFB. Lightning protection for parked F-35 Lightning IIs was also under investigation. One option under consideration was pre-charging fuel tanks with nitrogen using an auxiliary cart and adding a dedicated service port to the aircraft. This auxiliary cart would cause an increase in required ground equipment and also of the connected cost reducing affordability. The J/IST programme was about reducing support carts as they cost money. It was a setback of sorts and would have a negative influence on deployment key performance parameters. A two-phase re-design effort was initiated so that sufficient protection could be offered against threat induced fuel-tank explosions throughout the entire flight envelope. The JPO had the unfortunate task on 17 April 2020 to inform the services and partner countries and FMS customers that damaged pipelines from the OBIGGS had been found in a fuel tank in four F-35As. For this reason it was deemed necessary to inspect all aircraft to see if more F-35As had been affected by damaged OBIGGS pipelines. More aircraft with broken lines were found also by foreign operators, one of them being the Netherlands. Besides the inspection, an advice was issued that for the time being F-35s should not fly within twenty-five nautical miles of a known thunderstorm and that on the ground the F-35 should be put in shelter or other measures taken to protect it from being struck by lightning.

Breathing at high altitudes can be a problem, for this reason fighter aircraft were equipped with liquid-oxygen bottles. As the range of aircraft

was extended by aerial refuelling, demands on the capacity of the liquid-oxygen bottles increased. A solution was introduced with the on-board oxygen-generation system (OBOGS). Oxygen bottles were not removed from the aircraft but were to stay as a back-up should OBOGS fail. The emergency oxygen supply was an integral part of the ejection seat. OBOGS was important in cases of aerial refuelling and in fighters; it was introduced in fourth-generation fighters. Other fighters were slowly retrofitted with OBOGS; the first F-16 so equipped rolled off the production line in the first half of 2000. As OBOGS had gained its way into the fighter market the time was right to introduce the system in the JSF, replacing the liquid-oxygen tanks from the inventory of future operators. OBOGS produces oxygen-rich breathing gas from engine-bleed air using molecular sieve technology. A molecular sieve is a material containing tiny pores of a precise and uniform size that is used as an absorbent for gases and liquids. Opposed to the liquid oxygen tanks, OBOGS requires no exotic cleaning solutions, the liquid-oxygen system clearing the military use of Freon. Freon is having a bad effect on the ozone layer and can have fatal effects as was proven on a Russian submarine in November 2008 when twenty people died because of suffocation by Freon gas. A fatal accident of a Lockheed F-22 Raptor occurred on 16 November 2010 when, at 19: 43: 27 local time F-22A, serial number 06-4125, crashed to the ground killing the pilot, Captain Jeffrey Haney. Since OBOGS played a role in the accident, and other pilots experienced hypoxia in the F-22, the entire F-22 fleet was grounded for more than four months in 2011. No cause was found for pilots experiencing hypoxia and the fleet was allowed to return to flight; however, some pilots were not happy with the situation and refused to fly the F-22. The OBOGS in the F-35 was not affected, although links were made and it was considered a worry. During a press brief on 15 May 2012, it was acknowledged that a total of twelve cases had been reported involving F-22 pilots. The first reported hypoxia-related event was in April 2008 with a total of twelve reported between then and 11 January 2012, excluding five maintainers who suffered hypoxia-like symptoms. Humans breathe air with a 21 per cent oxygen concentration. If the concentration of oxygen gets lower it can cause hypoxia and, after longer exposure, death. At higher altitudes oxygen concentration gets lower and it is harder to breathe for pilots. The fact that maintainers had experienced hypoxia-like symptoms fuelled suspicions that it might have something to do with the special paint

used for stealth purposes as stealth coatings are considered highly toxic during manufacturing and also during working around the plane. A report by the USAF Scientific Advisory Board (SAB) on aircraft oxygen generation stated that:

1. The F-22 life support system lacks an automatically activated supply of breathable air.
2. Environmental Control System (ECS) shutdowns are more frequent than expected and result in OBOGS shutdown and cessation of breathing air to the pilot
3. The F-22 is the only OBOGS-equipped aircraft without either a Back-up Oxygen Supply or a plenum. (The Life Support System IPT eliminated the Back-up Oxygen Supply from the F-22 to save weight).
4. The 'OBOGS fail' light on the Integrated Caution, Advisory and Warning System (ICAWS) has a 12 seconds delay for low oxygen, providing inadequate warning.
5. The Emergency Oxygen Supply can be difficult to activate, provides inadequate feedback when successfully activated and has limited oxygen duration.

By the end of the year 2012 a solution had been found for the F-22 that, according to the USAF, solved the problems. Not everyone was convinced, however, that the solution was found and that the F-35 was not affected either. Honeywell was the supplier of OBOGS for the F-22 and F-35.

Hypoxia-like symptoms also appeared the F-35. Since 2 May 2017 five pilots had experienced physiological problems (hypoxia-like symptoms) events at Luke AFB, as reported on 9 June. As a result the aircraft were grounded for a short period. The difficulty was that the five occurrences had taken place with five different aircraft over three different production lots (6, 7 and 8) equipped with two different software blocks, 2B and 3i. Analysis was also performed over the maintenance procedures and if there were any connections with specific maintainers. The engineers looked into everything without actually tearing the aircraft down. The F-35A was only grounded at Luke AFB as other bases had no such occurrences. Over this period the forty-nine affected pilots at Luke were briefed on how the five pilots involved solved the problem and recovered their aircraft. The five pilots experienced physiological experience hypoxia in different aircraft.

The main positive was that the USAF and the JPO reacted rather quickly to pre-empt any negative reactions from the pilots as had been the case with the F-22. At the same time hypoxia-like events were also troubling the US Navy's T-45 Goshawk. All F-35 pilots were given a safety survey so that worries could be identified and the USAF could gauge the pilots' confidence and any questions they would have. As the technological solution might be quite some time away the USAF had funded pulse oximeters which could be carried on the fingertips and/or the earlobe as a tool to help pilots get confidence back in the F-35. The grounding of the F-35 at Luke AFB was lifted on 21 June 2017.

Health was also an issue in the 1999 request for information from the Netherlands. It informed in its Rf I of 8 materials that were restricted by law and another fifteen that were pending to be restricted by law and therefore the aircraft manufacturers had to eliminate or avoid the usage of these materials. Lockheed Martin in its offer to Norway also touted the F-35's environmental aspects. Although the F-35 has many positives to bare the most important to the public was the noise level. The information in its offer under the title of green production, green operations and green support the following details were given:

Hydrazine	None
Class I/II ODC	None
Halon	None
Volatile Organic Compound (VOC) Emissions	VOC-Exempt Solvents
Lead and Lead Compounds	Solder Only
Support Equipment Emissions	25–50% Lower Than F-16
Engine Air Emissions	50% Less CO, 82% Less VOC Than F-16
Beryllium	Only in Highly Loaded Busing
Chromium Primer	None

As can be seen from the above table, class I and II ozone depleting contaminants (ODC) are excluded from the F-35 Lightning II. In fact

Lockheed Martin prided itself on the fact that it had replaced all ODC-containing products as early as 1995 and as of 2006 had not allowed any class I or II ODC on the F-35.

Corrosion Prevention, Mitigation, & Control

Chromium primer was also of concern since the aircraft was to be repainted during its life and therefore the primer was affected as well. Chrome has a negative impact on the environment as well; it is one of the hazardous materials to come in contact with during the application and removal process and therefore requires special protective clothing for staff working around the aircraft. A new non-chrome primer was being developed and evaluated and on BF-1 it was applied to be evaluated for effectivity. On BF-2 it was fully implemented on the entire airframe. Implementation for the system suppliers was on a voluntary basis to avoid unnecessary cost increases. There was a risk here because the Lockheed Martin F-22 Raptor had also gone with a non-chrome primer due to environmental and occupational health concerns as a non-chromated does not contain hexavalent chromium but, later on in the production, Lockheed Martin returned to the chromium primer due to problems related with corrosion. As Director of Operational Test & Evaluation (DOT&E), Dr J. Michael Gilmore stated in one of his presentations on one of the lessons learned from the F-22 programme: the environmental and occupational health concerns drove use of non-chromated outer mould line primer that didn't provide the needed corrosion protection; this led to additional corrosion problems in the field. Lockheed Martin has selected a non-chromated primer for the F-35 that has never been tested on an aircraft in a corrosive operating environment which can be considered a risk after the experience with the F-22.

Paint has, however, a number of disadvantages such as weight, cost of removal and application, and the environmental hazard connected with removal and application. Another disadvantage is that it covers corrosion. As corrosion detection was deemed important, a small business innovation research (SBIR) programme was initiated. An SBIR phase I contract was awarded in 1999 to Systems and Materials Research Corporation to prove concept of detecting corrosion under paint on metallic aircraft structures. The Department of Defense (DoD) estimated in July 2010 that corrosion of military equipment costs the military services over $21 billion a year.

Corrosion is defined as the unintended destruction or deterioration of a material due to interaction with the environment. It includes such varied forms as rusting, pitting, galvanic reaction, calcium or other mineral build-up, degradation due to ultra-violet light exposure and mold, mildew, or other organic decay. Corrosion affects military readiness by keeping aircraft out of action, and has also affected safety, causing accidents that have led to fatalities.

A small handy device called the microwave corrosion detector (MCD) was the result of the programme by 2003. The MCD was introduced to the Lockheed Martin JSF team in January 2003. Lockheed Martin at first was not really impressed, but when it was discovered that microwave radiation (near-field) penetrates specialty coatings not only on metallic aircraft structures but also on composite structures and could also measure the thickness of the coating, interest was awakened within the Lockheed Martin team. Besides corrosion, the microwave non-destructive evaluation (MNDE) opened the way for locating under specialty coatings fasteners, seams and leaks. Locating of fasteners can be very helpful but locating does not help if you cannot mark the location for which reason a new use of MNDE is being developed. That was how the MNDE ™ toolkit originated and it was used as a software-based tool for maintainers. SMRC developed a different tool for maintainers to detect gaps and uneven or mismatches on the surface of the aircraft, the tool for which was called ChekMate™. Another tool developed on the basis of MNDE was called RoboChek™ and was used in the paint and coating facilities to measure the thickness of the coatings.

Corrosion was first noted on the F-22 Raptor during spring 2005, even before IOC had been reached. A little over two years later, in October 2007, 534 corrosion problems on the F-22 aircraft had been found. The corrosion problem did not go unnoticed and the Department of Defense published a report on 30 September 2010 called the ‘Corrosion Evaluation of the F-22 Raptor and F-35 Lightning II Joint Strike Fighter ‘after a directive from a house report in which the House Armed Services Committee expressed their concern about corrosion prevention and control (CPC) programme application of lessons learned on the Lockheed Martin F-22. The report as a result of the same directive was evaluated by the Government Accounting Office (GAO). The DoD corrosion study identifies several areas where the

F-35 programme has incorporated lessons learned from the F-22's corrosion problems;

1. The F-35 programme is mitigating corrosion risk associated with conductive gap filler (the sealant between exterior panels that is required by low-observable aircraft). and paint by using a gap filler that is less galvanically dissimilar from aluminium, an alternative to the conductive paint, a design with fewer seams that require gap filler, and more representative verification and qualification testing. Many of the F-22's corrosion problems were linked to problems with gap filler materials and paint.
2. The F-35 programme made organizational changes that integrated the personnel working within the corrosion materials and processes functional area and the low-observable (i.e., stealth) functional area. In contrast, personnel working within these areas for the F-22 programme were 'stove-piped'.
3. The F-35 drainage design is significantly improved with more, adequately-sized drain holes. Drain holes in the F-22 were found to be too small to enable good water drainage.

The report further identified several important differences between the F-35 and F-22 programmes. For example, the F-35 programme:

- has several technical performance metrics, such as sortie-generation rate, that are indirectly driving actions to improve supportability, while the F-22 programme did not;
- has a more robust corrosion design largely due to inclusion of more stringent Navy corrosion qualification tests;
- has a longer service life requirement (30 years vs 20 years for the F-22);
- has a Corrosion Prevention Advisory Board where corrosion issues are discussed in detail and both the contractor and the government display a willingness to address these issues.

However, neither aircraft had a corrosion prevention user requirement that would drive corrosion prevention and control (CPC) as a design requirement. Further, the programme offices for both aircraft only required 'corrosion resistance' within the system specifications, a poorly defined and

non-specific term that is difficult to ensure incorporation into aircraft components and to verify.

Besides the risk of the non-chromatic primer mentioned above the Department of Defense report identified two risks that the F-35 programme has the chance to reduce:

- No operational-level test for corrosion was conducted on the F-22 prior to initial operating capability, and none are currently planned for the F-35.
- The length of the F-22 full-scale climatic test was cut in half, and the programme office for the F-35 is currently considering reducing its full-scale climatic test.

In a presentation by Dr J. Michael Gilmore the lessons learned from the F-22 programme and used in the F-35 SDD were:

- Fewer outer mould line seams; gap filler less galvanically dissimilar from aluminium; less aluminium in outer mould line
- Early corrosion testing of conductive gap filler in representative operational environment
- Testing of full stack-up panel seams with simulated damage exposed to accelerated and outdoor (beach) exposures
- Sufficient internal drainage system
- Climatic lab testing planned to incorporate severe weather testing
- Flight testing in operational environments other than desert southwest ~3-4 years prior to IOT&E (Edwards CA, Eglin FL, Patuxent MD)

Trade-offs between low observables and corrosion prevention on the F-22 were mostly more inclined to low observables. In fact, prioritisation of low observable requirements led to acceptance of other corrosion risks during system development. Aircraft signature considerations drove design change in the number and size of drainage ports. For example, the amount of drainage ports was reduced from 201 in the initial design to twenty-seven; the remaining drainage ports proved insufficient in removing water and other corrosive liquids from the F-22's cavities. Water intrusion problems at deployed locations led to post-fielding drain-port redesign/retrofits.

Specialty coatings on low observable or stealthy aircraft are applied in thicker layers than the normal primer and topcoat on non-stealthy aircraft, according to a document published by the Office of the Secretary of Defense (OSD). These low-observable coatings require more time and care to remove than normal coatings, in part to prevent damage to underlying materials and or treatments. Most of the outer mould line of the aircraft skins are composites. The fact that environmental and occupational health laws made chemical strippers no longer acceptable did not help; new solutions had to be found and these normally cost more. Low-observable coatings have a high elasticity which makes removing the coating more difficult. On 29 October 2009 a statement of need was published to come up with a new method to remove these low-observable coatings. The proposed novel coating removal technology should:

- Effectively remove low-observable coatings without causing damage to the underlying layers such as graphite composites, bismaleomide composites, aluminium and titanium or treatments below the low-observable coatings.
- Be capable of full aircraft surface coating removal
- Not cause excessive thermal or impact damage to underlying coatings and materials that would render them ineffective
- Be as cost effective as current baseline coating removal processes and reduce the cycle time for removing coatings
- Generate no inherent waste streams other than the removed coatings
- Allow for coating debris capture and removal to manage cleanliness and air standards
- Be amenable to automated as well as manual operations
- Work in standard DoD industrial coating removal environments or cause minimal retrofit to existing facilities
- Allow for concurrent maintenance or related treatment removal processes if possible
- Not present environmental concerns or health and safety hazards that would limit or restrict the usefulness of the technology in different facilities
- Not cause ergonometric damage to workers

As can be seen from the requirements environment, health and cost are the three threads that should define the new system.

For all the effort put into corrosion prevention it was rather disappointing that from 21 September until 20 October 2017, deliveries of newly-built F-35s had to be halted as a new problem was discovered. The problem was encountered on an F-35A during regular maintenance at Hill AFB. When a carbon-fibre exterior panel was removed, corrosion exceeding technical limits was found. It was found around the spot where fasteners would connect the carbon-fibre exterior panel to an aluminium part of the airframe. A lack of protective coating at the fastening point that would have prevented corrosion was identified as the primary problem; it was not made clear if that was not applied or that during the thirty-day period they had come up with a solution which would be reintroduced into the fleet. It was clear that all aircraft delivered would have to be evaluated, a total of over 250 aircraft.

Chemical, Biological, Radiological, and Nuclear survivability

Chemical, biological, radiological, and nuclear survivability was a major part of the programme. This, however, was not standard and the F-35 was only the second fighter aircraft with a chemical/biological resistance requirement. The first aircraft with such a requirement was the F-22 Raptor. This requirement, although not adding visibly to the capability (it does not make the aircraft fly tighter turns), adds to capability but also to cost. When compared to previous generation fighters, the chemical, biological radiological and nuclear survivability was not a design problem. The F-35 pilot requires pilot chemical, biological and radiological survivability. Chemical biological and radiological contamination should have no effect on structure or systems in the sense that they would affect flight safety. The aircraft had to be able to be decontaminated so that it could be re-used. Chemical agents break up through natural decaying, a process that is very time consuming. With the JSF and all the new laws about chemicals and other substances it was important that the decontamination process would be environmentally friendly. The process still means that the aircraft is out of use for operational purposes.

In case of chemical/biological attack both maintainers and pilots would have to wear nuclear, biological and chemical (NBC) protection gear. The gear is always very cumbersome and does not allow for the same freedom

of movement. Furthermore, the risk of tearing the protective gear should be minimised and both factors should be designed into the aircraft. This means that during the design process sharp edges and corners of line replaceable units and other equipment are designed out of the aircraft. Spacing between buttons, switches and controls have to be separated from each other so that they can be manipulated with the protective gear on.

In the event of chemical/biological attack, these agents stick to all surfaces, internal and external. All these surfaces come from different suppliers and have different topcoats and therefore different reactions to chemical/biological agents. Such surfaces must use coatings that are relatively resistant and allow for decontamination processes to be applied.

In case of chemical contamination, hot air decontamination (HAD) was selected as the solution for the F-35 and in case of biological contamination a decontamination procedure called vaporised hydrogen peroxide (VHP) was selected for evaluation. Testing and evaluation had to take place prior to production and a test programme was established that counted on component testing and full-scale testing. To evaluate if the designed features were suitable prior to test flying, full-scale tests were performed on an F-16 at Edwards AFB. In January 2006 an F-16, serial number 83-1172, was used to evaluate decontamination of chemicals. The F-16 was sprayed with a chemical simulant, then washed, towed into a hangar and heated from 165-to 185-degree temperatures to accelerate weathering of the remaining chemical simulant. The goal of the testing was to decontaminate an entire aircraft and to quickly return it to service should it be exposed to a chemical or biological agent.

In September 2008 DoD instruction 3150.09 came into effect. This instruction required all DoD CBRN mission-critical systems to be CBRN-survivable. The JPM for collective programmes/platform survivability and integration (PSI) chemical biological radiological (CBR) defence support would facilitate the research, development, testing, procurement, operations and sustainment, and delivery of CBRN defence system of systems in support of platforms designated as CBRN-mission critical and those requiring CBRN capabilities, which meant the F-35 Lightning II as well. The joint programme manager for collective programmes is the lead for the decontamination system, also known as the environmentally friendly aircraft decontamination system (EFADS). The joint programme manager also supports the shelter/liner system, the interface with environmentally

friendly aircraft decontamination system (EFADS) and heaters for hot air decontamination. The next step was the signature of a memorandum of agreement between the JSF PEO and the joint programme executive office for chemical and biological defence (JPEO-CBD) regarding co-operation on joint service aircrew mask, JSF variant, and an aircraft decontamination system in January 2010.

JSF decontamination shelter requirements were set as follows:

- Sized to accommodate the JSF aircraft
- Be easily deployable
- Incorporate a chemical agent resistant liner compatible with vaporised hydrogen peroxide (VHP) and hot air decontamination (HAD) decontamination processes
- Compatible with negative pressure operation
- Interface with the decontamination equipment
- Thermal insulation to minimise heat loss during HAD
- Minimise air leakage into the liner
- Minimise electric power and manpower required for set-up and operation
- Allow personnel entry/exit during operation
- Withstand power loss of eight hours
- Withstand wind and snow loads

When the search started for a shelter system it was soon realised that the basis should be the aviation inflatable maintenance shelter (AIMS) which could accommodate four F-16s, two F-15s or two F-22s or, as projected, four F-35s. The initial shelter liner, however, was found to be too complex for field use and was not even tested for effectiveness. A new lighter and more robust shelter liner was developed which was due for full-up demonstration in 2014. The live fire test and evaluation was planned for the fourth quarter of FY2015.

A British requirement was the decontamination of the pilot's seat. The seat was tested for that purpose at DERA Porton Down during late 2010/ early 2011.

On 19 August 2016 it was announced that the decontamination shelter had been erected at the flight line at Edwards AFB. The decontamination shelter took almost four weeks to erect. The 461st Flight Test Squadron's F-

35A, AF-04, was to be contaminated several times starting the end of August and towed into the decontamination facility to see if it could be cleaned of chemical or biological weapons exposure. AF-04 was a highly-instrumented F-35 with modifications to specifically collect data while being tested in the air or on the ground. For the tests, the F-35A was to be 'contaminated' with simulants, which are elements that have been researched and tested to be safe, but mimic the properties of the harmful agents.

Test aircraft AF-4 had completed its flight sciences portion of the test flight programme by the end of July and was due to be used for chemical and biological decontamination tests. The aircraft was going to be exposed to simulants, chemicals and biological materials that were harmless, but had been examined in labs and by other field-operational tests to be harmless and safe.

'Because these are tests we're doing here, there's an extensive amount of sensors and test equipment that were going to be used to analyse and make sure the plane is clean. But, in the real world, theoretically, you put it in the decontamination facility and run the system, pull the jet out and go fly,' said Joe Nemes, Air Force Research Laboratory, Chemical/ Biological project lead engineer.

'To contaminate the aircraft for our tests, we're going to do engine runs at a different location (on the flight line) from the decontamination structure. We're going to spray simulant down the engine inlet and let it get distributed throughout the interior of the aircraft,' said Melanie Link, 461st Chemical/Biological 06 project lead. 'Once that contamination is done the F-35 will get towed to the decontamination shelter and decontaminated. During decontamination, samples will be taken from both the aircraft and surrounding environment so we'll have a baseline to see the effectiveness of how the decontamination process is working from beginning to end.'

Once complete it would be towed to a third site to collect more samples and conduct another engine run to verify no damage was done to the aircraft.

Engine Removal and Installation

Eglin AFB lost a lot of the attention as other bases gained the F-35, and surpassed them with the number of aircraft stationed there. The Mighty Gorillas remained at Eglin which had been proven a risk because of the

weather. Hurricanes were a problem so near the Atlantic coast. In fact aircraft had to evacuate on a regular basis to prevent damage: 2018 was no exception. The F-35s were deployed to Barksdale AFB for Hurricane Michael in October 2018. Michael, however, damaged Tyndall AFB more than any other base in the region and in the process damaged many F-22s. Shortly before deployment, an unrelated event caused problems for the deployed aircraft. A USMC F-35B crashed and the accident investigation indicated that fuel lines on the engine from a certain badge had to service checked, and if faulty had to be replaced. Although nothing out of the ordinary, this caused a one-time inspection (OTI) to be ordered. Every aircraft at 33rd FW needed to have a fuel line on the engine inspected. All the wing's aircraft were grounded until inspected.

'It was particularly worrisome for us because we had jets off station without access to all of our tools and personnel,' said First Lieutenant Patrick Michael, 58th Aircraft Maintenance Unit assistant officer in charge. 'We didn't have the guidance for changing out the part yet. The preliminary guidance said we would need to remove the engine to access and remove the line.' The guidelines at the time used for aircraft maintenance required that the entire engine be removed, which would require at least thirty-six hours per jet. Furthermore, engine trailers and tool boxes would need to be transported to the location, extending the timeline.

When the OTI was made official on 12 October, leadership at all levels of 33rd Maintenance Group and 33rd Aircraft Maintenance Squadron saw an opportunity for airmen to demonstrate how capable they are. They extended a challenge – find a better way. The maintainers at Barksdale AFB determined eight of the jets failed the requirements of the OTI. The remaining jets returned to Eglin AFB. Maintainers working with field support engineers from Lockheed Martin and Pratt and Whitney set out to find a way to replace the fuel line without removing the engine.

Crew chiefs determined they could access the part through a hole just big enough to fit a hand. The location of the fuel line is nearly impossible to see; they needed to detach and set aside another component without removing it, making room even scarcer. Despite the difficulty, they succeeded in finding the fix, the first across the F-35's global presence. Within three days of the official notification, 58th AMU had identified the jets that were deficient, found the fix, got it reviewed and approved to execute and were on their way to Barksdale AFB to implement the new

procedure. This was how the USAF released data about engine-removal time, wanting to point to something positive. This, however, uncovered a rather negative side of things. Engine reliability had increased as opposed to previous generations, but engine removal was quite long compared to other aircraft.

When the OTI was first accomplished, the fuel line swap took about twenty-four hours, twelve hours less than removing the entire engine and performing the maintenance on a stand. As they repeated the task on additional aircraft they were able to shave another four hours from that time, enabling jets to return home faster. That speed and accuracy ensured the wing could continue accomplishing one of its primary missions, training F-35A pilots.

The fact that engine removal would take thirty-six hours surprised many. Engine removal time during wartime situations and on ship maintenance would put an enormous strain on operations and space. It was peacetime and the jets were needed to provide training for student pilots and if each jet took thirty-six hours to do it would take a couple of weeks to check out all the aircraft.

Firefighting

The F-35 follows the trend in civil aviation that new materials are being used. These new materials have different parameters in case of fires. One of the last accidents, involving a relatively modern military aircraft, the B-2A at Guam on 8 December 2008, took six hours to extinguish. A mind-warping 83,000 gallons of water and 2,500 gallons of AFFF were used to achieve total fire extinguishment. The accident took place right after take-off when the B-2 was full of fuel, but the time to extinguish the fire was protracted due to new materials and little experience of the right solution to extinguish fires on these new materials. This brought a risk and was used also against basing proposals in the USA.

The USMC and the US Navy had on a regular basis firedrills on board of their ships. The Netherlands acquired a specific training model on which they could let their firebrigade train all aspects of extinguishing an F-35 that is on fire. It even got a tail number F-060. It was based at Woensdrecht air base where the Brandweer Opleidings- en Trainingscentrum (BOTC) or in English Firebrigade education and training centre is located.

Royal Navy specific trainer

Working on an aircraft means working in constrained space that has to be shared with other assets. For this purpose, the British have a special unit at Royal Naval Air Station (RNAS) Culdrose. At this unit everyone learns how to move about ships and handle helicopters and aircraft. Since 2010, when the last Harriers and their respective carrier were retired, the service had lost a bit of knowledge, which had to be re-learned. A new carrier type, the Queen Elizabeth-class was due to enter service and preparations for getting personnel acquainted with this new type of aircraft carrier, aircraft and helicopters began at RNAS Culdrose. For this purpose, the deck outline of the Queen Elizabeth-class carriers was painted on the tarmac at RNAS Culdrose.

The real aircraft in the case of the F-35B were still all in the USA, and it would be too costly to have them on the ground to have crew training on them. For this reason the British acquired at least four F-35B ground training aids (GTA). These F-35B ground training aids were basically F-35B lookalike models on a one-to-one scale made from fibreglass. These ground training aids had an internal tank, for the purpose of changing the weight of the model so that handlers could train with the aircraft with different weights, simulating different fuel and weapon loads in a real world situation. The GTA could change its weight from sixteen to twenty-four tonnes by tanking water into the internal tanks. For the purpose of training, aircraft handlers could move the GTA within the outlines of the Queen Elizabeth-class deck and learn the specifics of how the aircraft handled.

Re-programming laboratories

The first re-programming laboratory for the F-35 was for the US services and was located at the base where all services were expected to co-exist, at Eglin. Partner nations were due to have their own re-programming laboratory. A partner support complex (PSC) was established at Eglin under 53rd Wing and inaugurated on 11 May 2016 for those partner nations that did not have the capability. Some partners wanted to have this capability and teamed up to reduce cost; one such facility was the United Kingdom, Canada and Australia Re-programming Laboratory (UCARL). UCARL was to be set up at Eglin AFB and manned partly by personnel from the countries involved, but also by US military personnel as some of the code was only for US eyes only, although partners in the Joint Strike Fighter

programme. The unit that had the responsibility for these facilities was 513th Electronic Warfare Squadron (EWS). Canada did not commit to the F-35 but on the other hand did not leave the programme and contributed its due fees. At the official opening of the facility Canada was the missing partner. The acronym of the facility remained unchanged as there was still hope that Canada would opt for the F-35.

The first positive major news was that Norway was the first export country to receive its 3F Mission Data File. The delivery by 53rd Wing to Norway occurred on 26 October 2017. Norway had teamed up with Italy for its re-programming facility, the Norway Italy Re-programming Laboratory (NIRL), opened at Eglin AFB on 27 June 2019.

The delivery of Block 3F mission data is important because it enables the F-35 to accomplish its primary missions of air interdiction, close air support, and suppression and destruction of enemy air defences. Mission data files enable the aircraft to know what threats to search for and when, providing the F-35 with its means of deciphering the environment. The mission data files provide not only a database of threats, with information about the threats, RCS, signature of electronic mission systems, infra-red signature; if these threats change then the mission data files need to be upgraded accordingly' The files also have a similar library of the country's own assets and, in case of multi-national operations, should have the assets of coalition partners for the system to be able to recognise them as blue forces.

'Mission data files are essential to the combat capability of the Lightning II,' said Dylan Duplechain, F-35 Partner Support Complex (PSC) chief engineer. 'They provide the warfighter an extraordinary situational awareness capability and an unmatched ability to react to the threat environment.' Partner countries that did not develop their re-programming facility such as the Netherlands and Denmark would receive their data files from the US facility.

F-35 Training

The pilot input standard coming from the advanced jet training or lead-in fighter aircraft training has given the instructional systems development team an idea of the problems ahead. Development of the full mission simulator (FMS) and mission rehearsal trainer (MRT) had been delayed as much as possible so that the F-35 could mature and allow simulator technology to increase and mature. Production of the FMS was initiated thirty months before first planned production aircraft delivery with the first FMS planned for delivery prior to first aircraft delivery. Lockheed Martin training began detailed production in August 2007 following the successful completion of the critical design review (CDR) in July 2007. The FMS is 360 degrees similar to that of the F-22 Raptor but with one big difference. The new display technology supplied by UK-based company SEOS allows the projectors in the back quadrant, where the pilot is not looking, to be dimmed; this will brighten the remaining forward image on the display screen. In the past, with the full domes light, there was a washout of the image on the area the pilot was looking at. SEOS has received responsibility for the out-of-window displays of the F-35 programme, i.e. for the FMS and MRT. SEOS was acquired by Rockwell Collins in 2009. The Griffin^{TM} dome, as it was called by Rockwell Collins, was a rear-projected dome. The Griffin^{TM} has seven tower constructions around it in each one of which are placed three projectors at different heights. Four other projectors are placed on the ground and project data on the dome from the bottom. These twenty-five projectors give the 360-degree image on the dome. The 360-degree FMS allows the pilots to train fully in the total spectrum of air combat manoeuvring and give an immersed feeling to the training. For the pilot to enter the full mission simulator the pilot has sit in a mock-up of the F-35 cockpit which is placed on rails. As soon as the pilot is ready, the cockpit is moved into the dome. When the mock-up with a fully functional display system has entered the dome it is

lifted up and aligned according to the pilot's eyesight. Pilots wear a helmet-mounted-display (HMD) in the simulator although not the same version as in the real aircraft. The HMD used in the simulator is the SimEye TM SX50T II augmented training display.



The JSF training systems team demonstrates a training device the size of a laptop. (*Lockheed Martin*)



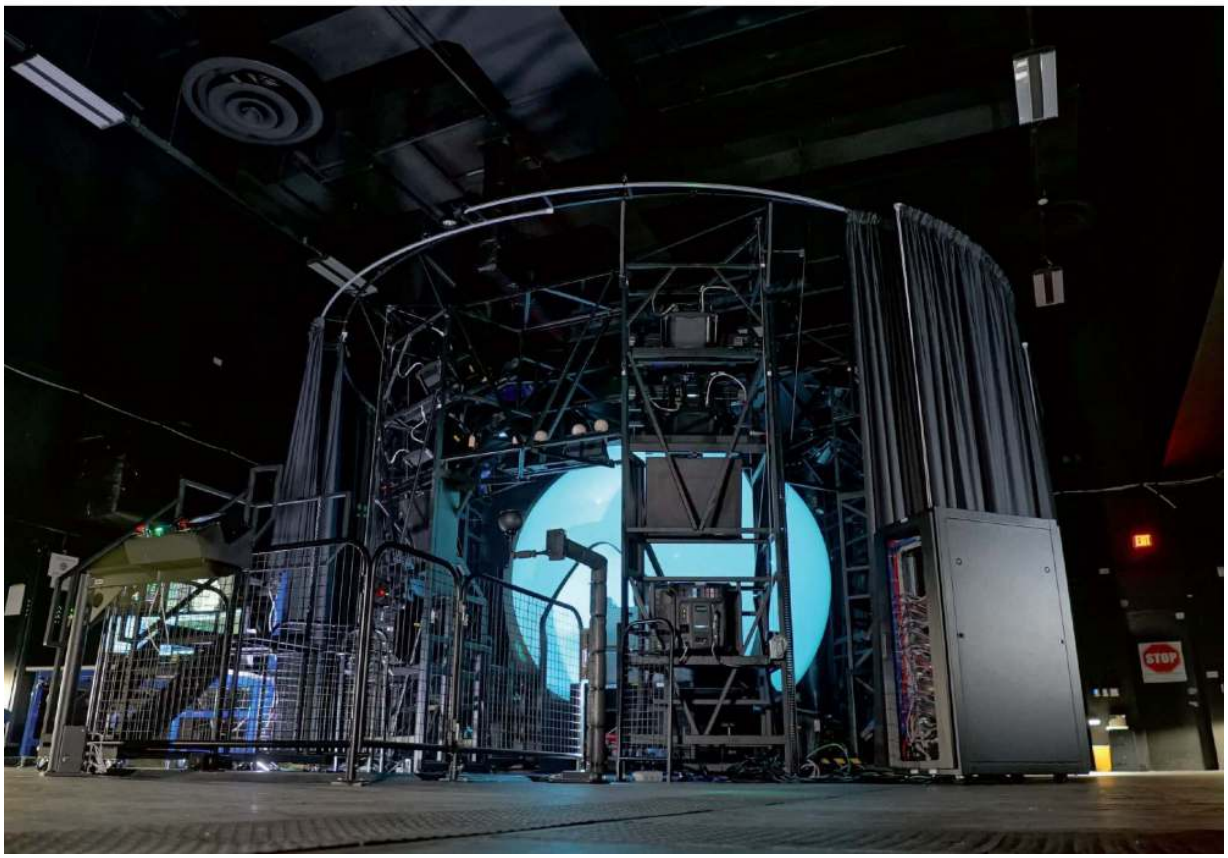
At this training station the head down display is replicated complete with contours and above it the skyline. (*Lockheed Martin*)



The HMD used in the Full Mission Simulator. As can be seen it is completely different from the one used in a real cockpit. (*Lockheed Martin*)

First FMS estimated delivery was autumn 2010, subject to facilities availability for STOVL Block 0.5. The first mission rehearsal trainer (MRT) was to be delivered in January 2010 for the CTOL Block 0.5. The MRT is supposed to be deployable, for which reason it is also known as deployable mission rehearsal trainer (DMRT). Every MRT was to be equipped with two cockpits which would allow units to train for missions according to local circumstances.

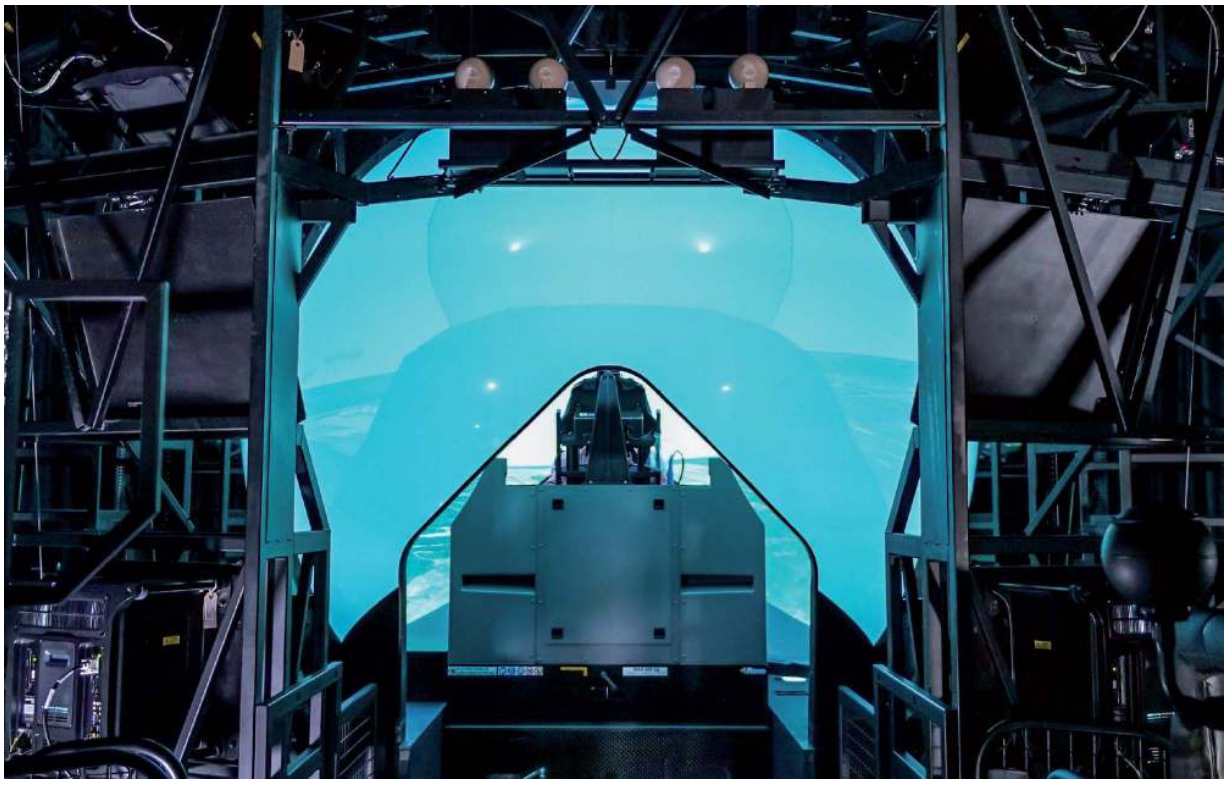
The training course for the F-35 basic initial qualification pilot student is currently planned to last between six to eight months but this depends on government approval and can therefore change. The obvious lack of a two-seater does not seem to have had such a big impact compared to the F-15 and or F-16 qualification training. ‘We are fairly comparable,’ said Joanne Puglisi. There are different blocks of F-16s and F-15s; some have a training course a little longer and some a little shorter.



The images on the 360 degrees screen are projected by projectors outside the bubble from all kinds of angles to give a seamless image. (*Lockheed Martin*)



The Full Mission Simulator has a 360 degrees view for the pilot minus the gap for the cabin, which the pilot can not look at in real life anyway. (*Lockheed Martin*)



The cabin is fully deployed in the Full Mission Simulator. You can see the rails on which it is entered through the gap just large enough to fit the ejection seat through it. (*Lockheed Martin*)

F-35 training for all the US services involved in the programme will take place at Eglin Air Force Base (AFB). The JSF programme office, together with the USAF, hoped that the partner nations will have their F-35 pilot qualification training also at Eglin AFB. This was initially the case but later the location changed to Luke AFB. This means that, besides the three obvious versions, a separate training syllabus will have to be formed for the Delta version – the national disclosure policy (NDP) stealth-capability-reduced version. Although this will have limited effect on training, it will require some alterations. The training facilities at Eglin AFB will include the full mission simulators, academic classes with three levels of Integrated Course Ware (ICW 1-3) and aircraft (all single-seat). The three levels of Integrated Course Ware include

- **ICW Level I:** This is the lowest level of ICW development. Level I lessons are linear (one idea after another) and are used primarily for introducing an idea or concept. The student acts solely as a receiver of information and there is little interaction other than the student touching the screen or using a keystroke or mouse click to continue. The media

used are primarily text, non-animated graphics, basic audio and video. There is no capability to provide feedback on student responses.

- **ICW Level II:** The student makes simple responses to instructional cues by making selections from a pull-down list or by using other peripherals such as light pens or touch screens. This level involves the recall of more information than a Level I presentation and typically incorporates text, graphics with simple animation, basic audio and video. Simple emulations or simulations are presented to the user for non-complex operations and maintenance lessons.
- **ICW Level III:** This level involves the recall of more complex information than a Level II presentation and allows the student to have increased control over lesson presentation; that is, there is more interaction. Level III normally combines audio, video, text and graphics with advanced animation. This simulates the operation of a system, sub-system or equipment to the user. Operation and maintenance procedures can be practised with Level III scenarios. Multiple software branches (two to three levels) and rapid responses are provided to support remediation. Moderately complex emulations or simulations are presented to the user.

On top of that, an electronic mediated classroom will be used which includes instructor presentations and instructor-led discussions in a classroom setting facilitated by various elements that are characteristic of an electronic classroom. A new facility will be that the pilot trainee will be able to take home a laptop; this facility is called a PTA, or pilot training aid, and rehearse in private the lessons learned. Other instruments for training such as datalink have not been defined yet and are open to discussion with the customer. Joanne Puglisi stated that data-link is a later block capability and ‘we have been concentrating on Block 0.5 and 1.0’. The pilot team from LM and JPO and Services had discussions beginning in June 2008 on the potential uses of data-link for training in the aircraft. Other more advanced systems as embedded training systems are required at a unit level beyond the initial qualification training. The pilot training aid (PTA) was rated as not an efficient use of classroom time during the operational utility evaluation (OUE). Most frequently occurring problems for this rating were slow responses to inputs, screens locking and system resets being required. The ratings from the OUE came from experienced pilots; it was, however,

stated that, for the inexperienced pilot, the ability to have a ‘take-home simulator’ afforded by the PTA is extremely helpful in learning to navigate the complex pilot interface and gain familiarity with the information-intensive displays.



The Helmet Mounted Display (HMD) used in the simulator is the SimEye TM SX50T II augmented training display, here seen used by the first operational female F-35 pilot. (*Lockheed Martin*)



The display image is projected from the outside and gives the pilot a seamless image just like reality. (*Lockheed Martin*)



A weapon loading trainer being prepared for a demonstration by Australian crew. These training aids should have as a side effect that the training is not required on a real aircraft thus increasing availability. (*Commonwealth of Australia Department of Defence*)

The initial flight training at Eglin for the pilot included about forty-seven classroom lectures and fourteen simulator missions covering normal and emergency operating procedures followed by a taxi ride and then six flights. The first three flights are for pilots to get used to how the aeroplane handles, accelerates, slows down and approaches runways for landing. The fourth and fifth are formation flights in which students fly their aircraft alongside either another F-35 or an F-16. They are asked to be the lead aircraft on the fifth flight. The final flight is a standard United States Air Force instrument qualification check ride that also requires students to instruct some or all of the mission brief for that flight. As the development of F-35 progressed, so did the syllabus and the flight training at the training unit stabilised around 40 flights equalling 70 flight hours. The entire training period for a pilot straight out of pilot school was around 9 months. For a pilot transferring from a fourth generation fighter this was about half of those 9 months.

In 2023 a company that considered itself still a startup brought a new simulator possibility. The company had been set up by someone that had a software and hardware development company since university. Marek Polčák the founder of VRgineers bought a top of the range Virtual reality headset and discovered that he was disappointed with the quality and said we can do better. A new company was set up in 2017 and a new virtual reality headset was the initial product. With this new head set the Czech Company VRgineers went to technology trade shows and exhibited their product. At first it was automotive industry that was interested but that market was not big enough for a sustainable business. Through these trade shows they came in contact with pilots and these pilots telling them what they expected from virtual reality headsets. This feedback resulted in the XTAL 3 virtual reality headset which has been developed and designed specifically for pilot training. The XTAL 3 impressive high resolution, 3840x2160 for each eye full 4K Red Green Blue (RGB) LCDs together 8K is of the highest standards. The name of the XTAL is derived from the initial reactions from people at tradeshows that stated that the image is crystal clear. The field of view is 180 degrees horizontally and 120 degrees vertically. An additional interesting capability is eye tracking capability which is integral to the headset. The instructors and pilots get analysing tools among which one is a heatmap. The system can be adapted for specific aircraft both civil and military and other sensors can be integrated if the customer requires it. If the user is wearing glasses the headset can be adapted to his or her personal requirements, the user will not require his or her glasses so these will not cause any additional discomfort. The weight of the headset is 600 grams without the strap which is required. The headset should know at which point in the sky the pilot is looking and for this reason the headset can be equipped with different head motion sensors. The head motion sensors that can be used include XTAL supports variety of heads motion sensors, ART - German, VICON, OPTITRACK - US, Lighthouse/SteamVR – Laser. we are also developing our own inside out tracking, so there is wide range of motion sensors we support stated Marek Polčák the CEO and founder of VRgineers.



The VRgineers simulation set is quite small and would increase deployability compared to systems. (*Vrgineeers*)

For that simulator they needed to change their virtual reality headset. The original headset was good enough for simple training with a HOTAS system and that was developed into a portable trainer. The next step was to make from open available data an F-35 simulator. but for the simulator they needed a see through capability for the XTAL 3 headset. So the headset received two cameras that show the pilot the head down display and the HOTAS. The new headset provides a mixed reality as the pilot can see the entire cockpit of the simulator but also the virtual reality image projected outside the cockpit. The cockpit replica is of modular design and as such can be quickly changed. Change the front display and the left and right hand side module and change them with modules from another aircraft and the pilot can train for a different aircraft. Since developing the F-35 simulator VRgineers also developed simulators for other fixed wing fighters such as the F-15, F-16 (one of these was donated to Ukraine during the war to prepare them for actual training), and F-18. Another advantage of the

modularity is that it can deploy with the squadron really easy as opposed to the simulators in use. The simulators are being used by the US Navy according to VRgineers. One such simulator was sent to Lockheed Martin during the first quarter of 2023 for evaluation. In the second quarter of 2023 VRgineers received feedback from Lockheed that the hardware of the simulator was good enough and that Lockheed Martin was able to support it with the real Operational Flight Program. This meant that if in the future a customer wanted to train their pilots with the aid of the VRgineers simulator they could do so as Lockheed Martin would supply such a customer with the original OFP. The next step that VRgineers undertook was to connect 8 of their simulators and provide tactical training in groups. VRgineers have been quite successful also in the civil market one their customers is KLM, the Dutch airliner. An F-35 simulator has also been delivered to the British MoD. The fact that VRgineers is now a part of the negotiations involving the acquisition of the F-35 for the Czech republic shows the long way that they have in the short history of the company and it might also give VRgineers their first domestic success. As the technology is moving forward hard Marek Polčák stated that the team at VRgineers is looking regularly at technology to make things either better and or smaller to maintain their edge over the competition. It was now a case of convincing the first F-35 customer, the Czech republic would be a good start.

Training of pilots was one side of the coin. The other side of the coin involved training the maintenance crew. Maintenance has been evaluated from early as the JAST stage of the programme. The JAST programme office, together with the Naval Air Warfare Center Training Systems Division (NAWC-TSD), sponsored demonstrations. One was performed by Boston Dynamics Inc. with the goal of replacing physical trainers with virtual-reality trainers. For this purpose, Boston Dynamics Inc. replicated two training maintenance tasks for the AV-8B. The advantages of the virtual-reality aircraft maintenance trainer were reduced equipment, inventory, reduced space requirements and training equipment deployability.

The comparison with the jets that the F-35 was to replace was stated by Lockheed Martin in 2010: training time for the F-35 maintainer was to take 49 per cent of the time it would take to train a maintainer on one of the so-

called legacy fighters. The mission-qualified maintainer (MQM) status is divided into three groups these are:



A detail of the front of the weapon loading trainer from a different angle during a presentation at Williamstown. (*Commonwealth of Australia department of defence*)

1. Initial Qualification – No previous maintenance experience
2. Transition – Previous maintenance experience other than JSF
3. Refresher – Previous JSF experience

The trainee gets a desktop computer that is a virtual environment simulator called the aircraft systems maintenance trainer (ASMT). The trainee controls a little digital human being that walks out to the aircraft, picks up tools and opens up panels. So he gets to accomplish all of his tasks in that virtual environment in the setting of a classroom with an instructor watching to make sure that all steps are in the right order, all safety procedures are followed and the actual laptop being used is being taking out to the appropriate aircraft. That has the specific work order which indicates the maintenance being performed, from step one to five. If the laptop is

plugged into the desktop in the classroom, the trainee can become very familiar with the device being taken out on the flight line.

The maintainer goes out to pieces of the aircraft in a big warehouse area. Those have functional similarities to the aeroplane so that he or she can practise open and closing weapon-bay doors, removing and replacing panels, do low observable restoration – all the things that can be practised on a full-scale simulator and that's before anybody ever gets near to a real aeroplane. The aim and hope is, according to Colonel Art 'Turbo' Tomassetti, that 'we made the training environment so realistic now, more so than we have with any other aeroplane, that when we can get them out to a real aeroplane for the first time, the first time they try a maintenance task they get it correct. So we have a 100 per cent success rate on the first attempt. So we don't have to use the real aeroplane to let them practise over and over again. Because if we are practising on the real aeroplane we are not flying the aircraft and we are not really maintaining the aircraft either.' All these pieces of aircraft are so-called hands-on training devices. This was nothing new, such systems had already been built for the Lockheed Martin F-22 Raptor

The aircraft pieces to which Tomassetti was referring are the weapons loading trainer (WLT), and the ejection-system-maintenance trainer (ESMT). The WLT and the ESMT were developed by EDM Ltd from the United Kingdom. The contract for both trainers was awarded in 2007 to EDM by Lockheed Martin. The WLT is a copy of the Joint Strike Fighter from fuselage station 230 to fuselage station 556 with features of the STOVL and CV version. It is equipped with an undercarriage tow point. The weapon bays are fully actuated with pipework and obstructions that resemble the real thing.

The ESMT had to be able to simulate the slightly different cockpit configurations since the STOVL F-35B has a different canopy due to the lift-fan. The effect on the maintenance was big enough to provide a need for a dual version of the ESMT. This would, however, increase the cost and, for this reason, the ESMT is equipped with an interchangeable top so that maintainers can gain experience on both versions or that one system can be used by more services. The first recorded use of the WLT with an inaugural seventeen-day weapons familiarisation class was on 19 March 2012.



Weapon loading trainer being put to use with an AMRAAM at Eglin AFB. (*USAF*)



The Aircraft Systems Maintenance Trainer (ASMT). Note besides the two screens on the desk students also have a Portable Maintenance Aid. (*USAF*)



Maintenance class: the basics are being instructed in a normal classroom. (*USAF*)



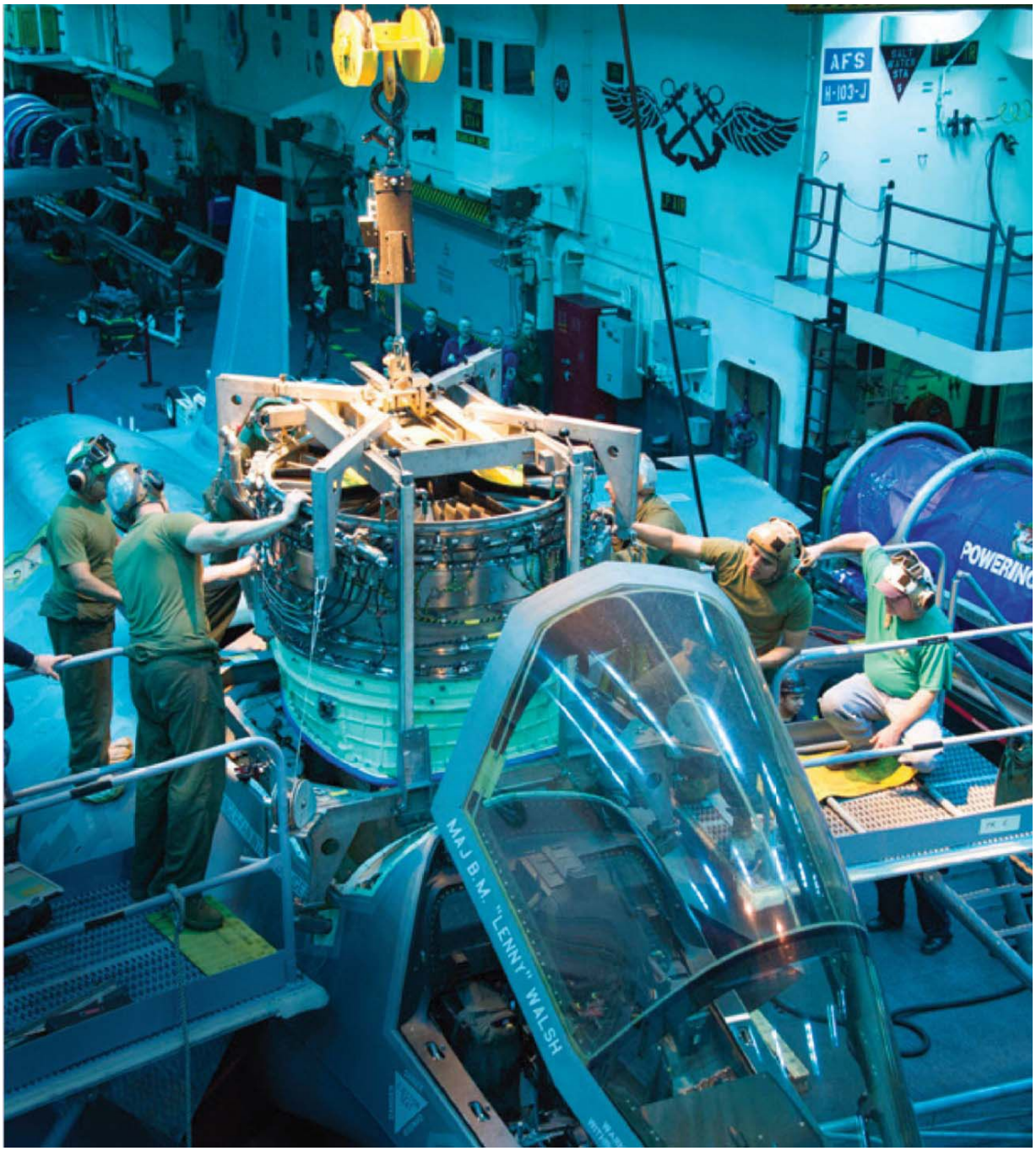
A view of the Landing Gear Maintenance Trainer. It is not clear if all so-called hands-on training devices are being bought by the partner nations or FMS customers. (*USAF*)



The Ejection System Maintenance Trainer here seen at Eglin AFB. The forward hinged cockpit should allow for relatively easy ejection seat removal in one piece, it still requires training. (*USAF*)



A landing gear trainer in the F-35 Academic Training Center. The weapon bay is there for accuracy. (*USAF*)



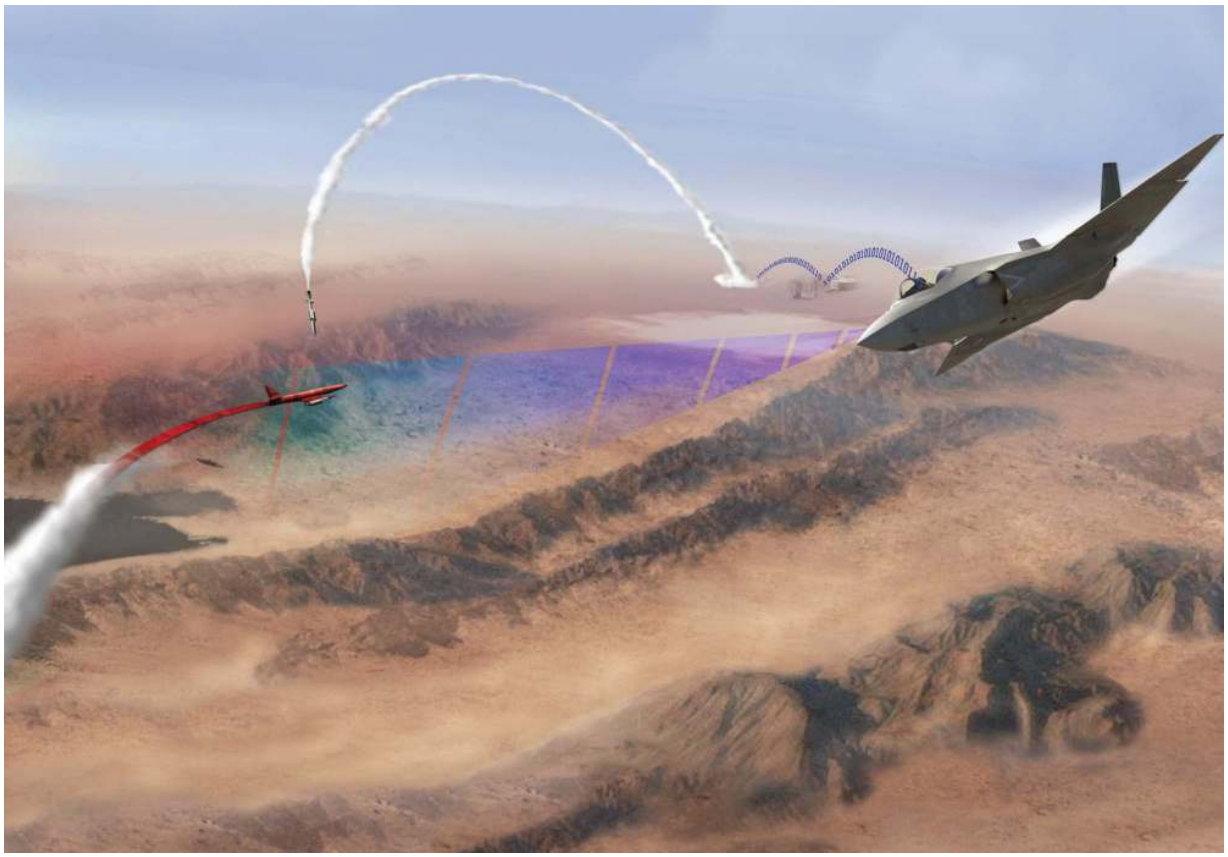
The removal and installation process is a task which requires precision. Here on the USS *America* LHD 6 they were proving it could be done. (*US Navy*)

Other full-scale trainers were ordered in a staged fashion. The third hands-on trainer, and probably the smallest one, was the integrated power package maintenance trainer (IPPMT). This trainer, developed by Astronics Test Systems, replicates the housing and the bay in which the integrated power package is located. It provides for IPP servicing and removal and

installation training. The next trainer was the landing gear maintenance trainer (LGMT) which is self-explanatory, although it only allows for training on the main landing gear. The tasks that it enables are removal and installation of main landing gear components, which are the shock strut, wheel and tyre assembly, brake and down-lock actuator. Another one aimed at the F-35B STOVL version was developed in Australia by Marand which, in spring 2016, won the contract for the design and manufacture of the engine and lift-fan removal and installation trainer (ELFRIT). As the name suggests, it would be for the STOVL version; however, maintainers of the other variants can use it as well since the installation of the main engine is similar over the three variants. Marand expected to complete the design phase in mid-2017 and deliver the first unit, the largest piece of hands-on devices thus far, in late-2018.

The Synergies of the F-35 on the Battlefield

The F-35 was not designed to operate alone but as a system of systems, an enabler for a network. The F-35 was often criticised for not having enough internal weapon capacity which would come back to haunt the pilots. That the F-35 would rarely operate on its own and had a weapon load similar to the F-117 was often forgotten. Anti-stealth systems would be on the increase, it was argued. The first and foremost of the synergies mentioned was the communication with older fighter aircraft, thus making them ‘smarter’. This was one of the main factors pointed out after the first Red Flag exercises. Fourth-generation aircraft were helped with situational awareness and enabled to make better use of tools they had. Co-operation between different generation fighters was not a new thing: just a major example from recent history was the co-operation between the Panavia Tornado and the Buccaneer during Operation GRANBY, the First Gulf War in 1991. During that war the Buccaneer was laser-designating targets for the Tornado crews. The idea was that the F-35 would take the concept a step further.



A graphical representation of that first mission test. The F-35 sends coordinates and other significant data so that long range targetting can be accomplished. The F-35 does not give its presence away. (*US Navy*)



The VMX-1 was part of the Initial Operational Test & Evaluation for a short time and played a significant part in testing the transformational character of the F-35B for the USMC. (*USMC*)

NIFC-CA

One of the operational synergies to be evaluated was with a naval system called Naval Integrated Fire Control – Counter Air (NIFC-CA). The operational test is part of the functionality of the systems on the aircraft which also tests the aircraft in conjunction with other systems fielded. The compatibility with different systems was to be evaluated, one of which was NIFC-CA. Testing the compatibility with this system fell to the VMX-1 with the first compatibility test taking place on 12 September 2016. An unmodified F-35B, flying ahead in stealth mode, detected a flying target beyond the horizon and sent target information through its MADL to the USS *Desert Ship* (LLS-1), a land-based launch facility designed to simulate a ship on the White Sands Missile Range. Using the latest Aegis weapon system it detected the target and launched an SM-6 missile to engage it. The point of the exercise was that with ship-borne sensors not having the range of the missile, the capability of using the F-35B behind enemy lines to

combine off-board munitions, increasing lethality at any point in the arena, made the most use of the aircraft's sensors thus negating the problem that most critics identified with the relatively small internal load. One small problem was that the target data was sent over the MADL and NIFC-CA mostly uses the Datalink-6 system; an antenna instalment for the MADL on ships with different positions was evaluated. This operational test shows that the F-35 is going to be a part of the network, part of the system of systems integrated to do damage, its quality as a sensor ship becoming more important than ever. The F-35's ability to send targeting data to other weapon platforms overcomes the need for using its own weapons for initial strikes against integrated air defence systems (IADS). Sending targeting data to other weapon platforms, such as the Naval Integrated Fire Control – Counter Air (NIFC-CA) to eliminate IADS or other targets means that the F-35 remains undetected. It is important to realise that the F-35's pilot doesn't have to be the shooter; the effectiveness of the F-35 would be multiplied through NIFC-CA which would normally carry a greater munition load.

High Mobility Artillery Rocket System (HIMARS)

One system to be evaluated for possible synergies in 2017 was HIMARS. The M142 high-mobility artillery rocket system (HIMARS) is the light, wheeled version of the M270 multiple-launch rocket system (MLRS). HIMARS uses the same pod as the M270 MLRS, which can hold six rockets or a single missile. HIMARS was not only in service with the USMC but also with the US Army. The chassis is produced by BAE Systems Mobility and Protection Systems (formerly Armor Holdings Aerospace and Defense Group Tactical Vehicle Systems Division) while the rocket-launching system is produced by Lockheed Martin Missiles and Fire Control. The system's purpose is to give a strike range normally associated only with military strike aircraft and the possibility of over-the-horizon targeting could become reality if these systems could communicate; it would be another form of sensor-to-shooter integration. During the integration exercise, it was important to identify deficiencies so that they could be passed on for solving, as often communications were the most important part of the exercise and the F-35 has three major ways of communicating: Link-16, multifunctional advanced data link (MADL) and variable message format (VMF). MADL is currently a system which can

only be used between F-35s and so is not much use for creating synergies with other systems. VMF and the Link-16 systems digitally send formatted weapon-employment quality target coordinates and other specifically formatted messages. Considering that the USMC is the only service with both HIMARS and the F-35 in service, they would make a priority of the integration of these systems. The fact that the US Army also has HIMARS in its inventory could make it a real force multiplier. The first evaluation culminated on 19 April 2017. Two F-35Bs from VFMA-211 took part in an exercise to evaluate the co-operation for future weapons and tactics instructor (WTI) courses. During this first evaluation, two F-35Bs transferred data gained from their sophisticated sensors, so that HIMARS could shoot from the guided multiple-launch rocket system (GMLRS). The targets were struck without the need for HIMARS to update any target information. As the F-35 was not able to send a digital 'call for fire' (CFF) a workaround had to be found. Although the F-35 could give a voice CFF, this would have to be entered manually into the system. For this reason, Force Artillery Headquarters personnel integrated with Direct Air Support Center (DASC) to reconnect the CFF digital loop between the F-35 and the platoon fire direction centre (FDC). The exercise took place at night and the targets were approximately twenty-three kilometres away, well within the range of HIMARS which is over 160 miles.





The M142 MIHARS system was deployed by C-130 during the WTI 17-2.

The second evaluation event took place between 4 and 17 June 2017, using F-35As from 34th Fighter Squadron, the reasoning being to bring interoperability between the USMC and USAF. This time the CFF came directly through the ultra-high frequency voice communications to the platoon FDC and the targets were struck at a range of approximately forty-two kilometres. It was realised that, if the communication of target data to the FDC could be made entirely digital, the amount of data coming from the F-35 force would enable it to become a real menace without even being armed.



From data received from the F-35, the M142 HIMARS fired and destroyed their target. The integration work was moved further in follow-on Weapons Tactics Instructor (WTI) courses.



The HIMARS could also be deployed on board ships and function onboard the ship as it did here from the USS *Anchorage* (LPD 23) October 2017.



The F-35B on the USS *Essex* in the same exercise Dawn Blitz 2017 as the M142 HIMARS and USS *Anchorage* (LPD) 23) Divids.

IBCS and the PAC-3

Lockheed Martin announced on 6 August 2019 that, together with the Army integrated air and missile defence (AIAMD) project office and the US Air Force, it had successfully integrated F-35 track data with the IAMD battle command system (IBCS) during Orange Flag Evaluation (OFE) 19-2 at Palmdale, California and Fort Bliss, Texas.

This was the first-time that live F-35 track data had been sent to IAMD IBCS via the F-35 ground station and F-35-IBCS adaptation kit, both developed by Lockheed Martin. This allowed IBCS to receive and develop fire-control quality composite tracks during the exercise, leveraging the F-35 as an elevated sensor. This capability enables multi-domain operations and the detection of threats that could challenge ground-based sensors and was the first step in connecting into the US Army's AIAMD and would

follow a similar process to integrating into the US Navy's NIFC-CA system.



At Farnborough 2016 this model of the UTAP-22 was presented as the ultimate wingman. (*Gérard Keijsper*)

'This demonstration represents a significant growth in capability for the Army IAMD programme and Army for multi-domain operations. The capability creates additional battlespace awareness, and the ability to track incoming targets and take action, if necessary,' said Scott Arnold, vice president and deputy of Integrated Air and Missile Defence at Lockheed Martin Missiles and Fire Control. 'The F-35, with its advanced sensors and connectivity, is able to gather and seamlessly share critical information enabling greater joint force protection and a higher level of lethality of Army IAMD forces.'

Another integration effort was announced on 21 January 2020. Two F-35s were integrated with the US Army integrated air and missile defence battle command system (IBCS), providing an airborne sensor capability to successfully detect, track and intercept near simultaneous air-breathing threats in a test at White Sands Missile Range, New Mexico. The December

2019 test marked the first time F-35s were used as sensors during an IBCS live-fire test against multiple airborne targets.

Linking F-35s to US Army IBCS via the multifunction advanced data link (MADL) provided enhanced situational awareness and weapons-quality track data to engage airborne targets. The proof of concept demonstration used experimental equipment developed by Lockheed Martin, including the Harvest Lightning Ground Station and IBCS adaptation kit (A-Kit).

'The F-35's advanced sensors and connectivity enable it to gather, analyse and seamlessly share critical information with the joint fighting force to lead the multi-domain battlespace,' said Greg Ulmer, Lockheed Martin vice president and general manager of the F-35 programme. 'This test validated the F-35's capability to serve as an airborne sensor and extend the range of critical Integrated Air and Missile Defense interceptors.'



The second UTAP-22 ready for launch. (*Kratos*)

A Lockheed Martin PAC-3 missile successfully intercepted a surrogate cruise-missile threat at White Sands Missile Range, New Mexico, using an F-35 as an elevated sensor. The mid-July 2021 US Army flight test marked a first in one flight test – F-35 data contributing to the global track used by the US Army IBCS to live fire a PAC-3.

IBCS, developed by Northrop Grumman, used the F-35 data with other contributing sensor data to initiate the launch of the PAC-3 to neutralise the incoming threat, using combat-proven hit-to-kll technology unique to the Lockheed Martin interceptor. ‘Threats continue to evolve, and it’s important that we always stay ahead of them. This flight test shows the impact of what we can do in Joint All Domain Operations when we use the US Army’s IBCS and communications gateways to bring together the world’s only combat-proven hit-to-kill interceptor with the world’s most advanced fighter jet’, said Brenda Davidson, vice president of PAC-3 Programmes.In all the above-mentioned integration efforts that provide immense synergies on the battlespace there was one common nominator: the Aegis combat system, the HIMARS rocket-launching systém and PAC-3 Patriot system were all products from Lockheed Martin.



The AV-8B Harrier seen side by side with two UTAP-22 giving a sense of size. (*Kratos*)

Loyal Wingman

Loyal Wingman was the name of a project that was experimented with during the fourth quarter of 2015. Initially, it was not experimented with on the joint strike fighter F-35, but would be an option for the future and its future makes sense especially for smaller forces as the acquisition and operational costs of the F-35 were quite high, even if they approached the cost of most fourth-generation fighters.

The first step forward in this technology was made by the Kratos unmanned tactical aerial platform 22 or UTAP-22. UTAP-22 is a modified UCAS-167A and a minimum of three were made. UTAP-22 is rocket launched by a rocket booster similar in principle to the zero-length launch (ZEL) evaluated on the F-84, F-100D and the F-104G in the 1960s but now used mainly by target drones. A relocatable containerised rocket-assisted take-off assembly and a recovery by parachute does away with runway requirements.



The UTAP-22 during launch, the rocket booster will release itself after it is redundant. (*Kratos*)



A computer graphic of the Kratos XQ-58A performing the strike mission information. (*Kratos*)

Three demonstration flights were made. The first demonstration flight took place on 24 October 2015 and objectives met included:

1. Tactical Data Link Command and Control (C2)
2. Semi-Autonomous control among these Waypoint Navigation, Point to Point, Hold, and Formation with virtual drone
3. Positive hand-off control
4. Range integration



The first flight of XQ-58A Valkyrie. (*Kratos*)



A computer depiction of Boeing's Loyal Wingman approach for Australia. (*Boeing*)

The second demonstration flight was interesting because it involved a manned fighter aircraft, a USMC AV-8B, one of the more work-intensive aircraft to fly. This demonstration took place on 23 November and the objectives achieved were:

1. Collaborative flight with manned aircraft via Tactical Data Link
2. Tactical Data Link Command and Control (C2)
3. Semi-Autonomous control via Tactical Data Link
4. Positive hand-off to a geo-separated controller

During this the UTAP-22 under the command and control of a ground operator was turned over to the AV-8B Harrier, the so-called hand-off to the geo-separated controller. It is imperative that, in a combat scenario, UTAP-22 would be able to continue its mission autonomously. However, if for any reason the control and command function or signal of the AV-8B Harrier would be lost, the signal would be transferred to another asset in the area.

The third demonstration involved multi-aircraft collaborative operations; semi-auto payload deployment. The flight involved two UTAP-22s on 11 December 2015.

1. Collaborative ops between two UTAP-22s via Tactical Data Link
2. Command a payload deployment via Tactical Data Link
3. Tactical Data Link Command and Control (C2)
4. Semi-Autonomous control via Tactical Data Link
5. Multiple vehicle Command and Control (C2) by one controller

This was followed by a different culmination of a project funded by the Air Force Research Laboratory (AFRL), and executed by the Lockheed Martin Skunk Works and Calspan Corporation under the Have Raider programme. The first demonstration, Have Raider I, focused on advanced vehicle control. The experimental NF-16D VISTA flew autonomously in formation with a lead aircraft and conducted a ground-attack mission, then automatically re-joined the lead aircraft after the mission was completed. These capabilities were linked with Lockheed Martin automatic collision avoidance systems (ACAS) to ensure safe, co-ordinated teaming between the F-16 and surrogate UCAV, the NF-16D VISTA.

‘This demonstration is an important milestone in AFRL’s maturation of technologies needed to integrate manned and unmanned aircraft in a strike package,’ said Captain Andrew Petry, AFRL autonomous flight operations engineer. ‘We’ve not only shown how an Unmanned Combat Air Vehicle can perform its mission when things go as planned, but also how it will react and adapt to unforeseen obstacles along the way.’ During the flight

demonstration, the experimental NF-16D VISTA aircraft acted as a surrogate unmanned combat air vehicle (UCAV), autonomously reacting to a dynamic threat environment during an air-to-ground strike mission. The demonstration success included three key objectives:

- The ability autonomously to plan and execute air-to-ground strike missions based on mission priorities and available assets
- The ability to react dynamically to a changing threat environment during an air-to-ground strike mission while automatically managing contingencies for capability failures, route deviations, and loss of communication
- A fully compliant USAF open mission systems (OMS) software integration environment, allowing rapid integration of software components developed by multiple providers



The first fuselage on the production line, the air inlets in plain sight. (*Boeing*)

The two-week demonstration at the Test Pilot School at Edwards Air Force Base, California, is the second in a series of manned/unmanned teaming exercises to prove enabling technologies. ‘The Have Raider II

demonstration team pushed the boundaries of autonomous technology and put a fully combat-capable F-16 in increasingly complex situations to test the system's ability to adapt to a rapidly changing operational environment,' said Shawn Whitcomb, Lockheed Martin Skunk Works Loyal Wingman programme manager. 'This is a critical step to enabling future Loyal Wingman technology development and operational transition programmes.'

Kratos went on to develop a larger unit that would conform more to the size of the requirement as the need for internal weapons would be required. The new larger model was initially designated XG-222 but, after it was revealed that the first flight of seventy-two minutes had occurred on 5 March 2019, it had changed its designation to the XQ-58A Valkyrie. During the third flight the XQ-58 completed the flight recovery function but shortly after the prototype cushion system suffered a deviation causing damage to the XQ-58A Valkyrie after the landing. The mishap was evaluated and, when it was deemed safe to return to flight, the XQ-58A was repaired. After repairs it resumed flight testing on 23 January 2020.

Boeing joined the Loyal Wingman field with a surprise move when they unveiled a mock-up of their design, partly funded by the Australian Ministry of Defence, at the Avalon Air Show in Australia in 2019. The fact that the RAAF was operating the Super



The mock-up being presented at Avalon Air Show Australia. (*Boeing*)

Hornet, the Growler and F-35 was not lost on anyone; the mock-up had been built in Australia. Boeing Australia, in co-operation with the Royal Australian Air Force, had gone in a different direction from Kratos and had given its Loyal Wingman mockup design a retractable landing gear. A total of three prototypes were to be built. The production of the first prototype was well underway as Boeing Australia announced that the first fuselage had been completed by 10 February 2020. Another milestone weight on wheels was achieved shortly after by 9 April and Boeing went full speed ahead with its thirty-five Australian partners because, on 4 May, the Airpower Teaming System as Boeing was calling it was rolled out. The milestones for this programme kept on following: the first time the unspecified commercial turbofan engine was powered up; with low speed taxi tests in October and high-speed taxi tests in December 2020. On 1 March 2021 the ATS took to the air for its maiden flight. A production manufacturing location had been agreed and production was foreseen in the middle of the decade; the Boeing ATS would probably be one of the first systems to get into service.

The Loyal Wingman concept was at first highly touted as being the future for the F-35 and it was expected a Loyal Wingman system would be developed for it. USAF Brigadier General David Abba actually stated that, had someone asked him in 2015, they would have developed a specific pathway to communicate with a Loyal Wingman system for the F-35. If then someone else came in with a different system, again a different pathway would be developed. However, at this time, they were looking at more flexible ways of integrating such systems and the idea was to integrate it in a similar way as was currently being done with the advanced battle management system (ABMS). The ABMS idea had come into being in 2017. The next test flight took some time to prepare but was interesting because of the other assets involved, two of them being the Lockheed Martin F-22 Raptor and the F-35. The fifth flight of the Kratos XQ-58A took place on 9 December 2020 at the Yuma proving ground with at least three other aircraft. An F-22 Raptor (ED 91-4007) and F-35A Lightning (OT 11-5020), the USAF's two fifth-generation fighters, formed up off the wings of the smaller Valkyrie as it continued to fly autonomously in formation. The USMC also participated in the test with an F-35B.

'The experiments represented a first step in demonstrating the potential of attritable aircraft as a force multiplier in a manned/unmanned environment,' said Brigadier General Heather Pringle, AFRL commander. The Valkyrie met 80 per cent of the overall flight test objectives with 100 per cent of the formation flying objectives being met before safely landing in the Arizona desert, according to AFRL XQ-58A programme manager Michael Wipperman.

'As the ABMS attritableONE Product Lead and XQ-58 Valkyrie AFRL Programme Manager, I'm proud of the partnership with AFLCMC, the Air Force Test Centre, and our Air Force acquisition and industry partners, and the team's ability to go from concept to demonstration in six months,' said Wipperman. 'This was the fifth successful launch of the Valkyrie, but the first time the platform has integrated a new war-fighting capability payload and flown in formation with an F-22 and F-35.'

Wipperman added, 'The XQ-58A modularity and ability to carry robust payloads enabled the rapid capability integration into an attritable experimentation vehicle. We're thrilled with the seamless integration and demonstration of this flight. We look forward to continued capability enhancement at future demonstrations.'

Lieutenant Colonel Kate Stowe, gatewayONE programme manager at the Air Force Lifecycle Management Centre, set out with eighteen test objectives and successfully achieved nine during the same test. ‘Testing is all about pushing the limits of what’s possible, finding out where the toughest challenges are, and adapting creative solutions to overcoming difficult problem sets,’ Stowe said. ‘The real win of the day was seeing the gatewayONE establish a secure two-way translational data path across multiple platforms and multiple domains. That’s the stuff Advanced Battle Management System (ABMS) is all about.’



A little over a year after the mock-up had been shown at the Avalon Air Show the weight on wheels milestones was achieved. (*Boeing*)



Lockheed Martin bid for MQ-25 air to air refuelling seen here. The MQ-25 could be operated in a similar way as the Loyal Wingman. (*Lockheed Martin*)



The one image published from Boeing Australia's Airpower Teaming System or Loyal Wingman roll-out. (*Boeing*)

Fifth-generation fighters are typically limited to communicating with each other and to command and control centres via legacy tactical data

connections, not in their native, but incompatible, digital 'languages' – Multifunctional Advanced Data Link for F-35 and Intra-Flight Data Link for the F-22. Not only can gatewayONE translate between those formats, in this test it moved data that is normally relegated to an operations centre or tactical ground node, directly pushing it into the cockpit at the edge of the multi-domain battlespace for the first time. In other words the incompatible datalinks of the F-22 and F-35 could communicate with each other through the XQ-58A.



Early test flight of the ATS. Landing gear down. (*Commonwealth of Australia, Department of Defence*)

The flight tests with the XQ-58A were coming at a seemingly slow pace but every test flight demonstrated a deliberate new capability and seemed to connect different programmes. The sixth flight occurred on 26 March 2021, during which the XQ-58A opened its weapon bays and, for the first time, dropped a smaller drone from it. An ALTIUS-600 small, unmanned aircraft system (SUAS) successfully separated from the XQ-58A's internal weapons bay over the US Army Yuma proving ground test range. It was the first time that the weapon bays on the XQ-58A had been opened and, after launch of the ALTIUS-600, the XQ-58A continued extending its flight envelope for future testing.

Integration into a System of Systems

Interconnectivity has been an objective from the outset for the F-35. For this reason the incompatible datalinks between the F-22 IFDL and the F-35 MADL came as a surprise in 2014. Lockheed had already initiated looking at the problem in December 2013 during Project Missouri which entailed an F-22 link-16 transmission multi-level secure (MLS) cross-domain solution. Open mission systems (OMS), although looked at, had not made it into the F-35 but this was to be changed during development of Block 4 and the next iteration that would lead to eventual communications with the F-35 being seen as an improvement for the U-2 as an intelligence surveillance and reconnaissance (ISR) platform. The demonstration or trial was called the open mission systems (OMS) intelligence surveillance and reconnaissance (ISR) demo 1. It involved a U-2S (80-1073) that was upgraded with an OMS that was separated from the critical flight functions. The following systems were also used:

- Honeywell designed dual-band apertures that were fitted to the U-2's payload bay.
- A modernised IP-based 'Gen3' modem datalink from L3Com relayed the output from the sensors to the prototype common mission control centre (CMCC), a 'smart' command and control and ISR ground station that exploited open architecture.

This demonstration took place in December 2014. A follow-on demonstration took place in June 2015, dubbed by the Skunk Works Project Iguana which tried to solve the connectivity between fifth- and fourth-generation platforms even though Link-16 existed for that purpose. However, this time multi-level secure (MLS) hardware was used in conjunction with the common mission control centre (CMCC) and a Lockheed U-2 was upgraded with a SIGINT sensor from BAE Systems; the F-22's intra-flight data link (IFDL), Link 16 and the latest Gen4 datalink modem from L-3 Com. The main demonstration was that the U-2 was used as data gateway between the F-22 and other assets on the ground and in the air with some fourth-generation aircraft. The CMCC was next connected with an U-2 through a satellite in a demonstration called the Jukebox; this demonstration took place in October 2016 and was targeted mainly at connecting the U-2 with ground forces via satellite. The next Skunk Works demonstration was Project Hunter which took place in May 2017 and

involved a new OMS computer, called the Enterprise open systems mission computer 2.0 (EMC2). The Lockheed Skunk Works upgraded a Lockheed U-2S (80-1070) with this new computer and deployed it to Elmendorf AFB in Alaska for the Northern Edge 2017 exercise. There the Enterprise open systems EMC2-equipped U-2S participated in the very intense operations, operating in conjunction via satellite while updating targeting details to a missile in flight. Another step undertaken was under DARPA's SoSite or system of systems integration technology and experimentation programme, for which DARPA had contracted four companies (Boeing, General Dynamics, Lockheed Martin and Northrop Grumman). Lockheed's flight trials took place in February 2018. This demonstration used their Enterprise open systems EMC2, some airborne platforms and ground stations to provide proof their concept. The next step in the rather fast development from the Skunk Works was Project Riot, the main aim of which was to get F-35 sensor data to the multi-domain battlespace. During this project the F-35 participated with the U-2S equipped with the Enterprise open systems EMC2. The F-35 detected a long-range ballistic missile launch with its sensors and provided that information through the EMC2-equipped U-2S the Common Mission Control Centre (CMCC).

Follow on Modernisation Development of the F-35

The JSF programme included several ideas on improving on the standard F-35. Besides the JSF programme, the US Navy and the USAF had their own ideas. Improvements were not always related to new capabilities but rather improvements to existing systems. To improve on the standard F-35 the tool most often used for the development of new technologies was a system called small business innovation research (SBIR). Every year many of these further developments were used, some of them initiated in time to be integrated into the standard three F-35 Lightning versions. However, as this was a continuous process it was likely that the F-35 would be improved upon in small steps. The first major improvement was due after the SDD was completed. Due to the financial problems, some systems and capabilities were deferred to the so-called Block 4 which had been talked about from the outset and was seen by export customers as a way to get their weapons of choice integrated. The initial start of the development of Block 4 was to start in 2010 but was now so much delayed that the in-service date was quoted to be in 2022. Since this was considered too late by partner nations, Block 4 development was broken into several sub-blocks. For future export customers, it was considered important as well to get certain capabilities integrated. One capability that could play a role in the Belgian selection, for example, was the nuclear capability, also known as the dual-capability aircraft. Negotiations on Block 4 were to be concluded by the end of 2015.

As soon as the first contract was awarded to Lockheed Martin regarding Block 4 development the GAO reported that they saw a problem with the follow-on modernisation since the Block 4, as it was now officially named, did not start as a separate programme. They compared it to the F-22 follow-on development programme which also had had many issues with performance and transparency increased once the follow-on development

was separated from the original F-22 programme. A comparison was, however, rather interesting.

Comparison between F-22 EMD/ F-35 SDD development.

Aircraft	Capabilities	Weapons
F-22	8	3
F-35	80	17

The number of upgrades planned went beyond weapons though. Many added capabilities were just software related.

The Block 4 was due to reports from the watchdogs such as the Government Accounting Office (GAO), Project on Government Oversight (POGO) and the Director of Operational Test and Evaluation (DOT&E) which were rather controversial. This controversy had to do with the disbelief that the schedule of the development Block 3F was based on a realistic schedule. As stated before, Block 4 was being divided into sub-blocks, the first of which was due to start testing by the end of 2019. Every two years the following sub-block would start testing. The initial block was designated block 4.1 with the last one 4.4. Delivery of block 4.1 was scheduled to be initiated with lot 13, due to begin delivery in 2021. Block 4.2 was due for delivery in lot 15 and Block 4.3 would be delivered with lot 17 and so forth. So, Block 4.4 would reach its customers by 2027. Block 4.1 and block 4.3 would be software-only upgrades; Block 4.2, the first upgrade to include hardware as well, would include technical refresh 3 new processors as it was expected that the processing power of TR2 would not be sufficient to cover the upgrades. Another advantage mentioned by Admiral Winter was that the hardware and computing power would provide a truly open architecture, owned by the government; the interface of the inner guts of the F-35 would allow for software and hardware modernisations and enhancements from different sources, ending the monopoly on the F-35, until that time owned by Lockheed Martin. It remained to be seen how far this could work. Block 4 is estimated to be 80 per cent software-driven, so there was an opportunity, instead of doing a large number of updates, to instal them as they became ready. Harris Electronic Systems was selected to develop and produce the next Technology Refresh 3 by the end of September 2018. The new Integrated

Core Processor (ICP) for Technical Refresh 3 (TR-3), designed to help reduce unit cost by 75 per cent while facilitating a twenty-five-times increase in computing power compared to TR-2 for planned capability upgrades. The first unit for test purposes was due in 2021. On 20 July 2022, L3Harris announced that they had achieved the Safety of Flight milestone for the Integrated Core processor for Technical Refresh 3 (TR-3). Lockheed Martin test pilot Tony 'Brick' Wilson said at Farnborough that CF-3 was the first test aircraft that was undergoing modification to the TR-3 standard.

Lockheed Martin stated in August 2022 that is in the process of completing final Software Integration and Test en route to delivering flight test software to Edwards AFB. TR3 Hardware modifications have begun on the developmental test fleet. Lockheed is projecting to have all 6 TR3 flight test aircraft modified and operational conducting flight tests in fourth quarter of 2022. The first flight test with block 4 40 series took place with TR-3 hardware on January 6, 2023. The flight will open the way for more technologies to be introduced on the F-35. Maj. Ryan 'BOLO' Luersen, a US Air Force experimental test pilot, piloted the mission in tail number AF-7, a specially instrumented flight test aircraft and the first with TR-3 upgrades installed. TR-3 is the hardware that allows new capabilities to be added. The main part of TR-3 is the ICP Integrated Core Processor which is promised to offer 25 times increase of computing power. The ICP is the brains of the aircraft processing data for the aircraft's communications, sensors, electronic warfare, guidance and control, as well as cockpit and helmet displays. Another part of the TR-3 is the (AMS) Aircraft Memory System. The AMS houses the operational flight programme, mission and theatre data, prognostics and health data, audio, display video and aircraft parametric data. A new head down display electronics unit has been ordered which offers approximately four times the processing capacity and 32 times increased memory capacity. All these aforementioned upgrades are all compatible with an Open System Architecture which the Joint Strike Fighter programme office has been evaluating since the 1990s. These upgrades are planned for integration on the production lot 15 which is supposed to roll off the production line during the second half of 2023. Considering that development flight test has just started, this gives the development test community at Edwards AFB and NAS Patuxent River very little time as the operational test community also has to evaluate the new systems before they are handed over to combat coded units.

The battle between the Joint Programme Office on the one side and GAO and DOT&E on the other side continued as one would expect. Deficiencies found during the SDD that were not resolved ended up being a part of the follow-on modernisation or, as it is was rebranded, continuous capability development and delivery (C2D2). The debt and deficiencies were expected to take well into 2019 to solve. Once these were solved, the Block 4 development would begin and in six-month increments be delivered, although the six-month increments were called unrealistic by DOT&E.

The contracts were being called out and one that caught many people by surprise was the contract award to Raytheon of the electro-optical digital aperture system; the promise of being ensured business was taken away from one of the major partners. The F-35 programme was going to be run on a best-horse basis and one would have to keep a competitive edge to remain on the programme. Harris received a contract to deliver a new integrated core processor (ICP) to be delivered by 2023. The surge in production would mean that the original systems would still be delivered in their hundreds and computing power was expected to be increased twenty-five times. At the same time, the cost would come down by an estimated 75 per cent with increased reliability; the new ICP would be introduced in production lot 15 aircraft.

A clear sign that C2D2 had gone into the flight-test phase was the fact that flight testing was initiated on the automatic ground collision avoidance system (AGCAS) by November 2018. Development went so fast that the effort actually was recognised by the award of the Collier Trophy. The Collier Trophy Selection Committee considered the AGCAS development and integration the greatest achievement in aeronautics or astronautics in the US, concerning improving performance, efficiency, and safety of air or space vehicles in 2018. AGCAS was the only new technology introduced in 2019 to the services from a planned eight technologies. The other technologies planned for introduction in 2019 had been delivered too late to the test sites and, for that reason, their introduction was deferred to 2020. One of the technologies under test at the time was dual-capability aircraft, or the nuclear capability. Some information was published but immediately withdrawn. Even export customers required that capability – Belgium and the Netherlands to name but two.

Another step taken was with a technology that had been introduced since the start of SDD in existing platforms but was still missing in the F-35 – video data link (VDL). The USMC deputy commandant for aviation sent a memo to the F-35 PEO requesting the rapid fielding of full motion video for F-35Bs, deeming the capability 'essential to the way we fight,' especially for close-air-support operations. The memo dated August 2016 initiated the process with financing for an interim full-motion video (FMV) becoming available in 2017.

The Kill Chain Integration Branch of the Special Programmes Division of the Command, Control, Communications, Intelligence and Networks Directorate, headquartered at Hanscom AFB, helped field interim full motion video (IFMV), a combination of a video stream and associated location metadata in one video file that replaces the F-35B combat training system. Even after installation, IFMV remains swappable with the combat training system with minimal maintenance actions required. IFMV has a performance threshold range exceeding ninety-two kilometres. Additionally, the system demonstrated interoperability with numerous ground receivers and other aircraft.

'Not only will IFMV provide the F-35B [with] an indispensable warfighting capability four years ahead of schedule, but it will also prove OMS as a viable architecture going forward, one that enables the acquisition community to deliver upgraded capability faster, and cheaper, than ever before,' Lieutenant Colonel Mike DiMaria, Kill Chain Integration Branch materiel leader, said. 'Open Mission Systems (OMS) compliance is now a DoD-wide requirement in all new platform projects, and the Special Programmes Division will be the first to show its power. It is essential to the way we fight not just for USMC, but now for all.' The IFMV was ready for delivery to the USMC in December 2020. The U.S. Operational Test Team (UOTT) conducted four large-scale, joint F-35 test events in four weeks, rapidly validating a series new F-35 capabilities in March 2022. The first of these test events was a Close Air Support mission at Marine Corps Air Station Yuma in Yuma, Ariz. Using the Marine Corps' F-35B variant, the UOTT executed a mission requiring pilots to strike ground targets in close proximity to friendly positions. The mission also used the U.S. Marines' Interim Full Motion Video (IFMV) – an F-35B-model only capability that allows ground forces to see what the pilot sees in the cockpit – to execute this mission.

Lockheed Martin announced on 11 June 2019 that it had selected the Cubic Mission solution. Cubic's offering is a secure mission-enhancing system that fits easily within the allocated communications, navigation and identification (CNI) sub-system volume. The software-defined, radio-based VDL solution features high-performance processing that can support future live video enhancements while minimising size, weight, power and cooling (SWAP-C). Cubic's solution enables the F-35 to transmit and receive sensor and metadata to and from multiple ground or airborne units. During one of the biggest strikes in Iraq against an ISIS tunnel network in the Hamrin Mountains in April 2019, the F-35 was able to share data to other aircraft; the VDL would give the F-35 the same ability as legacy fighters by exchanging full-motion video with joint terminal attack controllers (JTACs) embedded with ground forces. This capability had been developed after the SDD had been initiated and was very successful with the legacy platforms and therefore, from the outset, was a technology for Block 4. This was expected to be introduced by 2024 to the entire F-35 fleet depending on retrofit financing. The laboratory and flight-test demonstrations are to provide risk reduction for an F-35 block full motion video (FMV) capability. The FMV data is being provided by the F-35 electro-optical targeting sensor (EOTS) over the existing fibre channel. The EOTS video data will be compressed in software and routed to an L-3 Vortex transmitter. Data will be encrypted in a KGV-135A crypto module in the Vortex transmitter. The encrypted RF video data from the transmitter will be routed to a power amplifier (PA). The output of the PA will be routed to a production F-35 antenna. Depending on the frequency desired, either L or S band, the RF video signal will be routed to the correct antenna. On the receiver side, the RF video will be received by an L-3 ROVER 5 receiver; data will be decrypted in the ROVER 5 and displayed to the screen for user verification.

Another modification expected to reach units was a new flare and chaff dispenser. This was a novelty and information about it was released through a draft environmental impact statement for the Air National Guard (ANG). This was met with surprise since the F-35 would become the first operational stealth aircraft equipped with such defensive counter-measures. The other stealth assets in the USAF deemed such counter-measures superfluous. A bundle of chaff consists of approximately 5 to 5.6 million fibres that are cut to reflect radar signals and, when dispensed from aircraft,

form an electronic ‘cloud’ that breaks the radar signal and temporarily hides the manoeuvring aircraft from radar detection. The ARM-210 chaff proposed for use by the F-35A was intended to reach service entry by 2020.

The MJU-61 flares used by the F-35 provide an infra-red counter-measure to counter homing, heat-seeking surface-to-air and air-to-air missiles.

F-35 Operators

The Integrated Test Force

The Integrated Test Force (ITF) was the F-35 test unit responsible for the system development and demonstration phase. Paul Metz, the first, and chief, test pilot to fly the YF-23 and chief test pilot for F-22 EMD programme was now vice-president of the F-35 ITF. As Metz explained, ITF would, in a sense, be a step further than the Combined Test Force (CTF) during the EMD of the F-22 Raptor. Besides the contractor pilots, maintenance and support staff (Lockheed Martin, Northrop Grumman and BAE Systems) from two countries and the UK forces (two) and US forces (three) there would at selected times be pilots from the other participating countries. A parallel could be drawn with the LWF programme when partner nations had their pilots fly chase early during the F-16 full scale development (FSD), first the Dutch and the Danish in early 1977 followed by a Norwegian later in 1977 and a Belgian pilot in early 1978. The partner nations' pilots received their first chance to fly the F-16 in 1978. The ITF was again split in three parts for locations where flight tests were to be performed: ITF Fort Worth, ITF Patuxent River, also known as Pax River, and ITF Edwards AFB. Metz's deputy, Tom Philips, was responsible for ITF Pax River and ITF Edwards AFB. For ITF Fort Worth, John Korstian was responsible. The ITF started planning the first flight and subsequent flights in 2003; the chief test pilot of the F-35 programme was Jon Beesley. Other pilots who joined the test team in 2003 included Jeff 'Slim' Knowles Lockheed Martin CV project pilot, Dave 'Doc' Nelson, Lockheed Martin Mission systems project pilot (a former F-22 Raptor CTF pilot), Bill Gigliotti, Lockheed Martin test pilot, Lieutenant Colonel Dave Sizoo, USAF test pilot and Commander Brian Flachsbart, US Navy test pilot.



Flight testing with the F-35 started by the Integrated Test Force (ITF) at Fort Worth. AA-1 and the CATBird made some visits to Edwards and Eglin for use of their ranges and technology. (*Lockheed Martin*)



Some of the patches made and worn by staff of the ITF AA-1 and the ITF worked from Fort Worth initially. Flight testing however transferred quickly to Edwards and Patuxent River. (*Lockheed Martin*)

Jon Beesley took his place in the F-35 AA-1 cockpit shortly after the aircraft had its ‘flight’ out of the construction rig onto its own landing gear

in January 2006.

The delay in the programme, although rather small for the size of the project, was long enough for Paul Metz to leave his position prior to the first flight of the F-35 AA-1. He was replaced by Wilbert D. 'Doug' Pearson, a combat pilot and a retired USAF major general by January 2006. Doug Pearson was no stranger to test flight as he had held the position of head of the Air Force Flight Test Centre (AFFTC) until he retired on 1 January 2005. He had flown the only fifth-generation fighter flying until then, the F-22 Raptor. The test pilots of the ITF also had the work of testing or evaluating several technologies that were to find their way into the F-35, examples of those that had to be evaluated being the HMD and unified control.

ITF Fort Worth

AA-1 was the first aircraft to fly but with a year and three months delay on the schedule. The first flight was an important milestone since it gave partner nations a tangible result. For safety reasons it was considered better that, in the initial part of the flight-test programme, Jon Beesley would fly the F-35. Beesley relegated the best seat in the house on the twelfth mission to his Lockheed Martin test pilot colleague Jeff Knowles, a former US Navy pilot whereas Jon Beesley had been a USAF test pilot. Government test pilots were expected to get a chance to fly as early as autumn 2007 but this was out back when the entire test programme was delayed after the grounding of AA-1 for half a year. The first government pilot to fly the F-35 was former US Marine, now USAF Lieutenant Colonel James 'Flipper' Kromberg who took off in F-35 11.54 CST on Wednesday 30 January 2008 for the F-35's twenty-sixth flight. Kromberg, assigned to 461st Flight Test Squadron based at Edwards, had been in the Marine Corps from 1987 until 2003 flying the AV-8B Harrier. After graduating from the USAF Test Pilot School, he served as the lead AV-8B operational test director. In 2003 he switched to the USAF and since September 2005 was part of the JSF ITF. The dual-service experience made him a good candidate to become the first government pilot for the F-35. By that time a pilot from each service had flown the aircraft.



AF-1 and AF-2 during the transfer flight from Fort Worth to Edwards AFB. (*Lockheed Martin*)

In a briefing given by C. Douglas Ebersole, Director of Engineering of the F-35 programme, on 17 August 2011, it was noted that the JPO had decided to set up an engineering presence at ITF Fort Worth. This was a sign that all was not well and that the JPO, after ten years of SDD, was finally putting engineering feet on the ground on the development and production site.

ITF Edwards Air Force Base (AFB) 461st Flight Test Squadron, the 'Deadly Jesters' (ED)

Edwards is the home of major USAF flight testing and the organisation responsible there for testing is called the Air Force Flight Test Centre (AFFTC). A major part of aviation history has been written at Edwards AFB with the first supersonic flight by Chuck Yeager being probably the most iconic and glamorous moment in its history. Edwards, however, played an important role during the concept demonstration phase of the JSF programme and it was only natural that it would play a role again during the

SDD phase of the JSF programme, by then known by the F-35 Lightning II name.





AF-03 above Edwards in this image. (*Lockheed Martin*)


AF-01
F-35
AF-02
AF-03
LOCKHEED MARTIN
SPOT 1
W117° 53. 2590'
N34° 56. 0777'
ELEV.2293



The flight line at Edwards AFB. The main type to be tested was the USAF version. STOVL and CV were also integrated in the test programme. (*Lockheed Martin*)


CAVEANT COELUM NOSTRUM
461ST FLIGHT TEST SQ
F-35
JSF TEST SUPPORT
461st FLIGHT TEST SQUADRON
F-35
LIGHTNING II
ROYAL DANISH AIR FORCE

This Danish F-16 was in support of the ITF at Edwards AFB. Note the badge of the deadly jesters. (*Lockheed Martin*) Inset: The badge of the 461st Fighter Squadron which was the responsible unit at the Integrated test force at Edwards AFB. (*USAF*)

Since the first aircraft to fly was a CTOL version, Edwards AFB would be second in line to receive the first aircraft for testing purposes. Originally it was expected that the first F-35 would arrive in 2006 but, as the first flight was postponed, the arrival at Edwards was also delayed. In 2007 it was expected that the aircraft would be transferred to Edwards AFB as soon as it had begun air-to-air-refuelling testing. This, however, was delayed due to the aircraft being grounded. In-flight refuelling was initiated by the spring of 2008 and again technical difficulty with AA-1 delayed deployment to Edwards. The only major test aircraft related to flight testing for the F-35 that visited Edwards was the Boeing 737-300 CATBird. Edwards' moment arrived, however, on 1 October 2008 when AA-1 finally made its long-awaited transition flight from Lockheed Martin Fort Worth. The pilot during this transfer flight was Jeff Knowles who stated that the aircraft landed without discrepancies. Everything went according to plan; it was the longest distance flown so far by the F-35 and in-flight refuelling went as planned as well. After three weeks in which mainly engine restarts were evaluated, the aircraft returned to Lockheed Martin Forth Worth. For the programme office and the air forces involved the visit to Edwards AFB was also used for noise measurements. This was because of the enormous public outrage due to the expected increase in noise levels. AA-1 was to be used for live-fire testing (LFT) at China Lake AFB. Prior to this AA-1 returned once more to Edwards AFB. AA-1 left Edwards on its last flight from there straight to China Lake AFB.



The unit badge of the 31 TES. (*Edwards AFB*)



Edwards AFB also housed the 31 TES which was part of the Joint Operational Test Team (JOTT). It operated alongside the US Navy VX-9, USMC VMX-1 and RAF 17 Test Squadron and the Dutch 323 Test and Evaluation Squadron. (*Edwards AFB*)

For half a year this marked the end of visible flight-test activity of the F-35 from Edwards AFB. However, Lieutenant Colonel Hank Griffith, commander of 461st Flight Test Squadron, the 'Deadly Jesters', joined the test programme as an active test pilot in April to transfer together with Jon Beesley the AF-1 and AF-2 on May 17 to Edwards. There, flight testing took off at a better pace than anticipated, according to a new schedule which required 394 flights as opposed to the over 1,200 flights of the original schedule completed across the entire test fleet during 2010. The fact that the flight-test programme by the CTOL aircraft was ahead of schedule did not change the fact that the other aircraft were still delayed. According to a schedule set somewhere by the end of 2008, all SDD aircraft had to be flying by the end of 2009 and all delivered early 2010. The fact that AF-4 had still not flown by the end of November 2010 gave an idea of the kind of delays ahead. AF-3 joined the test fleet at Edwards AFB in December 2010 and 2011 proved to be a year of progress for the F-35 at Edwards with AF-4 joining the fleet on 22 January. The previous delays were having a side effect that now the first production aircraft were rolling off the production line. Software-wise it was not certain that these aircraft

could go to their assigned unit at Eglin AFB. The software had to be safe for training purposes and therefore had to be evaluated.

It was decided that these so-called maturation flights were to be held at Edwards. Both low rate initial production (LRIP) I aircraft, AF-6 and AF-7, were ferried to Edwards in May 2011. Maturation flights started when Air Force Lieutenant Colonel Eric Smith, director of operations for 58th Fighter Squadron at Eglin AFB, took A-7 for its twenty-third flight on 13 July. The software used for initial training and these trials was Block 1A. Considering that delivery of the aircraft was initiated during the summer and that development of software Block 1 had not been completed, some safety concerns were felt. To prove that the aircraft were safe to fly for student pilots, the first two aircraft were deployed to Edwards where they underwent so-called maturity flights. Those flights took place from 7 July but the Director of Operational Test and Evaluation, Dr Gilmore, stated that he was worried about safety during flight training. Those worries were set aside by General Schwarz but some members of Congress were not happy and asked for an explanation. So far, besides the two aircraft delivered to Edwards, six CTOL aircraft had been delivered to Eglin AFB but had not flown since. They had to wait till March 2012 to resume their flying careers.

31st Test and Evaluation Squadron Desert Pirates (OT)

On 6 March 2013 this Edwards AFB-based squadron received its first two aircraft, AF-18 and AF-19. The squadron had a history dating back to the First World War and was a distinguished bomber unit. As a bomber squadron it was de-activated in 1963 but re-activated in 1986 31st Test and Evaluation Squadron. Since then it has operated out of Edwards AFB; it was to be part of the Joint Operational Test Team (JOTT) with international partners joining them in the task.

The 31st Test and Evaluation Squadron was the first squadron to deploy with its F-35s to a base where there was no F-35 infrastructure to speak of; this was Mountain Home AFB. The entire squadron of six aircraft deployed (without the Dutch aircraft) on 8 February 2016. It was planned that the F-35 would work together with F-15Es and A-10 Thunderbolt IIs with the F-35s scheduled to fly four sorties per day and drop between twenty and thirty weapons during the deployment. The deployment was in preparation for initial operational capability (IOC), planned later during the year. The IOC

of the USMC had been criticised heavily and its combat capability put in question by the Director of Operational Test and Evaluation (DOT&E); 31st Test and Evaluation Squadron played an integral role leading up to the IOC. It remained to be seen if IOC for the USAF would be under similar criticism if it were declared with the Block 3i software. For the same purpose, the Desert Pirates took part in a Green Flag exercise with F-35A Lightning IIs from the squadron playing the US Army's primary close-air-support (CAS) platform during Green Flag 15-08. Two F-35s took on a primary exercise role as CAS providers, penetrating a contested and degraded battlespace and awaiting calls for fire from ground commanders below.

ITF Patuxent River VX-23 'Salty Dogs' (SD)

Naval Air Station (NAS) Patuxent River is the US Navy's answer to Edwards AFB and so it was inevitable that the F-35B and F-35C would be tested there. Although Patuxent River was the main test facility for the STOVL and CV F-35s, the first aircraft was not due to arrive before 2007 as Patuxent River was to be the last unit within the ITF to receive aircraft. Work, however, was initiated quickly because a complete new facility was being built for the F-35 test unit; the $24-million-dollar facility was handed over in January 2006. The weight problem caused the first aircraft to arrive later than planned and that first aircraft, an F-35B, was re-scheduled for arrival early 2008 with the first production representative aircraft due to arrive after initial flight testing at Fort Worth.



BAE System test pilot Graham Tomlinson was the first pilot performing a vertical landing in BF-1. He could have been part of the X-35 legacy as well but handed that honour over to Simon Hargreaves. (*Lockheed Martin*)

The STOVL engine problems caused initial STOVL testing to be delayed and therefore the arrival of the first F-35B, set for December 2008, at Naval Air Station (NAS) Patuxent River was again delayed.

Preparations for the STOVL testing continued, however, as the USMC would operate the F-35 from expeditionary airfields. Such airfields are built using AM-2 matting and the concern was the exhaust heat of the engine causing erosion. Notwithstanding this worry a 96 x 1,900-foot runway was built with the material. AM-2 matting was also used in connection with a ski-jump ramp replicating those from Royal Navy aircraft carriers, the ski jump ramp having a 12-degree angle. These were installed during spring 2009 in preparation for the arrival of the first STOVL aircraft. The mock ski jump is 150-feet long, with a 15-feet high 'lip' for aircraft launch. Operationally, a ski-jump ramp is more fuel efficient than catapult launching. However, the ski ramp can be used only by smaller fighters and places restraints on space for recovery of aircraft onboard the carrier. It was on 15 November 2009 that BF-1 arrived at Patuxent River and it was there to stay as opposed to the irregular visits from AA-1 to Edwards. Due to a

technical glitch, test flying from Patuxent River was initiated only on 23 December. The effort to speed up flight testing before year end or rather giving the test force a better position to start with in 2010 resulted in the second aircraft, BF-2, arriving at Patuxent River only three days later. Flight tests were to increase although unexpected small parts failures dogged the test tempo. BF-1 and BF-2 were joined by BF-3 and BF-4 but the flight-test programme stayed behind the schedule set for 2010. In contrast, the STOVL test force flew more flights than were accumulated in the previous two years. Graham Tomlinson flew BF-1's fiftieth mission 25 June 2010. BF-1 was the only aircraft equipped with sensors to perform vertical landings, of which so far he had performed only one. Some proof of progress was the hundredth flight test out of Patuxent River, made in BF-3 on 21 August 2010 by Lockheed Martin test pilot David 'Doc' Nelson.



VX-23 was the main test unit at the Integrated Test Force. But the VX-23 involvement in the Joint Strike Fighter programme dates back to the Concept Demonstration Phase.

More than eleven years before Colonel Art 'Turbo' Tomassetti had flown the X-35. He was one of the test pilots to fly all variants in the concept demonstrator phase and had been in several posts still involved in the programme. On 3 April 2012 he became the only pilot to have flown both the X-35 and the F-35B when he strapped himself into BF-4. Vice commander of 33rd Fighter Wing at Eglin, he flew his first mission in the F-35B from Patuxent River.

The Force Development Evaluation Unit and Weapon School at Nellis 422nd Test and Evaluation Squadron 'Green Bats' (OT)

USAF policy requires implementation of a force development evaluation (FDE) programme and weapon school training of all new aircraft. After development testing is completed, this task is performed at Nellis AFB. For this reason, Nellis is one of the first bases to receive new aircraft that are planned to enter the USAF inventory. For the FDE it was planned that Nellis AFB would receive twelve F-35A aircraft; for weapon school training an additional twenty-four F-35s were planned to be based at Nellis AFB. The first F-35 Lightning II was scheduled to arrive in 2012 with the last of these thirty-six F-35s arriving ten years later by 2022. The first F-35 was delayed until 2013 and the first two F-35As, AF-21 and AF-22, finally arrived on 6 March for 422nd Test and Evaluation Squadron. A week later a further two aircraft were flown from Fort Worth to Nellis but only one of them made it to Nellis as the other had to divert to Lubbock International Airport when an emergency light came on in the cockpit. This aircraft was flown to Nellis a few weeks later. These aircraft are part of 422nd Test and Evaluation Squadron 'Green Bats', whose motto is 'Innovate, Test and Teach'. The squadron was due to receive another eight aircraft which would, initially, be used to support development and operational testing. The 'Green Bats' were slightly different from other squadrons in the USAF in having all the other fighter aircraft in the force's inventory: they operated the F-16C, F-15C, A-10 and the F-22. With the full complement of F-35s they were due to have a total of fifty aircraft. As with 31st Test and Evaluation Squadron, 422nd Test and Evaluation Squadron is a part of 53rd Wing. The first aircraft were Block 1B aircraft, limited only to training flights with a very restricted flight envelope. The Green Bats were to develop tactics, techniques and procedures (TTP) for the young pilots.

The training unit or the Integrated Training Center (ITC)

There was a lot of competition as to which base should train operational pilots on the Lockheed Martin F-35. The reason was two-fold: this was a good function and would secure the base's future; active re-organisation had brought much insecurity. The re-organisation scheme was called base re-alignment and closure (BRAC) and was not related only to the introduction of the F-35, but was an examination of how the Navy and USAF could better use their bases and be more cost efficient. More bases were lining up

themselves to become the training unit's home in a move to secure their future towards the end of the BRAC, the recommendation from which was that Eglin AFB should be the training unit home base. Eglin was chosen because of the nearby range which was already used for weapon testing and was also useful for flight training. The choice of Eglin was confirmed on 10 August; personnel from Luke AFB with training experience would transfer to prepare the F-35 training syllabus and infrastructure. Training would not only be for the USAF but also for the US Navy, USMC and foreign partners – at least initially. Training for the three variants was supposed to be relatively simple, the sole difference being in the take-off and landing part of the flight envelope. The bit in between would be common due to the same avionics and the same systems. One major difference was that there was no two-seater and so experience from the F-22 conversion unit at Tyndal AFB would come in handy as well.



Patuxent River and Lakehurst were heavily utilised for carrier qualification tests by the VX-23. (*Lockheed Martin*)



A ceremony of the 422nd TES receiving its first aircraft. *Inset:* the patch of the Green bats. (*USAF*)



The badge of an F-35 driver from the 422 TES. (*USAF*)

58th Fighter Squadron 'Mighty Gorillas' (EG)

Not only was the base confirmed but the wing had also been selected: 33rd Fighter Wing. Then equipped with F-15 Eagles, 33rd's Eagles would be re-distributed among other fighter wings and 33rd would fall under aegis of Air Education and Training Command (AETC). The first commander was a

USAF officer, Colonel David Hlatky whose vice commander was USMC Colonel Art Tomassetti, who had been involved in the JSF programme as a USMC test pilot in the Lockheed Martin X-35 team. Tomassetti returned to the JSF programme a year after concluding the CDP flight evaluation in August 2001 and was the USMC JSF programme integrator from June 2002 until June 2004. His JSF programme experience made him the right man at the right place. In his own words the USMC decided to keep him close to the JSF programme.



An aircraft in the hangar at Eglin AFB with a full load out. The F-35A with a full load of 18000lb is rather impressive as there is no need for reconnaissance pods. Engine covers have unit badges. (*USAF*)



The Mighty Gorilla badge. (*USAF*)

The first F-35 Lightning was expected in early 2010, if the required environmental impact analysis (EIS) process had the right results. This analysis process was required by the National Environmental Policy Act and was designed to identify and assess potential environmental impacts of the proposed action. The first aircraft to arrive would be the two LRIP I aircraft which were due for delivery by January-February 2010 if they were not needed to speed up the delayed flight test programme either for operational or developmental tests.

On 4 October 2006 it was further announced that initial JSF locations, besides Eglin for primary maintenance and flight training, would include Nellis AFB, Nevada and Edwards AFB, California, for flight-testing; and Hill AFB, Utah, and Shaw AFB/McEntire ANGB, SC in the USA and Kadena Air Base in Japan, for operational squadrons. With this announcement, the Air Force was to initiate the environmental impact analysis process which could take up to two years. The analysis is not some simple document evaluating the environment effects on the base but also evaluates the effects on the areas where the training flights take place. In the analysis the effects on different animals, on schools, even the kind of people that visit the schools are evaluated to see what impact basing the aircraft will have on them. Noise levels were playing a rather big role since noise would have an effect on communities around the base. Two sets of flight-training alternatives were evaluated in the EIS and were studied over the entire spectrum of factors in the area in and around Eglin. The general public would be rather surprised about the thoroughness and broad angle of the EIS. The services anticipated that they would base a total of 107 F-35s at Eglin. General Davis outlined the schedule for the arrival of the first aircraft: the first F-35A for 58th Fighter Squadron ‘Mighty Gorillas’ was due by March 2010; the first F-35B for VMFAT-501 ‘Warlords’ was due by October 2010 and the first F-35C for VFA-101 ‘Grim Reapers’ was due by January 2012.



The US Navy was the last service to stand up its training squadron at Eglin. The flag ship of the VF-101 Grim Reapers is seen here over water near Eglin. The unit was rather short-lived as it was stood down after nearly six years of service. (*Lockheed Martin*)



The US Navy VF-101 Grim Reapers badge. (*US Navy*)

The record of decision initially allowed only fifty-nine aircraft divided over three squadrons, a USAF squadron with twenty-four F-35As, a US Navy squadron with fifteen F-35Cs and the third squadron from the USMC with twenty of the F-35B STOVL version. Further evaluation on the impact on the surrounding population was to be performed before additional F-35s

could be based at Eglin. Operational limitations due to noise levels were also put in effect on the first fifty-nine aircraft. Initially the numbers of aircraft arriving would be the most limiting factor on flying at Eglin but the restrictions would put planned training units for all three services in jeopardy. Noise levels, or rather anticipated noise levels, were a major concern around Eglin and Air Armament Centre commander Major General David W. Eidsaune, in an interview, confirmed reports that one of the test fleet F-35s would visit during spring 2009 for noise measurements. The visit would last up to four days and it was rumoured that AA-1 would be sent for the task. This was, however, not seen as sufficient by the authorities of the nearby town of Valparaiso. Rather surprising was that similar discussions were ongoing in the Netherlands where the arrival was still a couple of years away. AA-1 was indeed sent to Eglin AFB on 21 April where it spent a few days presenting itself in the air and on the ground. As if the noise problems were not relevant, or already solved, on 20 March 2009 a ground-breaking ceremony for the JSF academic training centre was held at Eglin. The first unit to stand up was the USAF 'Mighty Gorillas' during October 2009. The USMC unit to be based at Eglin AFB was Marine Fighter Attack Training Squadron 501 'Warlords', for which six marines were selected to train future F-35B pilots; one was a previous Top Gun instructor, Major Chad A. Vaughn, an operations officer with Marine Fighter Attack Squadron 314 at Marine Corps Air Station (MCAS) Miramar flying the F-18 Hornet. Four of the other pilots selected came from MCAS Yuma. VMFAT-501 Warlords stood up on 2 April 2010.

The ITC had to delay its actual acceptance of its first aircraft longer than expected caused by delays on the production line and with flight testing. But, by September 2010, a decision had been made that the development flight fleet required expanding, for which reason the two LRIP 1 aircraft would join the Integrated Test Force at Edwards before joining the ITC at Eglin. This would allow the flight envelope to be opened up and have put some more flight hours under the belt before regular pilots got their hands on the aircraft, giving the test team more time to iron out any problems. First flight of the LRIP 1 aircraft was now expected in the first quarter of 2011. This schedule was almost met as AF-6, the first Eglin-coded machine, took off for its first flight on 25 February. With AF-6 and AF-7 due to be delivered first to Edwards AFB to help out the delayed programme meant a further delay as a result of which the unit borrowed F-16s from 419th

Fighter Wing, the Air Force Reserve Command unit at Luke AFB, Arizona on which missions were flown during March 2011. Four months later the moment for which most people at Eglin had been waiting arrived when the first production F-35 landed. AF-9 was the first F-35 delivered to Eglin and was flown by the first USAF F-35 line-qualified pilot, Lieutenant Colonel Eric Smith of 58th Fighter Squadron, 'Mighty Gorillas'. New pilots required each HMD, as explained in the chapter about mission systems (p. 26), and had to undergo a 3D head-scan and other measurements in the VSI Pilot Fitting Facility (PFF) at Eglin AFB; VSI later became Rockwell-Collins – Elbit Systems of America (ESA).

Eglin AFB would train not only pilots but also maintenance staff. For pilots and maintenance staff a new Academic Training Centre (ATC) was set up, part of which was a brand new weapons loading trainer which was delivered in 2011. The Mighty Gorillas were not allowed to fly their aircraft although they received six during 2011. This equated to the delivery of all the low-rate initial production Lot II CTOL aircraft. Flight training could not be performed as safety of flight was a concern. Officials at the Aeronautical Systems Centre issued a military flight release on 28 February 2012, allowing the F-35A Lightning II fighter to begin initial operations at Eglin.

The first three STOVL production aircraft were flown during 2011 but the 'Warlords' would have to wait for their first delivery until 2012. The first flight of an operational aircraft occurred with a test pilot, Lieutenant Colonel Eric Smith, Director of Operations for 58th Fighter Squadron, from Eglin on 6 March but was cut short by a fuel leak. The next flight occurred a week later, on 13 March, in the hands of US Marine Corps Major Joseph Bachmann. To maintain proficiency, and add an operational milestone, Lieutenant Colonel Eric Smith, in preparation for flight training, air refuelled for the first time from Eglin AFB with a KC-135R Stratotanker from 155th Air Refuelling Wing. Flights were coming in slowly and when it was announced that the STOVL version had flown for the first time out of Eglin, piloted by USMC Major Joseph Bachmann it was the forty-eighth flight out of Eglin, not counting AA-1 flights. So far all flights out of Eglin had been flown by two test pilots, USMC Major Joseph Bachmann and USAF Lieutenant Colonel Eric Smith who would soon be joined by vice commander of 33rd Fighter Wing, Colonel Art 'Turbo' Tomassetti, and USAF Lieutenant Colonel Lee Kloos, commander of 58th Fighter

Squadron. USAF Lieutenant Colonel Lee Kloos was the first service pilot not qualified as a test pilot to fly the F-35. The aim was to have four instructor pilots flying at Eglin by the summer 2012 so that the F-35's operational utility evaluation (OUE) could begin. The OUE was only performed for the USAF; the USMC had decided that they could forego OUE and start training without it. The name 'operational utility evaluation' had an ugly ring to it as to date only the Bell/Boeing V-22 Osprey had been required to undergo such evaluation. The OUE was initiated on 10 September 2012.



Australian aircraft from 3rd Squadron flying in formation with F-18s that were soon to be replaced. (*Common wealth of Australia Department of Defence*)

Flights were increasing from Eglin, a sign that confidence was being gained. Eglin accomplished 500 sorties in 238 days cutting the time between each milestone sortie:

- 100th sortie – 12 July - accomplished in 123 days
- 200th sortie – 24 Aug. - accomplished in 44 days
- 300th sortie – 21 Sept. - accomplished in 30 days

- 400th sortie – 16 Oct. - accomplished in 25 days
- 500th sortie – 2 Nov. - accomplished in 16 days

After that the flight rate was stated to be about 100 flights every nine flying days but this was a bit optimistic since, on 11 January 2013, Eglin-based aircraft reached 1,000 flight hours during a total of 772 flights.

OUE was performed on Block 1A software from 10 September to 15 November 2012. During this period four pilots were trained, all experienced fighter pilots, three of whom were experienced F-16 pilots and one an experienced A-10 pilot. Those four pilots went through three phases of flight training.

Dates	**Phase of Training**	**Events**
10-25 September 2012	Academics	61 events (in-processing, equipment issue, classrooms, approx. 130 hours of instruction)
26 September-25 October 2012 (21 training days)	Simulator training	14 simulator events (including one emergency procedures)
26 October-14 November 2012	Flight training	1 ground (taxi) event and 6 flights

The evaluation was to take some time. OUE was declared a success on 17 December 2012, allowing initial training to begin. The first training class would begin with six pilots in January 2013. Although OUE was performed on Block 1A software, pilot training would begin on Block 1B software. The Block 1A syllabus was limited to six flights for every pilot but the Block 1B would be enhanced slightly with fusion and tactical data but still without weapon employment, which was expected to come with Block 2B – at least two iterations away. The OUE report was released on the POGO website and referred to the major restrictions that imposed on OUE because the test programme was in its infancy. VMFAT-501 ‘Warlords’ were planning to move to MCAS Beaufort in 2014.

The first carrier version arrived at Eglin in 2013 when VF-101 'Grim Reapers' received their first F-35C on 22 June, almost a year and a half late. It was flown in by US Navy Lieutenant Commander Chris Tabert and was followed by the first flight from Eglin by Tabert, one of their instructor pilots, 15 August. As the US Navy was one of the slowest buyers of the F-35, compared to the USMC and USAF, VF-101 Grim Reapers' activity was also on a slower burner. The USMC had some of its F-35Cs delivered to Eglin and integrated into the US Navy Fleet Replacement Squadron.

VF-101 Grim Reapers deployed for the first time with four F-35Cs to NAS Fallon for tactical development and evaluation, together with staff from the Naval Air Warfare Development Centre. The purpose of the deployment was to look at integration of fourth-and fifth-generation fighters. The deployment in September was with aircraft recently upgraded to Block 2B software which increased allowable AoA, g allowance to 6g and speed up to Mach 1.2.

The second deployment by VF-101 Grim Reapers was for the conventional weapons technical proficiency inspection (CWTPI) at NAS Lemoore. The Grim Reapers had to prove their capability to employ air-to-ground weapons in a realistic, i.e., operational, environment. The only air-to-ground munitions that were cleared on Block 2b software were the GBU-12 and the GBU-31. VF-101 deployed with six aircraft and during the two-week deployment managed to drop thirteen 500lb GBU-12 bombs and thirteen GBU-31 JDAM units over the Nine Palms range.

60th Fighter Squadron – 'The Fighting Crows' (EG)

Both the USMC and US Navy decided that Eglin AFB was not really suited for their training requirements and moved or disbanded their units. The idea of combined training of pilots had ended. The facility was still prepared to house a total of fifty-nine F-35s which opened the door for the USAF to increase its training capacity, for which reason the Fighting Crows were re-activated on 20 August 2021. The 60th Fighter Squadron had been de-activated since 1 January 2009. Prior to which it had been operating the F-15 Eagle.

Other training units

The USAF looked at alternatives for training since Eglin AFB was unlikely to base the required 107 aircraft originally planned. A USAF training

facility was thought to be required and therefore the USAF looked at different options for a pilot training centre: Luke AFB (the preferred option), Tucson, Boise, Roswell and Holloman. Each had a different background and were evaluated for their capability to fulfil the mission with minimum impact on the environment. For the selection, an environmental impact study was performed. Although the preferred option included basing seventy-two aircraft at the pilot training centre, the draft environmental impact study included alternatives from twenty-four to 144 aircraft with increments of twenty-four aircraft being evaluated. The options of twenty-four and forty-eight aircraft were, according to the USAF, not cost effective but were included in the draft environmental impact statement.

Luke AFB had a long history of training pilots. It was the main training base for F-16 pilots and support from the surrounding community leadership was immense. It was little surprise therefore that Luke was selected. The first unit to receive the F-35 would be 61st Fighter Squadron.

61st Fighter Squadron 'Top Dogs' (LF)

The first F-35 arrived on 10 March 2014 and from then instructor pilots started to prepare themselves for the task of training not only US F-35 pilots but also partner nations. The first partner nation aircraft to arrive at the base were for the Royal Australian Air Force (RAAF) on 18 and 22 December 2014. The first flight of a locally-trained pilot took place on 18 March 2015, the student pilot beings Brigadier General Scott Pleus, 56th Fighter Wing commander who was not part of a class. The first official class of student pilots was scheduled to begin at the Academic Training Centre, a 145,000-square-foot two-storey state-of-the-art training centre, on 4 May 2015.



A Dutch F-35 from 323 Squadron with support of Draken international aircraft and a Dutch F-16 from Tucson AFB.

All pilots for training were experienced, transferring from F-16, F-15 and A-10 units. At some point, this had to change. That change came about when the first six pilot students entered the initial qualification course (IQC). The IQC meant that a pilot who came out of pilot training school without any fighter aircraft experience went straight to the F-35. The IQC started in early December 2016 with the first announcement approximately two months later when the students were making their first flight on 8 February 2017. For the first two months the six pilots had been undergoing classroom academic instruction and were now ready to fly. Prior to the first flight in the Lightning II, each student completed sixteen simulator events and over the course of the programme forty-six simulator events occur. The F-35 simulator provides a highly realistic and immersive experience that prepares each pilot for the first sortie in an aircraft. All six pilots qualified six months later, marked by a ceremony at Luke AFB.

During the course, Lockheed Martin instructor pilots taught the academic phase, consisting of more than 156 events totalling 308 hours. Academics focused on pilots learning basic aircraft systems, emergency procedures, local area procedures, mission systems, weapons and tactical employment.

'Each student flew at least forty-eight sorties totalling seventy-seven hours,' said Lieutenant Colonel Rhett Hierlmeier, 61st FS commander, 'starting with the basics of taking off and landing, continuing across the full spectrum mission sets, and culminating in our Capstone phase of high-end employment. Along the way, our students dropped inert and live laser-guided GBU-12s, refuelled from a KC-135 day and night, and flew low-altitude step-down training.'

62nd Fighter Squadron – 'Spikes' (LF)

Like 61st Fighter Squadron, 62nd was an F-16 training squadron that was de-activated on 2 July. it activated with its first two F-35s which landed at Luke AFB on 10 August. The unit would be responsible for training pilots from partner nations Norway, Italy and Australia.

Co-operation with the partner nations within 62nd Fighter Squadron was also displayed during one of the biggest exercises when 62nd Fighter Squadron was invited to join Red Flag. It was not only the American contingent who went but also the instructor pilots of the Norwegian and Italian air forces.

63rd Fighter Squadron Panthers (LF)

With Luke AFB the F-35 training base, the third squadron to receive the F-35 was 63rd Fighter Squadron which had been flying F-16s but had been de-activated on 30 September 2009. The unit was re-activated in a ceremony at Luke AFB when Lieutenant Colonel Matthew Vedder, previously 62nd Fighter Squadron director of operations, became its commander on 1 August. The first F-35 to arrive at Luke AFB was flown in by Vedder on 20 March. The F-35 was expected to train pilots from partner nation Turkey. First sorties under 63rd Fighter Squadron occurred on 2 October when the squadron had received a total of five F-35s of twenty-four due to be delivered.



Royal Norwegian Air Force from the 62nd Fighter Squadron participating in the Red Flag 21-2 exercise. (*Joint Program Office*)

944th Operations Group Detachment 2 'Ninjas' (LF)

This unit was responsible for training the initial cadre of instructor pilots for the Republic of Korea Air Force (ROKAF) and Japan Air Self-Defense Force (JASDF). The exact date when the Japanese pilots commenced their training is not known, but the JASDF's Lt Col Nakano completed his first F-35A flight on February 7, 2017. Three months later, the 944th OG Det 2 'Ninjas' bid farewell to the Japanese graduates. The JASDF pilots were trained to instructor level before being posted back to Japan to train F-35A pilots in-country.

Following the departure of the Japanese, the unit began preparing to accept South Korean students. The first ROKAF pilot to fly the F-35A was Maj Kiyun Jung, who took to the skies over Arizona on July 20, 2018. The first two ROKAF aircraft – serials 18-005 (15-5225) and 18-006 (15-5226) – arrived at Cheongju Air Base in South Korea on March 29, 2019, after the training of the instructor pilots was completed. The 944th OG Det 2 comprises both active duty and AFRC airmen, civilians and contractors, and continues to train pilots on both the F-16 and F-35. According to some sources it also has the responsibility for training Israeli pilots.

308th Fighter Squadron – 'Emerald Knights' (LF)

The 308th Fighter Squadron, known as the Emerald Knights, was an F-16 training unit which was de-activated on 25 June 2015. The Emerald Knights were to integrate the Dutch training unit as well and at a later stage also the Danish training element. Eight Dutch F-35s were expected to find their long-term home at Luke AFB with the unit expected to stand up in autumn 2018. The first F-35A expected to join the unit straight off the production line was flown for the first time on 19 September. AF-164 (15-5189) was delivered to Luke AFB in October 2018 and, on 30 November 2018, a ceremony was held to stand up the 308th officially. For the occasion AN-01 and AN-02 were flown in from Edwards AFB. Lieutenant Colonel Robert 'Phantom' Miller took officially command of 308th Fighter Squadron.

The first two Dutch instructor pilots started their training at the Academic Training Centre at Luke in January 2019 with the first Dutch aircraft arriving there shortly after a formal roll-out ceremony at Lockheed Martin. The first Dutch F-35, AN-03, arrived at Luke AFB on 2 February 2019 and was followed within a week by AN-04. On 26 February the instructor pilots made their first flights when AN-03 also performed its first sortie from Luke. Milestones for the Dutch were following up fast as AN-04 had its training sortie on 2 March.

AN-06 arrived on 7 March and, five days later, was joined by AN-07 which, with tail registration F-007, received a special James Bond logo on the tail. The sixth Dutch F-35 due to join the 308th Fighter Squadron flew for the first time from Fort Worth on 17 April but was planned to join 323rd TES at Edwards for operational test and evaluation for a short period before joining Luke AFB. AN-08 arrived at Luke on 26 July 26, as the hundredth F-35 delivered there.

Software upgrades were part and parcel of the most software-intensive aircraft in the world with one of the first upgrades for the Dutch F-35s taking place over the weekend of 11-12 April 2020. Their F-35s received software Block 30 production tape 4 (30P04).

The first two Danish pilots arrived in 2020 to train for the role of instructors for 308th Fighter Squadron. The first Danish pilot was identified only as a lieutenant colonel with the call-sign 'Kin'. It was the second pilot, with call-sign 'Mon', who flew the first Danish F-35 from Luke AFB on 5 May 2021. In less than a year, Danes had accrued 1,000 flight hours on their

four F-35s with ‘Kin’ piloting the machine that passed the 1,000-hour mark on 4 April 2022.

310th Fighter Squadron The Top Hats (LF)
The sixth unit to stand up at Luke AFB was the 310th fighter squadron. This unit was previously operating F-16 and training pilots on that aircraft. On June 2, 2023 U.S. Air Force Col. Matthew Johnston, 56th Operations Group commander, hands the guidon to U.S. Air Force Lt. Col. Adam Vogel, 310th Fighter Squadron commander, at an assumption of command ceremony. Three days later it was Lt. Col. Adam Vogel, that flew the first mission in an F-35A (AF-22/10-5010).

312th Fighter Squadron the Scorpion (LF)
On November 1, 2019 it was announced that Luke Air Force Base had been selected for training the Belgian F-35 pilots The Fighter Squadron which stood up June 1, 2023 was a joint US – Belgian unit. The Belgium Air Force staff was really hyped about getting the F-35 as they already had their F-35 patches for the 349 Squadrons made in autumn of 2023. One of them even showed a few of the unofficial designs for the 312 Squadron patch on the mobile. The squadron commander is American Lieutenant Colonel Jason Wall, with Belgian Air Force pilot Major Pierre-Yves Libert as his deputy. The fact was that the first Belgian F-35A was due to roll off the production line in 2023 and be delivered before the year end however delays with the development of TR-3 were rumoured to prevent handover as the Belgians would not accept the aircraft until development would be complete. On October 10, 2023 an image was shown with the Belgian AY-01 on the production line getting its engine fitted. The AY-01 was rolled out and presented to the Belgian customer on December 10, 2023.

USMC
The USAF was the biggest customer but the USMC, in more of a hurry to get their hands on a new aircraft, was waiting impatiently for the F-35 Lightning. The ‘Moonlighters’, or Fighter Attack Squadron 332, based at Cherry Point stood down on 1 April 2007. The unit was flying the F/A-18 but the aircraft was ageing and with related manpower problems the unit was forced to transition to cadre status which meant that it would re-activate when the F-35 became available. Interestingly, at Farnborough

2008 a USMC general stated that, at that very moment, some officers of the USMC based in Quantico, Virginia, were selecting the person who would be leading the first F-35 squadron.

The Marine Corps active duty squadrons and reserve squadrons would each have up to sixteen F-35Bs while a pilot training centre (PTC) would have twenty in its inventory. OT&E squadrons would each have six aircraft. The USMC was dividing its needs for basing over east and west coast departments, the west coast operating the OT&E units and the east coast the PTC.

For the west coast department there were two bases requiring aircraft replacement: Marine Corps Air Station (MCAS) Miramar and MCAS Yuma. On 15 January 2009 the USMC published its notice of intent to initiate replacement of its current fighter aircraft fleet with the F-35 Lightning II. At the time MCAS Miramar was home to seven active-duty squadrons equipped with F/A-18A/B/C/Ds and the one training squadron, Marine Fighter Attack Training Squadron (VMFAT) 101. The basing proposals, anticipated to take twelve years to implement, were expected to be initiated in 2012 with a requirement for up to 182 aircraft. The options offered for public debate were:

MCAS	**Miramar**	**Yuma**
Alternative	**Number of squadrons**	**Number of squadrons**
1	5 Active Duty + 1 Reserve	5 Active Duty + 1 OT&E
2	3 Active Duty + 1 Reserve	7 Active Duty + 1 OT&E
3	7 Active Duty + 1 OT&E	3 Active Duty + 1 Reserve
4	1 Reserve + 1 OT&E	10 Active Duty
5	10 Active Duty	1 Reserve + 1 OT&E

For the east coast department there were two bases in contention: MCAS Beaufort and MCAS Cherry Point. When the process for the environmental impact statement was initiated by the USMC on 15 January 2009, MCAS Beaufort had seven active-duty squadrons equipped with F/A-18 A/B/C/Ds.

MCAS Cherry Point was home to eight active-duty squadron with four equipped with AV-8B Harriers and four with EA-6B Prowlers. The EIS confirmed the USMC intent to not only replace its AV-8B and F/A-18 fleet with the F-35B but also the EA-6B Prowlers. The number of F-35s to be acquired under current planning for the east coast fleet was up to 216 aircraft.

MCAS	**Beaufort**	**Cherry Point**
Alternative	**Number of squadrons**	**Number of squadrons**
1	3 active duty + 2 PTC	7 active duty + 1 reserve
2	2 PTC	10 active duty + 1 reserve
3	7 active duty plus 1 reserve	3 active duty + 2 PTC
4	10 active duty + 1 reserve	2 PTC
5	2 active duty + 2 PTC	8 active duty + 1 reserve

The USMC selected four Yuma pilots in January 2009 to become the first USMC instructor pilots at Eglin AFB. It was clear that more were required and would have to be selected prior to arrival, for which reason the USMC issued a solicitation to fulfil eight slots for F-35B pilots. The solicitation was issued on 9 June 2009, with one place for an OT&E pilot, one for a Defence Contract Management Agency (DCMA) acceptance pilot and six instructor pilots. The selected pilots were to report to either Marine Fighter Attack Training Squadron 501 at Eglin or the DCMA, Lockheed Martin in Fort Worth.

The applicants were to be either AV-8B Harrier-, F/A-18 Hornet- or EA-6B Prowler-qualified pilots with at least 500 flight hours, plus a division flight lead or instructor designation. At this stage it was planned that all the above-mentioned USMC aircraft would be replaced with the F-35B by 2024. Delays with the F-35B and talks with the US Navy caused a change in direction for the USMC which announced that it would acquire eighty F-35C aircraft and would operate them from US Navy aircraft carriers.

Yuma Marine Corps Air Station
VMFA (AW)-121 – 'Green Knights' (VK)

The first operational unit on the F-35 would be VMFA (AW)-121 Green Knights at Yuma, which would receive aircraft from production lot IV. The problem encountered with STOVL operations during early flight test in 2010 and 2011 required design changes and it was not clear if these changes could be incorporated fast enough to allow for operational use. This could mean that the first unit to receive its aircraft would have to fly only in CTOL mode. Shortly before VMFA (AW)-121 was due to receive their first F-35B aircraft, another problem arose. The autonomic logistics information system (ALIS) software Block 1.3 had to be ready for delivery for the service since delivery of aircraft without a functioning ALIS would make no sense, according to Lieutenant General Christopher C. Bogdan. Certification of ALIS Block 1.03 was initiated by AF-7 from Edwards AFB on 4 December; this was one of three flights required for certification.

The first F-35B aircraft arrived at Yuma on 16 November 2012, flown in by pilot instructor Major A.C. Liberman, followed shortly by the arrival of three more F-35Bs and an official ceremony to celebrate a new beginning for Yuma and the Green Knights. By year end three F-35Bs had been delivered. The F-35B did not fly from Yuma until 20 February 2013 when BF-20 was taken for its first outing from Yuma Air Station. A couple of days later the entire F-35 fleet was grounded. Embarrassingly, Lockheed advised of the first operational vertical landing at Yuma. The first vertical landing was, however, performed by a USMC test pilot. The F-35B was to be presented to the Europeans for the first time in 2014 at the Royal International Air Tattoo and Farnborough International Air Show. The aim was to fly one of the British and three USMC F-35Bs to the US, but a string of technical problems and a fire caused by an engine in AF-23 at Eglin AFB caused the entire fleet to be grounded. The staff of the Green Knights were present at Fairford selling souvenirs for an aircraft that was not there.

The Green Knights were the unit that had to reach IOC by July 2015, the objective date, but at the latest by December 2015, the threshold date. IOC for the USMC meant the stage when the first operational squadron was equipped with ten to sixteen Block 2B-equipped aircraft, and US Marines were trained, manned and equipped to conduct CAS, offensive and defensive counter air, air interdiction, assault support escort and armed reconnaissance in concert with Marine Air Ground Task Force resources

and capabilities. Preparations for initial operational capability included demonstrations of ship-board operations, weapon release and ALIS operation. Six F-35Bs were sent to the USS *Wasp* for OT-1. Shortly before the target date six F-35Bs were used over Restricted Area 2507 in south-eastern California to employ both inert and high-explosive munitions. In total, eighteen guided bomb unit (GBU) 12s and twelve GBU-32s were employed during the exercise. Fourteen pilots got the opportunity to participate in the exercise which took place from 22 to 26 June.

According to Chief Warrant Officer 2 Matthew Beard, ordnance officer with VMFA-121, the munitions employed by the pilots were the same as those dropped by legacy Marine Corps fixed-wing aircraft, but the dimensions, installation and technology that targeted and employed them were different. 'The training was hugely successful,' said Beard. 'We showed that we could employ the weapons that were supposed to be employed, and that we have sound weapon employment systems at this point.'

In accordance with the guidelines set by US Marine Corps Deputy Commandant for Aviation Lieutenant General Jon Davis, fleet F-35Bs need to demonstrate the ability to employ ordnance for the squadron to declare IOC. 'The ordnance employment was one of the last pieces the squadron needed for the IOC declaration,' said Major Brendan Walsh, operations officer and a pilot with VMFA-121. 'This training validated the simulated procedures pilots have been training for, and gave us confidence in the jet's ability to perform with real weaponry.'

The unit was declared 'initial operational capable' in July. Soon after, however, the first cracks showed with news that the deployment to sea was not considered such a success by the Director of Operational Test and Evaluation. His yearly report made it clear that the declaration of IOC was more or less just a political declaration: the F-35 had so many deficiencies at the time that it could not be effective in combat without help.

VMFA-121 Green Knights moved to MCAS Iwakuni, Japan, arriving on 18 January 2017. Iwakuni is located on mainland Japan, south of Hiroshima. This allowed General Bogdan to state in front of the House Armed Services Committee that the F-35 was flying in four countries: Israel, Italy, Japan and the USA. F-35Bs from VMFA-121 Green Knights participated in the Northern Edge 2017 exercise in Alaska. Despite these

reports, pilots who flew the F-35 were very clear that if they wanted to go into combat and choose a platform they would select the F-35.

Tensions in the Korean peninsula were increasing and the F-35 helped make a couple of statements by flying to South Korea and back. North Korea was a provocation on its own, launching an intermediate-range ballistic missile that over-flew Japan on 28 August 2017. In response the Green Knights joined Japanese F-15Js and a B-1 Bone from Anderson AFB, Guam, and flew to South Korea where the Japanese F-15Js were replaced by South Korean F-15Ks and they all proceeded to drop live weapons at the ROK Pilsung Range training area.

From VMX-22 – 'Argonauts' (MV) to VMX-1 – 'Flying Lions' (MV)

Marine Operational Test and Evaluation Squadron 22 was charged with testing the full range of Marine aviation combat element (ACE) operational test and evaluation, including MV-22, CH-53E/K, F-35B, UH-1Y, AH-1W/Z, command and control systems and unmanned aerial systems. VMX-22 is headquartered at MCAS Yuma, with detachments at MCAS New River, NC, West Palm Beach, FL and Edwards AFB. VMX-22 had one of the most experienced pilots, Major Richard Rusnok, who was among the first USMC pilots to fly the F-35. He was used for a publicity act, the first vertical landing by the Green Knights. He piloted BF-19, an aircraft assigned to the Green Knights, to land vertically. However, after modernisation, the aircraft would join VMX-22 on 9 October 2014

BF-17 and BF-18, which were based at Edwards to help out with SDD avionics trials, were also part of the developmental test of 461 FLTS. A milestone occurred later when one of the previous VMFA-121 aircraft landed at Edwards AFB and became the first aircraft handed over to Marine Operational Test and Evaluation Squadron 22 (VMX-22). VMX-22 'Argonauts' took delivery of their first F-35B on 9 October 2014; the remaining three were due within the following two months. The USMC was counting on an IOC by 2015 which seemed very difficult to achieve at the time. The squadron's designation changed to VMX-1 Flying Lions on 13 May 2016.

VMX-1's F-35B detachment had been involved in multiple high-profile events including:

- Block 2B, 3i, and 3F Developmental Test support

- Block 2B Air-to-Surface Weapon Delivery Evaluation
- Global Position System testing
- A deployment to the United Kingdom in support of the Royal International Air Tattoo and Farnborough International Air show.

This was followed by a deployment to support developmental and operational tests. Three F-35B aircraft and seventy-five US marines from Marine Operational Test and Evaluation Squadron 1 F-35B detachment at Edwards AFB, with twenty-one test personnel from the JSF operational test team at Edwards deployed to Eglin AFB, from 9 August to 1 September 2016 to complete operational test missile shots of the AIM-120 advanced medium-range air-to-air missile.

The detachment completed multiple engineering runs in preparation for the expenditure of five AIM-120 missiles and one GBU-12 Laser-guided bomb. The operational test team developed complex air-to-air and air-to-ground scenarios and the F-35 weapons system performed as expected to deliver weapons on target. On day one of live-fire testing, the team was able to shoot two missiles on two separate test set-ups within twelve minutes – an exceptional level of efficiency in a test environment. Another test mission involved an F-35B dropping a GBU-12 and supporting it with Laser guidance while simultaneously engaging a QF-16 drone. Both weapons were successfully guided to their targets.

VMX-1 played a major role in operational testing during DT-III with the F-35B to the USS *America* during October and November 2016.

VMFA-211 – 'Wake Island Avengers' (CF)

VMA-211, known as the Wake Island Avengers, flying AV-8B Harriers, had seen a lot of action during the war on terrorism but returned home to the US by April 2015 to Yuma. It ceased operations with the AV-8B a little over a year later on 6 May, was re-designated VMFA-211 and, on 9 May 2016, received its first two F-35Bs. The unit was training hard to become operational and to see if they were ready to be to Red Flag 2017-3. Red Flag 17-3 was held from 10 to 28 July 2017 and the unit deployed ten F-35Bs and a total of 250 marines to the exercise.

VMFA-211 embarked on the USS *Essex* (LHD 2) as part of 13th Marine Expeditionary Unit. During this deployment in 2018 the Wake Island Avengers became the first US unit to drop a precision-guided bomb on a

Taliban target in Afghanistan. The first use of the F-35B over Afghanistan took place on 27 September 2018. VMFA-211 was also the first USMC unit to deploy on Carrier Strike Group 21 (CSG-21) HMS *Queen Elizabeth*.

VMFA-122 – 'Flying Leathernecks' (DC)
VMFA-122 was a unit, then known as the Werewolves, flying the F-18C out of MCAS Beaufort. The transition from the F-18C to the F-35B was initiated on 14 November 2017. The transition took place under the VMFAT-501 but the unit moved to MCAS Yuma. The first operational flight from by VMFA-122 'Flying Leathernecks', as they were renamed, took place on 29 March 2018 from Yuma by the commanding officer Lieutenant Colonel John P. Price. In 2019 VMFA-122 became one of the first units to participate in Red Flag exercise 19-3. VMFA-122 performed the first landing on the fourth LHD and soon after became F-35B qualified. The first landing took place on 11 January 2022.

Marine Aviation Weapons and Tactics Squadron One (MAWTS-1)
A unit with its history dating back to 1978, according to the USMC history of MAWTS-1. In 1975 a study group was formed at Headquarters Marine Corps to determine requirements for the enhancement and standardisation of aviation training. A series of recommendations, labelled as numbered projects, was made to the head of Marine Aviation and to CMC in early 1976. Project 19 recommended establishment of the weapons and tactics training programme (WTTP) for all Marine aviation. The cornerstone of WTTP was the development of a graduate-level weapons and tactics instructor (WTI) course and the placement of WTI graduates in training billets in every tactical unit in Marine Corps aviation. A WTI course takes seven weeks: an academic phase lasting 2.5 weeks, followed by the flight phase lasting 3.5 weeks, the course is then completed with a final exercise, FINEX, in the last week. During the academic phase students begin with general air and ground combat and risk mitigation lessons before moving into more and more specialised training for their specific platform. The flight phase begins with the students planning and executing missions for their platform alone at first, then into fixed-wing or rotary-wing groups and then the entire air element.

Due to the overwhelming success of the consolidated WTI courses, the Commandant of the Marine Corps commissioned Marine Aviation Weapons and Tactics Squadron One at MCAS, Yuma, on 1 June 1978. The MAWTS-1 organises two WTI courses per year. MAWTS-1 received other responsibilities in 1983. The aviation development, tactics and evaluation department (ADT&E) was established in June 1983 to co-ordinate the MAWTS effort of developing and evaluating tactics and hardware in all areas of Marine Corps aviation. In short, they were responsible for writing the tactics for every aviation platform in the USMC. People from all units are sent so that each unit has a subject expert who can become a teacher back at their unit.

The first time an F-35 unit participated was in 2014. The participation of the F-35 in WTI 2-14 was rather limited due to the capability of the aircraft. Flying only with early block aircraft, none of the combat capability was included and it was limited to strike so-ordination and reconnaissance (SCAR); the software load available at the time would have been Blocks 1B and 2A. From the critics' point of view it was unbelievable that they were gaining glowing references for those missions which critics put down to fear of career; it was early days in the programme's operational life.

Beaufort Air Station

VMFAT-501 – 'Warlords' (VM)

In December 2010 the Navy announced its decision to base three new active-duty F-35B squadrons and two pilot-training squadrons, eighty-eight jets, at the Beaufort Air Station. Infrastructure changes were estimated at US$351.8 million. One of the new infrastructure features was a vertical landing pad. The first F-35B was due to arrive in 2014 at Beaufort. As the first unit to establish itself was the VMFAT-501 Warlords from Eglin AFB, this was pretty easy going as the squadron already had some experience from operations at Eglin. VMFAT-501 Warlords transferred to Beaufort in July 2014 with the first F-35B arriving on 17 July. Three months later VMFAT-501 initiated pilot training from Beaufort. Integrated with VMFAT-501 was a British contingent that moved with VMFAT-501 from Eglin AFB. Besides the most obvious foreign participation the Italians, also a customer of the STOVL F-35B, joined for their training on the F-35B. It was not only pilots who were trained: aircraft were based there from both

countries. The first accident in which the ejection seat was used successfully occurred with an F-35B from VMFAT-501 at Beaufort.

VMFAT-502 – 'Nightmares' (WF)
At Beaufort the following F-18 Squadrons were based:

F-18A VMFA-115	Silver Eagles
F-18C VMFA-122	Werewolves
F-18C VMFA-251	Thunderbolts
F-18C VMFA-312	Checkerboards
F-18D VMFA (AW)-224	Flying Bengals
F-18D VMFA (AW)-553	Hawks

It was just a matter of time before some of these units would transfer to the F-35B. On 26 June 2020 the next unit at Beaufort was re-designated and stood up. The former Marine Fighter Squadron 513 'Nightmares' were re-designated VMFAT-502 Nightmares and as such became the second USMC Fleet Replacement Squadron. In December 2021 relocated to MCAS Miramar to take F-35B pilot training to the US west coast.

VMFA-314 'Black Knights' (VW)
The USMC had committed from the outset in the ASTOVL programme that it would replace all its fighter aircraft with a ASTOVL aircraft. This was not the political reality and they had to accept that they had to support the US Navy if they were to operate from Navy ships. As a result of the commonality, however, this was a small price to pay for the USMC. The first unit to actually receive the F-35C was VMFA-314 who were flying F-18 Hornets that were retired by 21 June 2019, after which pilots and maintainers started their conversion to the F-35C at NAS Lemoore. The first F-35C for the 'Black Knights', piloted by Marine Corps Lieutenant Colonel Cedar L. Hinton, commanding officer of VMFA 314 landed at MCAS Miramar. The unit still had to wait another two months for another milestone, certification of safety of flight which they received on 20 March 2020. That meant that could operate the F-35C without the oversight of VFA-125 'Rough Raiders' who provided them with conversion training from September 2019 to January 2020. IOC was declared on 1 December 2020 and would pave the way for the first shipborne deployment planned

for 2022. VMFA-314 flew out to the carrier to gain experience a couple of times during 2021 but it was not until 3 January 2022 that the unit deployed for the first time as a part of the United States Navy Carrier Strike Group 3 aboard the USS *Abraham Lincoln* (CVN-72).

First deployment included the following aircraft:

Construction number	Lockheed number	Tail number
169633	CF-38	VW-300
169635	CF-40	VW-302
Unknown	Unknown	VW-303
169640	CF-45	VW-304
169704	CF-48	VW-306
169788	CF-50	VW-312
169789	CF-51	VW-313
169790	CF-52	VW-314
169703	CF-47	VW-310?
169634	CF-39	VW-301?

VMFA-242 'The Bats' (DT)

The USMC was probably one of the most active services in upgrading its units. On 16 October 2020 this unit was stood up with relatively little fanfare at MCAS Iwakuni in Japan and would equip with the F-35B. With the same amount of fanfare this unit achieved IOC on 9 September 2021. It was the second USMC F-35 unit based in Japan. It was, however, the first unit to transition in Japan. A little short of a year after standing up, the unit was involved with an operational test, involving a Japanese ship, the JS *Izumo* (DDH-183), originally designed for helicopter operations. It has a similar deck to the American LHD in USMC service. Construction of the JS *Izumo* was initiated on 27 January 2012 and it was launched on 6 August 2013, followed by entry into service in March 2015. The *Izumo* had been prepared for helicopters, not for military fighters, and had to be modernised. With the deck modernised, the way was paved for USMC Lieutenant Colonel Robert Guyette to land his F-35B on the *Izumo* on 3 October 2021, the first time that a fighter aircraft had landed on a Japanese aircraft carrier

since the Second World War. It was a tremendous step for the Japanese Self Defense Forces. The two F-35Bs from the VMFA-242 Bats involved in the trials were BF-87, 169623 (DT-01) and BF-88, 169624 (DT-02).

VMFA-225 Vikings (CE)
VMFA (AW)-225 Vikings had operated the F-18D with the type's last flight on 23 January 2020. On 29 January 2021 the unit became VMFA-225 as an F-35 squadron, its first flight with the F-35B (169296/BF-54) having taken place in September 2021, since when at least eleven F-35Bs have been delivered to the unit.

VMFA-214 Blacksheep (WE)
VMA-213, based at Yuma, ceased operations on their AV-8Bs and the unit was re-designated on 25 March 2022, changing, like all previous USMC units, to the VMFA designation. The transition should be completed with the Blacksheep when the Blacksheep have received six 'primary aircraft' assigned the end of 2022 with full strength attained the second half of fiscal year 2024 with ten primary aircraft assigned.

VMFA-311 Tomcats (WL)
The VMFA-311 squadron operated the McDonnell Douglas AV-8B Harrier II. As a USMC STOVL capable unit it was transferring to the F-35C. For this reason it stood down in October 2020. Two and a half years later on 14 April 2023 the squadron stood up with their first F-35Cs. The Tomcats had been operating out of Yuma but with their transition a new location was also selected, the unit transferred to MCAS Miramar.

VMFA-542 Flying Tigers (WH)
On 1 December 2022 VMA-542 ceased operations with AV-8Bat MCAS Cherry Point. During the same ceremony VMA-542 became Marine Fighter Attack Squadron (VMFA)-542. The first two F-35s arrived June 2023 followed shortly by a third F-35B. The Flying Tigers will be able to locate, attack and destroy surface targets, intercept and destroy enemy aircraft, and provide electronic warfare support.

USAF
As the biggest customer for the JSF programme, the USAF was planning where to base these aircraft. Basing training aircraft was obvious due to the

joint effort in training. Operational squadrons required basing options. Those considered were Mountain Home AFB, Idaho, Hill AFB, Utah, Burlington Air Guard Station (AGS) Vermont and Shaw/ McEntire Joint National Guard Base (JNGB), South Carolina. All were included in the operational basing environmental impact statement.



The first operational test aircraft arrives at Nellis AFB. (*Lockheed Martin*)

Ogden Air Logistics Centre at Hill Air Force Base

Although not an operational unit in the sense that it flies its own fighters, this is one of the units that takes care of depot-level maintenance. Ogden Air Logistics Centre (OLC) was selected formally by the USAF in June 2008. Selection did not come as a surprise since Ogden was already responsible for depot-level maintenance of the F-16 and A-10 Thunderbolt II.

The first F-35 to land at Hill AFB was also the first aircraft to undergo work at Ogden. The F-35A (OT 10-5009) arrived at Hill AFB from Nellis on 13 September to undergo modification and preparation for the initial operational test and evaluation due to start in 2016. But work had to wait

for an official ceremony to celebrate the first aircraft to receive depot-level maintenance. Depot-level maintenance also included modifying faulty parts that were discovered during durability testing. F-35A, OT 10-5009, an LRIP IV aircraft, received four structural modifications intended to strengthen areas of the aircraft and extend its service life. The first of the four structural modifications included a root rib modification, which replaces a section of the aircraft's wing-root rib with a titanium splice. The other modifications, also structural, involved a station 3/9 modification, a mid-fairing fitting, and a forward engine-mount modification, all of which are intended to extend aircraft's life. The aircraft returned to Nellis on 26 March 2014. Ogden did not have to wait for the next aircraft since one of the Royal Netherlands Air Force F-35As had arrived on 14 February. A day later the next USAF F-35A arrived as well. The Dutch F-35A would not get the engine-mount modification but would receive a major modification to the fuel-boost pumps. Otherwise maintenance was going to be the same and would get the aircraft up to Block 2B standard. By 10 March 2017 it was announced that a total of twenty-two aircraft, including two Dutch aircraft and two USMC, received the upgrade, now called the Group 1 Structural Life Limiting Parts (SLLP). All aircraft needing this modification had a flight-hour lifespan limit but, with the new root rib parts installed, each aircraft could now expect to reach its full 8,000 flight hour service life. To replace both left and right root-rib segments on the aircraft took significant disassembly and low observable restoration. The team from Ogden completed the work in just under 3,000 hours per aircraft.

Flight Readiness Centre East (FRCE) Cherry Point

The Flight Readiness Centre East received its first F-35B on 9 July 2013 since when depot work has been carried out on the F-35B on this USMC base. For a rather long time the unit had nothing newsworthy for itself regarding the F-35, until 23 April 2018 when one aircraft, after receiving modifications, had an inflight emergency. During the flight the integrated caution and warning system (ICAWS) showed a fuel-related warning. The pilot returned to Cherry Point immediately and landed, leaking fuel. During the roll out the engine died because of fuel starvation before the aircraft came to a full stop. It was not clear what the cause of the problem was; this was under investigation. With no damage to property, the chance of learning what happened is small; ICAWS showed its worth and the pilot saved some

tax-payers' money. The second notable thing that happened was that the FRCE completed its first F-35C overhaul on 17 May 2018. The F-35C had arrived from Eglin during November 2017.

Hill Air Force Base (AFB)
34th Fighter Squadron 'The Rude Rams' (HL)
On 3 December 2013 it was announced that Hill Air Force Base was to become the base for the first operational USAF unit. The USAF wanted to reach IOC between August 2016 (Objective) and December 2016 (Threshold). IOC should be declared when the first operational squadron is equipped with twelve to twenty-four aircraft, and airmen were trained, manned, and equipped to conduct basic CAS, interdiction, and limited suppression and destruction of enemy air defences (SEAD/DEAD) operations in a contested environment. The first F-35 was due to arrive in 2015, which would mean that it would have to receive at least twelve aircraft within a year and a half to meet the IOC goal by the objective date. By 22 June 2014 it became official that 34th Fighter Squadron (FS) 'The Rude Rams' would be the first to receive the F-35A. The unit, having been de-activated after its last deployment to Afghanistan in 2010, had a long tradition dating back since 1944. It was also the first fighter squadron to receive the F-16. The first two F-35s arrived on 2 September 2015.

The Air Force was tracking twelve specific requirements to declare IOC, including:

- A minimum of twelve operational aircraft.
- Aircraft equipped with Block 3i software
- All jets modified with the required hardware for full 3i implementation
- Pilots and maintenance personnel trained
- Proper Joint Technical Data and Flight Series Directives.
- Autonomic Logistics Information System (ALIS) 2.0.2 software with Squadron Operating Unit (SOU) v2.
- Mission Data File delivery
- GEN III helmets fielded
- Weapons testing and certification complete.
- Spares
- Proper support equipment and Alternate Mission Equipment
- Pilot and maintainer manning.

The twelfth aircraft to be upgraded by a depot service and delivered to Hill AFB arrived on 30 June, fulfilling the first three requirements. GEN III was in production and had been delivered already as a standard to the Rude Rams. On 2 August 2015 IOC was declared by General Hawk Carlisle, commander of Air Combat Command. As with the USMC, the USAF IOC was criticised heavily by the Director of Operational Test and Evaluation.

Approximately a month later, however, almost fifteen aircraft that had been delivered recently had to be grounded as 'peeling and crumbling' insulation was discovered inside avionics cooling lines in some A-model fuel tanks, which are used as heat sinks. The 'peeling and crumbling' was noticed on one aircraft during depot maintenance and caused others to be inspected. 'Non-conforming insulation was found on coolant tubing carrying Poly-Alpha-Olefin (PAO) throughout the jet's wings.' The non-conforming insulation was tracked back to a second supplier that was introduced because of the anticipated production ramp up. Another forty-two aircraft that had yet to be delivered were affected as well. Of the fifteen aircraft delivered, two were from the Norwegian Air Force and thirteen from the USAF. Of the forty-two affected aircraft, it was reported that the Israeli and Japanese aircraft were affected as well. Since Israel was planning to have its two aircraft in country those would be dealt with as a priority. Italian and Japanese aircraft were also affected which meant that the mistake had occurred at the wing-manufacturing stage since it also affected the Italian final assembly and check-out (FACO) facility. It was not known if it affected the Japanese FACO as well. It was clear, however, that it was a supply chain manufacturing quality matter. General Bogdan applauded Lockheed Martin for picking up the bill for repairing all fifty-seven aircraft involved.

The Rude Rams deployed to Okinawa, Japan, with twelve aircraft. Okinawa is not on the Japanese mainland as opposed to Iwakuni, where VMFA-121 Green Knights were deployed. The forward deployment was planned to last six months at a time that warmongering was going on the between the US and North Korea and was seen by many as a statement towards the defence of Japan. The number of F-35s in the region had doubled overnight.

Used quite often for deterrence missions, one of the most notable for the Rude Rams was to Spangdahlem in Germany just before the Russian invasion of Ukraine, the unit arriving on 16 February 2022. Twelve F-35s

deployed: 15-5172 (AF-147), 15-5173 (AF-148), 15-5175 (AF-150), 15-5178 (AF-153), 17-5237 (AF-179), 17-5254 (AF-196), 17-5255 AF-197), 17-5256 (AF-198), 17-5257 (AF-199), 19-5478 (AF-306), 19-5483 (AF-311) and 19-5539 (AT-20). They made short deployments in pairs from Spangdahlem to Estonia, Lithuania and Romania but all returned to the German base. The unit had a small incident when 19-5539 (AT-20) /HL had a tyre burst on landing. Some hydraulic fuel was spilled and, with the runway closed, the other three F-35As diverted to Ramstein.

4th Fighter Squadron 'Fighting Fuujins' (HL)

After the Rude Rams, it was the turn for the Fighting Fuujins to receive the F-35. The unit's history dates back to the Second World War and its first F-35A arrived at Hill AFB on 27 September 2017.

The squadron was the first USAF unit to deploy to a warzone, moving to Al Dhafra AB approximately twenty miles (32km) south of Abu Dhabi in the United Arab Emirates on 15 April 2019. It took fifteen days from that point for them to be used in anger for the first time on 30 April 2019 above an unspecified country, most probably Syria or Iraq. Images released by the USAF with the press release showed the F-35 with Luneberg reflectors, which have been used on four spots on the aircraft, two on the top of the fuselage in front of the vertical tails and two on the bottom of the aircraft's keel. Their purpose is to enlarge the F-35's radar cross section (RCS) so that an opponent cannot glean information about its true size. Luneberg reflectors have been used also on the F-22 and F-35 while it was deployed to Japan including at the time an overflight over South Korea occurred during one deployment.

421st Fighter Squadron 'Black Widows' (HL)

This squadron's history also dates back to the Second World War. It has flown Douglas P-70 Havoc (1943-44), Lockheed P-38H Lightning (1944-45), Northrop P-61 Black Widow (1944-1947), Republic F-105D Thunderchief (1963-67), McDonnell F-4D Phantom II (1969-72), McDonnell RF-4C Phantom II (1972), McDonnell F-4E Phantom II (1972-75), General Dynamics F-16A Fighting Falcon (1980-90) and the General Dynamics F-16C Fighting Falcon (1990-2017).

The third squadron belonging to 388th Fighter Wing was 421st Fighter Squadron which received its first two F-35s from the Lockheed Martin

production line on 12 December 2018. The squadron commander, Lieutenant Colonel Richard Orzachowski, and First Lieutenant Ryan Allen, the squadron's youngest wingman, flew the jets to Hill AFB.

466th Fighter Squadron 'Diamondback' (HL)
This unit does not receive the normal twenty-four aircraft as it is the USAF reserve unit which receives a limited number of aircraft. Transition from F-16 to F-35 took place under the command of Colonel Surya Frickel and started in 2017. The first aircraft to roll off the production line specifically for 466th Fighter Squadron was 15-5194 (AF-169).

Nellis AFB
16th Weapons Squadron 'Tomahawks' (WS)
An F-16 unit received a couple of F-35s although it never relinquished its F-16 and its status of F-16 operator. The first F-35A delivered was the 12-5049, an aircraft from LRIP VI equipped with Block 2B software, which landed at Nellis on 15 January 2013. The F-35s operated initially with 16th Weapons Squadron until 6th Weapons Squadron was set up when all their aircraft were transferred to 6th Weapons Squadron.

6th Weapons Squadron (WS)
Inactive since in 1947, when it had flown the Northrop P-61 Black Widow, the squadron was re-activated as 6th Weapons Squadron on 20 June 2017. As it stood up it was stated that it would become one of the largest units, expected to receive twenty-four aircraft and thirty instructor pilots. The first nickname of the F-35 came to light with the squadron the pilots of which were seen with batches with the words 'Panther Tamer' and unit skull-and-lightning flashes. The nickname of Panther for the F-35 was accepted at Nellis but it remained to be seen how it would fare within the remainder of the F-35 community.

Eielson AFB
356th Fighter Squadron (AK)
Eielson AFB had been selected to receive two squadrons in early 2016 with the F-35 to operate alongside 18th Aggressor Squadron, equipped with F-16s. Although the F-35 had been at Eielson AFB to support the initial operational test and evaluation (IOT&E), it was not until the re-activation of 356th Fighter Squadron that it would become a more permanent sight.

The re-activation was announced on 10 October 2019, followed by delivery of the first two permanent F-35s on 21 April 2020. The unit was receiving the F-35 for the remainder of the year, although slightly slower than planned due to the pandemic. In August 2020 Eielson hosted Red Flag Alaska and 356th Fighter Squadron took part with F-35s from Hill AFB.

On its way to IOC, 356th took part in an air-to-air weapons system evaluation programme (WSEP) at Tyndal AFB between 8 and 23 October 2021. Nine live missiles, including the AIM-120 AMRAAM and AIM-9X Sidewinder, were fired during the exercise, all by first-time 'shooters' who also had the opportunity to fire the F-35's 25mm cannon against a QF-16-towed aerial target gunnery system. Some six weeks later, aircraft from the squadron deployed to MCAS Iwakuni in Japan for Operation IRON DAGGER. The F-35s deployed included 18-5366 (AF-257), 18-5369 (AF-260), 18-5376 (AF-267), 18-5378 (AF-269), 18-5380 (AF-271) and 18-5381 (AF-272) and trained with VMFA-242.

At the end of 2020, the first deployment of 356th Fighter Squadron was to Guam for Cope North 2021.

355th Fighter Squadron 'Fighting Falcons' (AK)

An operational unit equipped with A-10 Thunderbolt IIs until 2007 and known as the Pugnacious Pups, the squadron bade goodbye to its final three A-10s on 15 August and was disbanded. Revived through re-designation, it was re-activated on 18 December 2020, this time returning to where it had been stationed in the 1990s to become the second F-35A unit in Alaska at Eielson AFB, receiving its first two F-35s on 29 April 2021; those were 19-5534 (AT-15) and 19-5536 (AT-17). Lieutenant Colonel Samuel Chipman, the unit commanding officer flew one of the pair.

RAF Lakenheath

495th 'Valkyries' (LN)

RAF Lakenheath had been selected as the first European base to receive the F-35A with 48th Fighter Wing at Lakenheath as the responsible wing. On 15 September 2020 it was announced that the first USAF unit in Europe to receive the F-35A was 495th Fighter Squadron, which was not an operational unit. Although disbanded, it had a rich history, one of the main events of which was operation El Dorado Canyon. At the time 495th Fighter Squadron was equipped with General Dynamics F-111F Aardvarks

and attacked Libya in 1986. The unit's last claim to fame was participation in Operation DESERT STORM in 1991, after which the unit was disbanded in December 1991.

The unit previously had been the 'Thundervarks', a nickname with a clear reference to the General Dynamics F-111F it had operated. Thus, it wanted a new nickname and asked the public for proposals. From over 700 proposed names five were selected: Archangels, Sabres, Sentinels, Swordsmen and Valkyries. In the USAF announcement dated 16 February 2021 the selection of the name 'Valkyries' was presented. The reasoning was as follows: in Norse mythology, Valkyries are female figures who choose those who will live or die in battle. RAF Lakenheath is in the east of the United Kingdom, an area with extensive Norse history. Additionally, 495th FS's motto, *Mala Ipsa Nova*, means 'Bad News Itself '. Both factors emphasise 'Valkyries' as an extremely suitable nickname for the UK-based unit. The first F-35A was due for arrival in late 2021, depending of course mainly on the pandemic.

One of the other steps taken was an evaluation of the shelters at Lakenheath. The Air National Guard sent two aircraft (17-5278 and 18-5361) from its first F-35 squadron at Vermont's Burlington International Airport which arrived at Lakenheath on 15 December 2021. Those were the first USAF F-35s to be based permanently in Europe. By February 2022 the number of aircraft delivered had risen to seven and the F-35 became a regular visitor to the Mach loop where, like other military aircraft, it would train in low-level flying.

493rd Fighter Squadron 'Grim Reapers' (LN)

Operating from Lakenheath with the F-15C/D, the Grim Reapers were the second unit due to re-equipe with the F-35 as the F-15s were gradually being returned to the USA. The squadron's first F-35A (19-5493/AF-321) made its first flight from Fort Worth on 2 March 2022; together with 19-5495/AF-323, it was delivered to RAF Lakenheath on 19 April 2022. The first F-35, AF-321, had a Grim Reaper painted on its tail as it was to be the unit 'flagship' while AF-323 was adorned with a Valkyrie as the flagship of 495th Fighter Squadron Valkyries.

65th Aggressor Squadron (WA)

The 65th AGRS was previously active at Nellis from 2005 to 2014, replicating the tactics and techniques of potential adversaries with a fleet of F-15 Eagles. On 9 June 2022 it was re-activated with two F-35s (11-5020 and 11-5021) in a new paint scheme for the aircraft. One F-35 had 57th Wing markings and the other (11-5021) 65th AGRS markings. The unit was set up to replicate fifth-generation capabilities from adversaries such as China and Russia.

95th Fighter Squadron Boneheads (TY)

The next base to receive the F-35A was Tyndall AFB. The 325th Fighter Wing under which the 95th Fighter Squadron Boneheads belong received their first three F-35A's on August 1, 2023. The base had previousely housed an F-22 Formal Training Unit (FTU) but these were forced to vacate the base as a result of damage by Hurricane Michael in October 2018. As new infrstructure was required it was decided to prepare the base for the F-35. For the Boneheads it will take wo years to receive all 26 aircraft (24 primary assigned Aircraft + 2 reserve) Tyndall will be housing another two F-35A squadrons.

378th Fighter Squadron (WI)

A squadron that was activated without any fanfare. This squadron was set up with the Air National Guard 176th Fighter Squadron. Both units are to supplement each other and operating out of Truax field.

ANG

134th 'Yellow Scorpions' (VT)

In December 2013 it was announced that the first Air National Guard to receive the F-35 would be the Vermont ANG. Based at Burlington International Airport, the unit was flying the F-16, the last four of which departed Burlington on 6 April 2019. From then the pilots and maintainers had their hands full with F-35 conversion training. The first two (17-5265 and 17-5266) arrived in Burlington for 134th Fighter Squadron on 19 September 2019. Vermont Air National Guard held an official arrival ceremony exactly a month later; 134th Yellow Scorpions are expected to receive eighteen F-35s.

On 15 December 2021 two F-35s were transferred from Eglin AFB to Jacksonville in Florida, the second new base to receive its first F-35s on the

same day.

The first overseas deployment for 134th Yellow Scorpions was to Spangdahlem in Germany in response to Russian aggression in Ukraine. Eight F-35As deployed on 2 May 2022, of which 17-5265 (AF-207), 17-5278 (AF-220), 18-5336 (AF-227), 18-5338 (AF-229) 18-5339 (AF-230), 18-5349 (AF-240), 18-5360 (AF-251) are known at the time of writing. The Yellow Scorpions guarded the skies over Europe before returning home 6 August 2022.

176th fighter Squadron Badger Air Militia (WI)

The Wisconsin Air National Guard's 115th Fighter Wing was the second unit from the Air National Guard. The first four F-35s for the 176th fighter Squadron were flown in Truax Field by pilots Capt. John Lorbiecki, Maj. Jacob Jerzewski, Maj. Joe Pavela and Lt. Col. Michael Koob on April 25, 2023 for the very first time. Making it the second Air National Guard unit to operate the F-35A.

100th Fighter Squadron Red tails (AL)

The third Air National Guard unit to receive the F-35 was the Alabama Air National Guard belonging to the 187th Fighter Wing based at the Dannelly Field it was announced in December 2017. This unit was known as one of the Tuskagee Airmen Squadrons. African Americans flew P51 against all odds and under severe discrimination. The 100th Fighter squadron had been flying the F-16 Fighting Falcon for 35 years when they retired them on April 21, 2023 and flew the last training sorties on April 1, 2023. The transition had been going on already but the first F-35As were due for delivery in December 2023. The tradition of the red tails was continued even on the stealthy F-35A. The bright red tails would make it easier to visually spot the aircraft but at least for the first aircraft the red tail was retained. The first three F-35A landed at the Dannelly Field were the 18-5414, 18-5420 and 20-5628.

US Navy

VX-9 'Vampires' (XE)

The VX-9 Vampires are normally based at NAS China Lake but the F-35 detachment was based at Edwards AFB where it is part of the international Joint Operational Test Team. VX-9 was due to receive six F-35Cs. They

received their first two examples in November 2016 and a year later had received all their aircraft; of those six, two had been equipped with software Block 3F6.2 which was still limited since the full g capability for the F-35C had not been opened up in developmental testing. In co-operation with its partners it was preparing for IOT&E, due to begin in summer 2018. As VX-9 Vampires was the only unit to have the carrier trap responsibility it was co-operating with the fleet replacement squadrons, VF-101 and VFA-125, to get their ten pilots carrier qualified. The first VX-9 pilot to achieve day carrier qualification did so in September 2017. As the gen-3 HMD had not completed developmental testing, VX-9 had to postpone night carrier qualification to a later stage, still expected prior to the initiation of IOT&E. This was not a problem since the official IOT&E was delayed and started in December 2018.

VFA-101 'Grim Reapers' (NJ)

A unit set up as a conversion unit at Eglin AFB, it was supposed to be a part of the biggest training base for the F-35. However, limitations set at the base did not allow this to happen. The USMC left the base and, according to some, it would only be a matter of time before the US Navy left as well. VFA-101 was planned to stand down once all units at NAS Lemoore were up to speed. The unit flew its last F-35s out to NAS Lemoore

VFA-125 'Rough Raiders' (NJ)

According to the media, the US Navy was the least impressed with the F-35 and the most likely to ditch it. The comparison with the F-111 was made constantly. The US Navy required an air superiority fighter rather than the F-35C. After the training unit at Eglin the planning for introduction into the US Navy was gaining traction but the Navy was still ordering the least number of F-35s in the early low rate initial production (LRIP) lots. After the Grim Reapers, the next unit planned was a second Fleet Replacement Squadron based at Lemoore, VFA-125 Rough Raiders whose first four F-35Cs arrived on 25 January 2017 with ten planned to have arrived by year end.

The job of a fleet replacement squadron is to deliver qualified pilots to operational units with carrier qualification an integral part. The first time that VFA-125 Rough Raiders sent aircraft out to a ship was when it was still based with VF-101 Grim Reapers. However, the carrier qualification was

credited to the Grim Reapers. The USS *Carl Vinson* (CVN-70) became the real first opportunity on 18 October 2017 when the first F-35C from VFA-125 Rough Raiders trapped successfully. The USS *Carl Vinson* (CVN-70) will likely be the first west coast-based carrier to deploy with an F-35C squadron after undergoing a scheduled maintenance period in 2019.

VFA-147 'Argonauts' (NE)

During the annual Tailhook Association convention in 2016, the identity of the first naval squadron to be become operational on the F-35C was announced by Commander Timothy F. Locke, the F-35 requirements officer for the director of air warfare. After VF-101, the Grim Reapers at Eglin AFB, and VFA-125 Rough Raiders at NAS Lemoore, VFA-147 Argonauts would convert to the F-35. VFA-147 Argonauts were operating the F-18E and were also based at NAS Lemoore. Transition from the F-18E to the F-35C was supposed to begin by January 2018 in time for them to reach IOC target date of February 2019. During the period 17-21 March 2018 VFA-101 Grim Reapers and VFA-125 Rough Raiders went for carrier qualification to the *Abraham Lincoln* in support of pilot training for VFA-147 Argonauts. A total of 140 carrier landings were performed during this deployment over day and night missions. The first pilot from VFA-147 to make his maiden flight on the F-35 was Lieutenant Dave 'Stokes' Hinkle on 18 April. His first flight was out of NAS Lemoore with VFA-125 Rough Raiders. On 12 December 2018 VFA-147 Argonauts received the designation 'safe for flight'. This was one of the major milestones prior to reaching IOC and meant that it would be able to operate independently from VFA-125.

The safe for flight designation came later than expected. The logical step was to follow up with a IOC declaration which arrived on 28 February 2019. Being the third US service, and the fifth service altogether, to declare IOC, VFA-147 Argonauts would train and prepare for first deployment on the USS *Carl Vinson*, planned for 2021. For this purpose, they joined VFA-125 on the USS *Nimitz* in July 2019 for pilot carrier qualification, which was achieved for both squadrons. The pilot-carrier qualification could not take place on the USS *Carl Vinson* which was undergoing maintenance. For its first deployment with VFA-147 Argonauts equipped with the F-35C, the USS *Carl Vinson* set sail on 2 August 2021. Not only was it the first deployment of a US Navy F-35C unit but also the first deployment of

CMV-22. At the latter stage of the deployment, the *Carl Vinson* joined up with the *Abraham Lincoln* (CVN 72) which was operating with the first operational USMC F-35C unit, VMFA-314 Black Knights.VFA-147 Argonauts also became the first unit to lose an F-35C during a landing accident.

First deployment included the following aircraft:

Construction number	Lockheed number	Tail number
169632	CF-37	NE-400
Unknown	Unknown	NE-401
169636	CF-41	NE-402
169161	CF-25	NE-403
169163	CF-27	NE-404
169302	CF-28	NE-405
169304	CF-30	NE-406
169305	CF-31	NE-407
169424	CF-32	NE-410
169636	CF-34	NE-411

VFA-97 'Warhawks' (NE)

After VMFA-314 had completed its transition, VFA-125 took up the responsibility of helping VFA-97 transfer from the F-18E Super Hornet to the F-35C. VFA-97's history goes back to 1967 when it was established on 1 June. Since then it had operated in several versions of the Vought A-7 Corsair II and the McDonnell Douglas F-18 Hornet. The VFA-97 Warhawks would be the second operational US Navy unit to get the F-35C. So, in February 2021, VFA-97 said goodbye to the F-18E it had been operating since 2013 and reached IOC in 2015. The last flight on the F-18E was on 26 February. Almost a year later, VFA-97 Warhawks reached the milestone of 'safe for flight' on 18 February 2022. From then on pilot training and carrier qualification continued so that the unit could go on its first operational deployment. The USS Carl Vinson (CVN-70) departed San Diego port October 12,2023 to join Annual Exercise (ANNUALEX) 2023

in the Pacific. The Warhawks deployed on the USS Carl Vinson together with the “Bounty Hunters” of VFA-2 – F/A-18F, the “Stingers” of VFA 113 – F/A-18E, the “Golden Dragons” of VFA 192 – F/A-18E – all from Naval Air Station Lemoore and the “Gauntlets” of Electronic Attack Squadron VAQ-136 – EA-18G – from Naval Air Station Whidbey Island, Washington, the “Black Eagles” of Airborne Command and Control Squadron VAW-113 – E-2D – from Naval Air Station Point Mugu, California. The “Titans” of Fleet Logistics Multi-Mission Squadron (VRM) 30 – CMV-22B – from Naval Air Station North Island, California, the “Blue Hawks” of Helicopter Maritime Strike Squadron (HSM) 78 – MH-60R – from Naval Air Station North Island and last but not least the “Black Knights” of Helicopter Sea Combat Squadron (HSC) 4 – MH-60S – from Naval Air Station North Island.

VFA-86 Sidewinders (AG)
The Sidewinders concluded their last deployment on the USS George H.W. Bush (CVN-77) with the Super Hornet April 2023. From that moment VFA-86 retired their F-18E’s and were taken under the wings of the VFA-125 Rough Raiders who would be responsible for their transition to the F-35C. The VFA-86 Sidewinders would be the third US Navy operational squadron and the fifth F-35C. As a delay with the TR-3 hardware and software was having a impact on aircraft deliveries it was not sure when the first VFA-86 Sidewinders F-35C would be delivered in 2024.

Australia – Royal Australian Air Force (RAAF)
The first ten Australian aircraft were delivered to Luke AFB where initial training took place and the first instructors trained in preparation for training back home at Williamstown. Aircraft delivered were for both 3 Fighter Squadron and 2 Operational Conversion Unit (OCU). At Luke AFB the first Australian pilots were trained to become instructors and the crew for the first operational squadron, 3 Fighter Squadron.

No. 3 Squadron
The first two aircraft arrived in Australia on 10 December 2018. The first task would be getting operations up and going from Australian soil. Although not a conversion unit, 3 Squadron initiated pilot training. The training bore its first fruit at Williamstown when the first pilots trained in

Australia had their first flight on 15 July 2019. The two pilots involved, experienced fighter pilots, had completed an intensive two-month academic and simulator-training programme at the base's integrated training centre. The unit first verified that the F-35A was capable of doing the tasks it was supposed to do, evaluated its integration with the other aircraft in service, such as the KC-30 and Boeing E-7A Wedgetail AWACS and once that verification was complete IOC was declared.

No. 2 OCU

When the first pilots received their training at RAAF Williamstown, 2 OCU was still flying the F-18A/B aircraft and performing conversion training. The final conversion to the F-18A/B was due to start in July 2019 and be completed by year end at which point the F-18s were be retired and 2 OCU would convert to the F-35. Once the training contingent moved from Luke AFB to Australia, the preparation for the training of future RAAF pilots would begin at home. The first graduations of pilots at this unit at Williamstown occurred on 12 July 2021, the conversion course taking six months. Pilots coming through the training course had come straight out of basic flying training. With operational training up and running in Australia, the Royal Australian Air Force was able to train its pilots and maintainers independently which was seen as a part of the IOC process, which was completed January 2021.

No. 77 Squadron

This squadron was operating F-18 Hornets which were retired by December 2020. In 2021 conversion to the F-35 began and the first aircraft, AU-35, for the unit had its maiden flight on 8 March from the Lockheed Martin Fort Worth facility. Deliveries sped up so, by the end of 2021, the Royal Australian Air Force had received forty-eight aircraft. As the RAAF was calculating on the basis of sixteen aircraft per squadron, it was possible to initiate the transition of the next unit. No. 77 Squadron would also be operating out Williamstown.

No. 75 Squadron

No. 75 Squadron had been operating the F-18A/B Hornet for thirty-three years out of Tindal. During a ceremony at Williamstown the RAAF made its goodbye to the Hornet on 29 November 2021 with aircraft of 75

Squadron providing the fly-past. No. 75 was the first unit to transition to the F-35 and be based at Tindal. Their first machine was AU-29 which had its first flight from the production line on 30 July 2020. Transition overlapped with that of 77 Squadron. The first four F-35s arrived at Tindal on 9 December 2021, starting a new era for the unit.

UK Royal Navy and Royal Air Force

As far back as 2005 the MoD selected RAF Lossiemouth as the base for the future JCA.

In January 2006 the MoD announced that eight British pilots would begin training in 2007 so that they could participate in test flying during the SDD. Another eleven pilots were to follow after the first batch to become instructors for the UK on the F-35. The UK planned that a total of sixty-four pilots would be trained in the US and the first British service pilot to fly the F-35 was Squadron Leader Steve Long in January 2010. The choice of Lossiemouth as the main operating base was changed when the UK switched from the F-35B to the F-35C. On 25 March 2013 the then Defence Secretary, Philip Hammond, announced that the new main operating base was to be RAF Marham.

No. 17 (R) Squadron – the Black Knights – *Excellere Contende* (Strive to excel)

The first unit to receive the F-35 was No. 17 (Reserve) Squadron, was previously based at RAF Coningsby as the operational conversion unit (OCU) for the Eurofighter Typhoon. The history of the squadron dates back to 1915 and the squadron motto is *Excellere Contende*, which means 'Strive to Excel'. No. 17 (R) Squadron was to relocate to Edwards AFB, operate as a joint RAF/Royal Navy unit and join 31st TES where together they would shape the initial part of the joint operational test team (JOTT). On 12 April 2013 No. 17 (R) Squadron set up for receiving its first F-35B. While based at Edwards the aircraft were considered part of VMFAT-501 Warlords. BK-01 and BK-02, the first aircraft for 17(R), were equipped with US test equipment, distinguished by its orange colour; the aircraft are also known as orange-wired aircraft.

No. 617 Squadron – Dambusters – *Apres Moi le Deluge* (After Me, the Flood)

No. 617 Squadron needs no introduction, its soubriquet coming from one of military aviation's most daring feats from the Second World War. The last type in its inventory, before standing down in 2014, was the Panavia Tornado GR.4. Soon after it was announced that 617 Squadron would be the UK's first operational F-35 squadron with most of its initial work taking place in the US at Beaufort integrated with VMFAT-501. Prior to its retirement, the UK Harrier Force was a joint RAF/Royal Navy formation, a practice to be copied within the F-35 force, at least initially. The unit was working its way to achieve IOC and was supposed to deploy to its Marham in 2018. As a part of VMFAT-501, it participated in the first deployment to the UK, in 2016, for participation in not only the International Air Tattoo at Fairford, but also at the international Air Show at Farnborough with BK-03. Although the first pilots were, as to be expected, experienced pilots, by the end of 2017 the first four British ab-initio pilots flew for the first time in the F-35. Nine aircraft were expected to deploy to Marham during summer 2018, a significant year since the RAF celebrated its centenary anniversary and 617 Squadron its seventy-fifth anniversary. All pointed to participation at the RAF centenary celebrations taking place at the RAF Fairford International Air Tattoo. Wing Commander John 'Butch' Butcher led a four ship of F-35s over the Atlantic and landed as the first F-35 pilot at RAF Marham on 6 June. The Dambusters had come home. The four aircraft that arrived in the UK were ZM145, ZM146, ZM147 and ZM148 and were escorted by two Voyagers, ZZ335 and ZZ330, and one Atlas, ZM401.

A technology glitch meant that it was a while before the first operation from RAF Marham could be made on 28 June, in time to participate in the centenary flypast over London and participate in the RAF Fairford International Air Tattoo and at Farnborough. Those obvious marketing occasions were soon replaced by hard work requirements in preparation for deployment on HMS *Queen Elizabeth*. The main aim was to get ready for the deployment. One major step was declaring IOC which was achieved for land-based operations on 10 January 2019. As the plan was to deploy to the *Queen Elizabeth* the aim was to gain sea-based IOC. Three months later the F-35 deployed to RAF Akrotiri, Cyprus, for Operation LIGHTNING DAWN. During this first deployment it was decided to give the unit its taste of operational missions and it was sent on an operational mission for the first over Syria on 16 June.

No. 207 Squadron/Operational Conversion unit

The second unit to operate from RAF Marham was 207 Operational Conversion Unit which had, prior to its displacement to RAF Marham, been teaching British pilots in co-operation with the USMC VMFAT-501 at MCAS Beaufort. No. 207 Squadron arrived with six Lockheed Martin F-35B Lightnings (ZM137, ZM139, ZM149, ZM150, ZM151 and ZM152) at RAF Marham on 6 July 2019. A few weeks later a small ceremony was held as the unit was stood up. The squadron deployed to HMS *Queen Elizabeth* to get the instructors carrier qualified and be able to qualify pilots from the Dambusters as they were the first unit to go on an operational deployment.

Once the Dambusters were on deployment, 207 deployed to HMS *Prince of Wales* in 2021 and as such, for the first time for several years, the UK was operating fighter aircraft from two aircraft carriers to qualify more pilots and help HMS *Prince of Wales* ready for operational service.

No. 809 Squadron the Immortals

The first two squadrons were of Royal Air Force legacy and although there are pilots from both the Royal Navy and the Royal Air Force operating the F-35s there was a feeling that a Royal Navy unit should be operated from the two aircraft carriers. The 809 Squadron called the immortals was selected to be that squadron. This squadron with a long legacy and with their last combat experience during the Falklands war of 1982 when they were operating from both the HMS Hermes and HMS Invincible. One of the pilots that was flying with the 809 squadron in the Falklands was a young Lieutenant Simon Hargreaves. The 809 squadron will also have Royal Air Force and Royal Navy crews. Many of the Royal Navy Fleet Air Arm were not appreciative about how the funds flow to the Royal Navy Fleet Air Arm and considered the Royal Air Force as a disruption for funds and mission as the Royal Air Force had claimed they could cover the Royal Navy anywhere over the world. With a program of record of 138 aircraft it should not be a problem to get enough F-35Bs to equip the squadron. However history was repeating itself a bit as the funds were now being funnelled in to a new project called Tempest. There was a huge question mark on how many F-35Bs the United Kingdom would actually acquire. On December 8, 2023 809 Squadron stood up with the first aircraft at RAF Marham with a beautifull phoenix on the tail. The aircraft also equiped with

the number 809 on the nose. The last commanding officer Tim Gedge who had led the 809 squadron during the Falklands conflict in 1982 was there to hand over the unit crest – a phoenix rising from the flames to the new Commander Nick Smith.

Italy

Amendola – 13o Gruppo

The first two aircraft to arrive at Amendola from the Italian final assembly and check out (FACO) facility arrived on 12 December 2016. As Italy already had some of its F-35s based at Luke AFB, it had pilots available for training. Operations were slowly gearing up and during 2017 the unit celebrated its centenary with MM7357/32-07 receiving special markings, applied only to one side of the vertical tail.

The unit participated in an exercise for the first time from 8 to 15 June 2018 with four aircraft from Rivolto Air Base. The four F-35s flew six flights per day. During a tactical leadership programme (TLP) Chief of Staff of the Air Force, General Alberto Rosso, announced that the F-35A had achieved IOC on 30 November. The 13° Gruppo (Squadron) was also the first unit to send 6 F-35A for Iceland Air Policing.supported by an Italian Boeing KC767 the 6 Italian F-35's were performing their air policing task from October 1 till October 25, 2019. The main task during Iceland Air Policing is the Quick Reaction Alert interception mission and the training for this mission. This was repeated by a second deployment for Iceland Air Policing in June 2020 which lasted till Mid July 2020. The unit was special in the sense that it received an F-35B and would be the first operational unit to operate two versions of the F-35. So when it was announced that, for the very first time, two Italian F-35Bs had landed on HMS *Queen Elizabeth* one was from the Aeronautica Militare and one from the Marina Militare.

The third deployment to Iceland with the Italian F-35 took place from April 25 till July 4, 2022. This time there was an interesting twist in the deployment as four F-35A's and two F-35B's from the 13° Gruppo (Squadron) were used. This deployment was supported by a Boeing KC767 and a Lockheed Martin C-130J Hercules. The F-35 assigned to the Marina Militare had markings different from those of the *Aeronautica Militare* and it was not clear if they would be integrated.

Ghedi – 102o Gruppo

AL-16, the sixteenth F-35A for the Italian Air Force was noted with tail number 06-01 on the production line. It was not clear which of the Panavia Tornado IDS/ECR units it would replace at the time. The three squadrons based there are 102º Gruppo, 154º Gruppo and 155º Gruppo. 102° Gruppo was selected to be the first to operate the F-35 out of Ghedi.

Israel

Nevatim – 140 Squadron – Golden Eagle

The first Israeli unit to receive the F-35I Adir was the Golden Eagle Squadron at Nevatim. The unit received its first aircraft in December 2016 and following aircraft arrived in increments of two. Almost a year later, the unit declared IOC. The Golden Eagle unit was also the first to take the F-35 into combat. The exact extent of combat performed by the F-35 remains unclear. It was rather controversial as images were published of an Israeli F-35 overflying Lebanon. This squadron participated in several Blue Flag exercises.

Nevatim – 116 Squadron – Defenders of the South Squadron

The aircraft of 116 Squadron painted a stylised lion's head on its aircraft tails. The first aircraft for this unit arrived in November 2019 and the squadron reached IOC on 6 August 2020, which also signalled that the next Israeli Air Force squadron would initiate its transition.

Nevatim – 117 Squadron – First Jet Squadron

The First Jet Squadron was operating the F-16C at the Ramat David Air Base when it was disbanded on 30 September. This unit had taken part in the bombing of the Iraqi Osiris reactor and all major wars fought by Israel. On 1 July 2021 it was re-activated as an F-35I squadron.



116 Squadron based at Nevatim in Israel. (*Israeli Air Force*)



The third unit, 117 Squadron, to be stood up in Israel. Although low visibility at least the Israeli kept tradition of tail art intact. (*Israeli Air Force*)

Japan

Misawa - 302 Hikotai

The first Japanese pilots initiated training with 944th Fighter Wing from Air Force Reserve Command (AFRC) in December 2016. The first Japanese Air Self-Defence Force (JASDF) pilot, Lieutenant Colonel Nakano, to make his 'solo' flight on the F-35 did so from Luke AFB as part of a three-ship on 7 February 2017. Lieutenant Colonel Nakano and one of his colleagues graduated on 18 May 2018. Those pilots in training would continue training as instructor pilots so that they could continue instructing their own pilots back in Japan. The two Japanese pilots were the first group to be trained at Luke from a total of three Japanese groups. Five Japanese aircraft that had been providing support for the Japanese pilot and maintenance training at Luke AFB all arrived at Misawa on 28 May 2018. There they joined F-35s delivered straight from the Nagoya FACO at the Rinji F-35A Hikotai. This signalled the completion of training of the three

groups. No. 302 Hikotai was still operating the F-4EJ Kai Phantom at Hyakuri and planning to cease operation on the Phantom on 2 December 2018. The hikotai would then move to Misawa and begin operations on the F-35A on home soil. During a ceremony, 302 Hikotai stood up its first operational squadron on 29 March 2019. This was followed shortly after by a tragedy as 302 Hikotai was the first foreign unit to lose an F-35 on 9 April, with fatal consequences for the pilot. The unit was grounded immediately in the wake of the accident. Although the flight recorder or the black box were not retrieved, the accident investigation team concluded that pilot error was partly to blame for the accident.





Japanese Air Self-Defence Force (JASDF) flying near Luke AFB. Both these aircraft were based only briefly at Luke AFB and were both built in Fort Worth. (*Lockheed Martin Liz Lutzjob*)



Three F-35s from the Japanese Air Self-Defence Force (JASDF). (*Lockheed Martin Liz Lutzjob*)



Two Japanese Air Self-Defence Force (JASDF) F-35As from the 944th Operations Group Detachment flying over the USA. (*Lockheed Martin Liz Lutzjob*)



Japanese F-35s might return to the USA as they plan to order more aircraft after the first batch but these should be assembled in Fort Worth just like the first four aircraft. (*Lockheed Martin Liz Lutzjob*)



After the roll out ceremony the first F-35 of 38 assembled in Japan. (*Lockheed Martin*)

No. 301 Hikotai

Having operated the F-4EJ since 1972, 301 Hikotai began its transition from the F-4EJ to the F-35 with the retirement of the Phantom in November

2020. The second unit was gaining in strength during 2021 and would reach IOC some time after writing.

The Netherlands

No. 323 Squadron TES Diana *Impetu Feroci* (Attacking Fearless)

This unit had a proud history flying aircraft such as the Gloster Meteor, the Hunter, F-104 Starfighter and F-16 Fighting Falcon and has in its emblem Diana the Huntress. While flying the F-16 Fighting Falcon from Leeuwarden Air Force Base, the unit transferred its responsibilities to another and was due to stand up again once the F-35 arrived at Edwards AFB. When the Dutch aircraft left Eglin and flew to Edwards AFB on 17 January No. 323 Squadron stood up again and started to prepare for its mission, participation in the IOT&E. The first year was building experience for all involved working with and around the F-35. This included dropping the first weapon, a GBU-12. The second aircraft was flown shortly after its arrival at Ogden for structural upgrades. During the first year there was also an opportunity to fly with the Dutch F-16s based at Tucson AFB. To demonstrate the capability, the Draken International provided A-4 Skyhawks to provide 'red air'. The F-16 pilots could experience first-hand the data-sharing through Link-16. According to Laurens Jan Vijge, the first Dutch F-35 pilot, they tried to maximise the amount of information they shared and the F-16 pilots were very impressed. The fact that at the time the F-35A was flying the Block 2B software and that the F-16 pilots experienced a big improvement spoke volumes of the promise that Block 3F held. One of the milestones reached that covers the experience the four Dutch pilots were gaining was that AN-02 reached 500 flight hours on 26 October 2016. Some equipment was outdated at and had to be replaced as the aircraft were updated. The original HMD supplied to the pilots did not meet the requirements for the OT&E and new HMD (Gen III) were to be fitted, the Dutch pilots going through the fitting process on 17 August 2018. Lieutenant Colonle Laurens Jan Vijge departed his role as an operational test and evaluation pilot with his last flight at Edwards AFB on 17 August 2017. He moved on to become the operations group commander at Leeuwarden.

Two F-35s (AN-01 and AN-08) from 323 TES flew from Edwards AFB, dropped bombs on the Vliehors training ground on the Dutch island of Vlieland in the north of the country, successfully struck the targets and

landed at Volkel Air Base where they remained and participated in Air Force Days (Luchtmachtdagen). AN-01 ran into unforeseen technical problems and could only return to the US on 17 July 2019. The Dutch had received all their aircraft from the USA production line, but the 308th was expecting a total of eight aircraft. Once the operational test and evaluation was being wound down from the Dutch perspective, AN-01 and AN-02 were due to join the six F-35s. AN-01 was handed over on 22 May 2020, after it had accumulated more than 1,100 flying hours.

Defensie Materiaal Organisatie (Defence Material Organisation)

On 30 October 2019 AN-09 arrived in the Netherlands from the Italian FACO to a large welcoming ceremony. It was not assigned immediately to an operational unit. As with the Norwegians, the F-35 first joined the local Defence Material Organisation.

No. 322 Squadron Polly Grey

No. 322, based at Leeuwarden, was the first squadron on Dutch soil to receive the F-35. After receiving some of its first aircraft, 322 Squadron flew the F-35 from Leeuwarden with all training and maintenance designed to achieve that goal. One of the tasks the squadron was to perform once it achieved IOC was to deploy anywhere with four aircraft. To evaluate if they had learned enough and could so deploy, the squadron moved to Volkel Air Base, under the title Frisian Lightning II, from 9 to 20 November 2020. Since it was an exercise to evaluate the logistics of deployment, the unit was forbidden to return to home base for any forgotten parts or tools. During the deployment munitions were dropped as well.

In 2021 the squadron deployed with eight F-35s (17-5308/F-009, 17-5309/ F-010, 18-5405/F-011, 18-5406/ F012, 18-5409/F-015, 18-5410/F-016, 18-5411/F-017 and 18-5412/F-018) to the USA as part of the preparation of reaching IOC, which was achieved on 27 December 2021. For the *Koninklijke Luchtmacht* this mean that 322 Squadron could deploy four F-35's anywhere in the world. This is how the Dutch Air Force had deployed with their F-16s to Afghanistan, and elsewhere, and integrated with other coalition forces. The unit received its last aircraft in January 2022 and also the first F-35 due to be based at Volkel Air Base. Once Volkel was ready to receive their first F-35s those aircraft would move there. The next Dutch unit to receive the F-35 was the 313 Squadron.

Unfortunately, the world was turned upside down on 24 February 2022 when Russia invaded Ukraine. This caused the eastern European NATO members to feel insecure and in need of assurances. Much material was deployed to the area and 322 Squadron Polly Grey played its part by deploying four aircraft to Graf Ignatievo in Bulgaria. Among the F-35s deployed were F-012, F-015, F-016 and F-017 (17-5308/F-009, 17-5309/ F-010, 18-5405/F-011, 18-5406/ F012, 18-5409/F-015, 18-5410/F-016, 18-5411/F-017 and 18-5412/F-018). Two were deployed for the defence of the country, deterrence and the other two were in reserve to be available at all times. The aircraft deployed with Sidewinders on the outboard underwing stations and Luneburg lenses (radar reflectors). Two days later the twenty-sixth F-35 arrived in the Netherlands.

The 322 squadron deployed to Malbork in Poland to provide security over the eastern flank of NATO during the spring of 2023.

No. 313 Squadron Tiger squadron

The first tangible milestone for the 313 Squadron was the arrival of their first aircraft at Leeuwarden Air Base. Although Leeuwarden was not the home base but pilots that had completed their training Luke AFB with the 308th Emerald Knights moved to Leeuwarden to continue their training in preparation for their move to Volkel, their home base. Pilots were pilots from the F-16 and also fresh pilots with no previous fighter experience. Once the first four F-35 aircraft would have been delivered to Leeuwarden for the 313 Squadron which was due to occur in the May/June 2022 the unit would transfer to Volkel air base planned for June 30, 2022. This occurred exactly according to plan with the arrival of four F-35s on June 30, 2022. One of the first major exercises where the 313 squadron was involved was the Arctic Challenge Exercise. As the 313 Squadron celebrated its 70 anniversary it was only appropriate to celebrate with a special tail marking for this reason F-031 (AN-031/20-5660) was donned with a celebratory tiger tail, equipped also with the silhouettes of all previous operated aircraft types in similar fashion to the special tail adorned on the F-002. The biggest exercise was in their short existence as an F-35 operator was their deployment to Nellis AFB for Red Flag 24-2 in March 2024.

Norway

Norwegian Defence Management Agency.
The last three of the first ten aircraft delivered ordered by Norway were delivered straight to the Ørland Main Air Station and the Norwegian Defence Management Agency (NDMA) would operate them until the first squadron would stand up. The aircraft would be passed to an operational unit, as soon as sufficient personnel were trained and sufficient aircraft were available; a further batch of three arrived on 22 May 2018. NDMA also held trials with the drag chute specifically developed for Norwegian operational requirements. The Royal Norwegian Air Force was due to achieve IOC in 2021. Ørland Main Air Station was also visited by the JSF programme executive officer (PEO), Vice Admiral Mathias W. Winter, to see for himself how the Norwegians were standing up and to learn first-hand from one of the few foreign operators.

No. 332 Skvadron
The unit that took over from NDMA was 332 Skvadron (Squadron), which traced its history back to the Second World War where it was formed and fought from North Weald airfield. No. 332 Skvadron received a visit from two F-22s from USAF Tyndal AFB that were in Europe for a three-week training deployment.

On 5 March 2019 the Royal Norwegian Air Force had fired an AMRAAM for the first time from an F-35 over at the Halten proving ground north-west of Ørland air station. This milestone was accredited to 332 Skvadron and was seen as stepping stone towards IOC which was scheduled to be achieved later in the year. According to the commander of 332 Skvadron, Lieutenant Colonel Ståle Steel Nymoen, the first AMRAAM firing had taken place in co-operation with the TTT squadron (Testing, Trening og Taktikk or Testing, Training and Tactics). On 7 May 2019 another batch of three aircraft arrived in Norway, thus making a total of twelve aircraft in the country and bringing closer the IOC of 332 Skvadron. As the RNorAF was, at the time, the sole operator of the brake chute it is perceived as a system used only during winter time. One cannot be more wrong: the brake chute is used regularly throughout the year so that it does not give any surprises and crews know how to deploy it. On 1 September eight of the RNorAF F-35s deployed for the first time to Evenes Air Base, to practise the quick reaction alert (QRA) mission and become acquainted with the base. On 6 January 2022 the QRA mission performed by the F-16

was handed over to the F-35, which would perform the task from Evenes. This was a major step in replacing the F-16 fleet with the F-35. At the time twenty-seven F-35s had been delivered to Norway with the remaining seven at Luke AFB and 62nd Fighter Squadron.



The Royal Norwegian Air Force F-35's has taken Quick Reaction Alert. (*Forsvarets*)



Up until writing the Royal Norwegian Air Force was the only operational air force actively flying with brake chute. (*Forsvarets*)



The brake chute deployed. (*Royal Norwegian Air Force*)



332 Squadron from the Royal Norwegian Air Force has been operating the brake chute on a regular basis. (*Royal Norwegian Air Force*)



Another important step for the Royal Norwegian Air Force was the first separation test of the JSM Norwegian Defence Management Agency.

331 Skvadron

Deliveries of F-35s to the 332 Skvadron continued at the planned intervals when by the end of 2023 the size of the 332 Skvadron was big enough to instate a second separate Norwegian F-35 squadron. The second squadron was established without major fanfare similar to the 332 skvadron. The second squadron is designated 331 skvadron and its first deployment out of Norway was to Iceland in January 2024. As both the 331 skvadron and the 332 skvadron belonged to the132 Luftving (132 Air Wing) at Ørland aircraft were drawn from both squadrons. As the Norwegian F-35s were not applied with unit markings it was impossible for the outsider to discern the difference. It was expected that the 338 Skvadron Tiger would be re-established in the future as a third F-35 squadron.



Republic of Korea Air Force takes off for its first flight. This one already had its country roundel present on the fuselage. (*Lockheed Martin Mikaela Maschmeier*)



The third ROKAF F-35 taking off. At the time of writing this book the ROKAF had received all its 40 ordered F-35s. (*Lockheed Martin Angel DelCueto*)



Departing and tucking its landing gear away. (*Lockheed Martin*)

Republic of Korea Air Force

Major Kiyun Jung became the first Republic of Korea Air Force (ROKAF) pilot to fly the F-35 on 24 July 2018 although the date that the Koreans arrived in the USA for their flight training has not been disclosed. That first flight occurred in the first F-35 delivered for Korea and the Koreans were training with 944th Operations Group Detachment 2 at Luke AFB.

When training was complete the aircraft transferred to South Korea where they became part of 151 Squadron. The ROKAF had decided that the F-35 squadrons would each have thirteen aircraft. As part of 17 Wing, 151 Squadron achieved IOC on 17 December 2019. After 151 Squadron had received its full complement of F-35s, deliveries continued to the same base for 152 Squadron. The final three of the forty aircraft ordered were delivered in 2022.

Denmark

727 eskadrilla Volat – Percutit – Revervitur

'I have decided that the new squadron should be called Squadron 727. Squadron 727 has been chosen, partly because it is the Air Force's oldest

existing fighter squadron, but also because the squadron has twice previously been responsible for introducing new aircraft types', says Major General and Commander of the Air Force Jan Dam. The squadron 727 has Thor's hammer Mjølner, as a symbol and the motto: 'Volat, Percutit, Revervitur' or in English 'It flies, it hits, it returns'. The plan is that while Squadron 727 transitions from the F-16 to the F-35A the unit will remain current on the F-16. Only at the time that they can provide the capability to replace the F-16s will they be replaced. So once the first F-35A was to be delivered there will be in effect two units under the same unit Squadron 727 operating the F-16 and Squadron 727 operating the F-35.



One of the first F-35A for the 727 Squadron seen departing Fort Worth. (*Lockheed Martin*)

On Deployment

With all the impressive technologies involved it is easy to forget that the F-35 is basically a system for war. Since the United States has been in an almost continuous war situation in the Middle East since 1990 it was little surprise that the F-35 would be used there once it had entered service. Critics might point out that the F-35 would be an 'overkill' system to use in the Middle East as stealth features are not necessary since the US was flying with impunity over the Middle East and Afghanistan.

The first unit to record combat was actually from outside the USA. It was the Israeli Golden Eagle 140 Squadron. While exact circumstances remain unclear, Israeli Air Force Commander Major General Amikam Norkin announced on 22 May 2018 that the F-35I Adir had been operating all over the Middle East and had twice been used in anger.

In March 2022 the Israeli Air Force revealed that, in March 2021, four F-35 Adirs were used to deal with UAVs approaching Israeli air space. Four fighters were scrambled for the interception, two from 116 (Lions of the South) Squadron and two from 140 (Golden Eagle). Colonel N., 116 Squadron's commander at the time, said: 'We sent two jets beyond Israel's borders, to identify, classify, and down the UAVs within seconds. The aircraft is extremely powerful, capable of detecting slow targets far from "home", and in co-ordination with the control units they provide wide-ranging air defence against constantly evolving regional threats.' According to the Israeli Air Force the downed Shahed 197 UAVs were used to deliver weapons to the Hamas terrorist organisation. In the video one of the kills was performed by a missile and, interestingly, the F-35 ground-collision warning, also known as 'Bitching Betty', could be heard warning the pilot about his altitude.



A dedicated test aircraft for the Israeli Air Force: unique aircraft, note the colour roundel on this F-35. (*Israeli Air Force*)


The two aircraft loaded out. Note that the aircraft in front has its weapon bay doors open and that one AMRAAM can be seen in the inner weapon bay door. (*Aeronautica Militare*)

The first US unit to deploy the F-35 in anger was the Marine Corps VMFA-211 'Wake Island Avengers'. The squadron operated from the USS *Essex* near Afghanistan; VMFA-211 formed part of the 13th Marine

Expeditionary Unit. On 28 September 2018, the F-35B used precision bombs against the Taliban. It was first time during the operations, but probably not the last, that VMFA-211 would be called upon.

The USAF deployed their F-35A to the Middle East for the first time in April 2019. The F-35s were from 388th and 419th Fighter Wings based at Hill AFB. The twelve F-35s departed on 11 April and arrived at Al Dhafra Air Base in the United Arab Emirates (UAE) on the 15th. It was the first time that they had deployed to a conflict zone. The F-35As conducted the first airstrike using a joint direct attack munition (JDAM) to strike an entrenched Daesh tunnel network and weapons cache deep in the Hamrin mountains, a location that threatened friendly forces, on 30 April 30. The biggest strike performed during the half-year long deployment was on Qanus island near Mosul, where ISIS was thought to be hiding. To make sure that the island was without any ISIS presence 36,000kg of munitions were dropped by F-35As and F-35E Strike Eagles on 10 September. Further news about the deployment was not forthcoming. Brigadier General David Abba did call the results of this deployment eye-watering. In a briefing for the Mitchel Institute, he told the audience that roughly 1,300 combat sorties had been performed, accounting for roughly 7,300 combat hours during which approximately 150 weapons were employed. There were no ‘bad bombs’ due to aircrew error or weapon systems malfunction. At the beginning of the deployment the full mission capability rate was in the low seventies but, by the end, the maintainers had got that up to the low nineties. Another interesting fact mentioned was that during one mission a two-ship formation of F-35s had picked up on their display a high-value surface-to-air missile as a result of their sensors scanning the area. Since they had a different task, they sent the co-ordinates of the SAM back to base for them to take care of it. After six months the twelve aircraft returned to Hill AFB in October 2019.



An F-35B landing on the USS *Essex* during Dawn Blitz.

On 13 November 2019, 34 Fighter Squadron, 'the Rams', deployed to Al Dhafra on a six-month deployment.

Operation OCTAVE QUARTZ

In the war on terrorism, the field of operations was not limited to Afghanistan and the Middle East. Somalia, in the east of Africa, was another battleground. By 16 January 2021 the USS *Makin Island* (LHD 8) arrived off the coast of Somalia and initiated operations with the F-35Bs from VMFA-122 as a part of the Marine Medium Tiltrotor Squadron (Reinforced) 164, 15th Marine Expeditionary Unit, providing close air support and using the gun pods in action for the first time.



An Italian F-35B with an almost full load out coming in for a vertical landing. (*Aeronautica Militare*)



The Italians were trail blazers with many milestones. They were the first partner country to operate with two versions of the F-35. (*Aeronautica Militare*)



A F-35 from the VX-23 Salty Dogs on the Italian carrier *Cavour*. (*Marina Militare*)



An Italian F-35B from the Italian Navy deployed to the ITS *Cavour*. In the background an Italian AV-8B Harrier. (*Marina Militare*)

Carrier Strike Group 21: First Operational Deployment of HMS *Queen Elizabeth*

On 1 May 2021, HMS *Queen Elizabeth* (R08) departed from its homeport of Portsmouth, equipped with seven Merlin HM.2 helicopters, three of which had the Crowsnest capability, from No. 820 Naval Air Squadron. The deployment was planned to last seven months and would be a busy one as, besides friendly exercises, the two squadrons of F-35Bs planned to operate from the *Queen Elizabeth* arrived from either RAF Marham or RAF Lakenheath on 2 and 3 May; one arrived at a later date and it is unclear when it departed RAF Lakenheath and when it joined the *Queen Elizabeth*. The two F-35B squadrons were No. 617 Squadron 'The Dambusters' and USMC VMFA-211 'Wake Island Avengers', arriving respectively from RAF Marham and RAF Lakenheath. A total of eighteen F-35Bs embarked on *Queen Elizabeth*, eight from the Dambusters and ten from the USMC, well below the maximum capacity of the carrier.

Date of embarkment	Production number	Registration	Nose number
2 May 2021	169597 BK-16	ZM150	016
2 May 2021	169598 BK-17	ZM151	017
2 May 2021	169629 BK-18	ZM152	018
2 May 2021	169699 BK-20	ZM154	020



Deployed on the *Queen Elizabeth* VMFA-211 participated in several exercises. One of the first was Exercise Falcon Strike. (*Dvids 1 Lt. Zachary Bodner*)

Date of embarkment	Production number	Registration	Nose number
2 May 2021	169620 BF-84	CF-00	00
2 May 2021	169621 BF-85	CF-01	01
2 May 2021	169587 BF-62	CF-02	02
2 May 2021	169589 BF-64	CF-04	04
2 May 2021	169678 BF-93	CF-05	05
2 May 2021	169607 BF-71	CF-06	06
3 May 2021	169421 BK-13	ZM147	013
3 May 2021	169422 BK-14	ZM148	014
3 May 2021	169698 BK-19	ZM153	019
3 May 2021	169700 BK-21	ZM155	021
3 May 2021	169608 BF-72	CF-07	07
3 May 2021	169610 BF-74	CF-08	08
3 May 2021	169614 BF-78	CF-09	09
May 2021	169416 BF-61	CF-03	03



Carrier Strike Group 21 under the leadership of the *Queen Elizabeth*. If an F-35 takes off and passes the handlers on the deck most of them turn their backs to the exhaust to protect them from the heat. (*Dvids 1 Lt. Zachary Bodner*)



The *Queen Elizabeth* is larger than the LHD in the USMC service and for this reason holds more F-35s and is therefore a fantastic power projection tool. Note the ski ramp is another difference between the UK and US ships. (*Dvids 1 Lt. Zachary Bodner*)

HMS *Queen Elizabeth*'s first deployment had a full schedule with the first exercise being Strike Warrior, which would ready the ship for its deployment. Exercise Strike Warrior was mostly maritime. On 10 May 2021 an ASRAAM was fired from a British F-35B for the first time. After Exercise Strike Warrior, the *Queen Elizabeth* took part in Exercise Atlantic Trident 2021, from 17 to 28 May. This exercise included participation by France and the USA and was the first airpower exercise. Atlantic Trident had already taken place twice in the USA but this time it was based in Mont de Marsan, France. The French provided the Dassault Rafale, the USA provided the F-35A from 4th Fighter Squadron, and the F-35B from the 'Wake Island Avengers' on the *Queen Elizabeth* while the UK also provided the F-35B and the Eurofighter Typhoon.



Operation Octave Quartz was off the coast of Somalia and as can be seen the F-35B carried a gun pod meaning it provided close air support. (*Dvids*)



An F-35B behind a tanker during operation Octave Quartz. (*Dvids*)

After Atlantic Trident the *Queen Elizabeth* sailed around the Iberian peninsula to join Exercise Falcon Strike, participants in which were the F-35s from Amendola, Italy, F-35As from Nevatim Israel, and F-35Bs, both Dambusters and USMC, from HMS *Queen Elizabeth*.

Carrier Strike Group 21 passed through the Suez Canal and from there to the Indian Ocean paying a short visit to Singapore and before continuing to the South China Sea upsetting China which claims those waters as their own although, according to international rules, these are international waters. CSG 21 was also protecting other countries' ships in the area by performing such freedom of navigation operations. From there the group continued around South Korea to Japan and, by October, had begun the return trip.



Dropping away after just having refuelled this F-35B from the VMFA-122 Flying Leathernecks is on a Close Air Support mission.



The crew of the VMFA-211 look on as an F-35B from the 617 Squadron Dambusters comes in to land. (*US Navy*)



A pilot walks past a British F-35 on the HMS *Queen Elizabeth*. The 617 Squadron Dambusters deployed only with 8 aircraft. This will not improve in the near future as HMS *Prince of Wales* has also become operational. (*US Navy*)



The Green Knights on arrival to MCAS Iwakuni, one of the first major deployments of the F-35B. (*Dvids*)



This image already taken before Carrier Strike Group 21 set sail. It does give a good view of how the F-35Bs are located around the ramp. (*Dvids*)



The pilot and ground crew check that everything is in working order before removing the chains. (*Dvids*)



Authentic US Army Air Force National Star and Bars used from 1941-to 1943 on the inside of the liftfan door of BF-78, serial number 169614, nose number 09. (*Dvids*)



The American flag painted on the inside of the liftfan door of BF-64, serial number 169589, nose-number 04. (*Dvids*)



BF-72, serial number 169608, seen taking off from the *Queen Elizabeth*. (*Dvids*)



The British were also using the lift fan door as can be seen by this Union Jack applied on the inside of this F-35B from the 617 squadron, the Dambusters. The BK-16 serial number 169597, English registration ZM150 and nosenumber 016. (*Dvids*)



The ground handlers show the pilot that he has been detached and that he is free to move. (*Dvids*)


A batch of F-35B coming in to land on the *Queen Elizabeth* carrier. The mix of aircraft are from both countries. (*Dvids*)



Two F-35s supporting Operation Shader during the deployment of Carrier strike group 21. (*Crown copyright*)



Two F-35s from the Dambusters during the first deployment of Carrier Strike Group 21. ZM152 was later lost in an accident. (*Crown Copyright*)

Although on its way back from its first deployment, for CSG21 the return voyage was still an opportunity for integrating partners. On this leg of the deployment, the co-operation and integration was with the Italian Navy and Air Force as they deployed to the ITS *Cavour* together for the first time with their F-35Bs while also landing on the



Two F-35B's patrolling the skies equipped each with minimally two ASRAAMS, but what was in the weapon bays is anyone's guess – they might be empty. (*Crown copyright*)



The handler stands behind the white line which is a safety demarkation. (*Crown Copyright*)



The aircraft handlers waiting for the F-35 to land to tow the aircraft to its spot and initiate the after flight maintenance. (*Crown Copyright*)



Two F-35Bs landing in quick succession on the *Queen Elizabeth*. It was the largest deployment of F-35B's till that point. (*Crown Copyright*)



Landing of BL-04, an F-35B from the Italian Navy. Italy was the third country to land an F-35B on the *Queen Elizabeth*. The Italians deployed two aircraft one from the Italian Navy and one from the Italian Air Force. (*Crown Copyright*)



The Italian Navy F-35B being secured. Note in the background the ITS *Cavour*. (*Crown Copyright*)



At the time of writing this is the only F-35B, BL-3, assigned to the Italian Air Force. (*Crown Copyright*)


A M



The Italian Air Force landing on the *Queen Elizabeth*. The deployment was promoted the entire way as one of cooperation between allies. (*Crown Copyright*)

Queen Elizabeth. In return two USMC F-35Bs from *Queen Elizabeth* visited the ITS *Cavour*. This cross-deck operating between the Italian Air Force and the Italian Navy and the Royal Navy and Royal Air Force was an early test for future interoperability of those forces. The USMC VMFA-211 did not complete the entire deployment. On 25 November the ten F-35Bs of VMFA-211 'Wake Island Avengers' left HMS *Queen Elizabeth*. By then the *Queen Elizabeth* had only seven F-35Bs from 617 Squadron as ZM152 had been lost during a take-off accident.

Operation Swords of Iron

As a result of a terrorist attack on October 7, 2023 where 1200 people were killed. Israel started a war against Hamas. The operation to destroy Hamas was called Operation Swords of Iron. Town in the Gaza were bombarded and three units that fly the F-35I were involved. The US confirmed in a hearing that it had rushed modifications of the Mission Data Files to Israel in the week leading up to the operation which started October 27, 2023. The only specific success of the F-35I was the reporting of it shooting down a cruise missile after being scrambled to intercept it. The cruise missile was fired from Yemen probably by the Houthi militants.

Mishaps

Society has become risk averse although the risks taken in the prime years of aviation just after the Second World War brought the biggest advances. The following overview should be seen in context of the number of flight hours compared with previous generation fighters. If one would compare the safety of the Lockheed F-104 Starfighter, or the General Dynamics F-16A/B, the number of accidents will come out favourably for the F-35. One could also take the safety record of the Harrier and compare it to the F-35B's; one will come to surprising conclusions. If one takes into account the advanced technology, especially the propulsion system, the shaft-driven lift-fan was considered a high risk by many but here the comparison will also be favourable, compared to the same stage of development for service. Mishaps tend to lead to discovery of problems and these are often remedied as a result make the aircraft a better product.

F-35A AA-1 3 May 2007
Although never really acknowledged as a mishap the pilot performed a hard landing and as such was happy for the test team to return the aircraft in one piece. An electrical anomaly occurred during the flight. For 30 milliseconds the aircraft's electricity was cut off as the aircraft's computers reconfigured. Previously the AA-1 had only been flying up to 30,000ft. The problem occurred at a height of 38,000ft and the problem was connected with one of the Electro-Hydrostatic Actuators (EHA). The problem was caused by arcing between electrical units, arcing is the luminous discharge of electricity across a gap between two electrical terminals. The electrical short cut that occurred during the nineteenth flight was due to a cable touching the lid in a box in one of the Electro-Hydrostatic Actuators (EHA).

F-35A AF-27 10-5015 total write off 23 June 2014 USAF
The first accident with a production aircraft occurred on 23 June 2014. The mishap aircraft was AF-27 or serial number 10-5015. It was based at Eglin

AFB and was assigned to the 58th Fighter Squadron. This accident was due to technical malfunction within the engine and as such no human failures from maintenance or flight personal were observed. The 58th Fighter Squadron (FS) was the first US training squadron with little experience on the F-35 and as such not able to learn from other squadrons experiences. The mishap pilot had a total of 984.5 flight hours of which 33.8 hours was in the F-35A at the time of the mishap according to the Accident Investigation Board (AIB) report. Of the 33.8 hours 8.1 hours were as an instructor pilot. The pilot had previous experience as an instructor pilot in the F-16. The operations tempo of the 58 FS was average to low based on a comparison with a comparable F-16 Formal Training Unit Squadron. Due to the fact that the F-35A production and developmental test phases were being conducted simultaneously at the time, there were multiple restrictions on the F-35A flight envelope that reduced the number of mission types on which the squadron trained at the time. The squadron's instructors were all previously experienced instructor pilots in their previous fighter aircraft. Experience in the F-35 was most of the time low due to fairly recent transition to the aircraft. Extended groundings and software immaturity caused the squadron to accrue only limited experience. This had, however, no effect whatsoever on the mishap.



AA-1 during its ninth flight, that is ten flights before its emergency landing on the 19th flight. Note the pink color AA-1 on the underwing and aft fuselage. This paint was used for fuel dumping evaluation as contact with fuel left clear maps of where fuel had reached after a fuel dump. (*Lockheed Martin*)

At 09: 09 local time the pilot with call sign 'Thug' began take off from runway 12 at Eglin AFB as the second pilot of a two flight. According to the report at the correct rotation speed the pilot began to rotate (lift the nose wheel of the ground). During the rotation the engine stalled. On the pilot's display is the integrated caution, advisory, warning system (ICAWS) and showed the shortened warning message ENG STALL. Immediately the pilot applied the abort procedure and at the same time other warnings were presented to the pilot by the ICAWS. The warnings that came up were FIRE FIRE, FIRE GEAR and HYD FLUID B. FIRE GEAR indicated that the fire detection sensors located in the wheel wells detected fire. The caution HYD FLUID B indicated that the hydraulic fuel in system B was below minimum levels. As the aircraft came to stop more warnings were presented to the pilot on the ICAW, these included BLD LEAK ENG, IPP FAIL and HYD FAIL B. The last warning indicated that the hydraulic system B was without fluids. The IPP FAIL indicated that the integrated power package (IPP) was not working. BLD LEAK ENG indicated that hot air from the engine was detected outside the engine. The pilot managed to stop the aircraft about

8000 feet down the runway. The pilot left his aircraft at 09: 10: 38 only one minute and a couple of seconds after he began his take off.

According to the Aircraft Accident Investigation Board (AAIB) the fire continued for approximately seven minutes spreading from the initial fire on top of the aircraft to a ground fire fed by leaking fluids (from pressurised hydraulic fluid and JP-8 fuel from the fuel tank) and a subsequent internal engine bay fire.

f. Egress and Aircrew Flight Equipment (AFE)

All AFE performed its intended function, without incident or hindrance to pilot recovery (Tabs J-1.63 and J-5.15). The MP initiated ejection at approximately 4,900 above ground level or 200 ft above the ground (Tab J-2.7 and J-2.10). The MP initiated a successful ejection conducted at low speed and low altitude (Tab J-2.43). The ejection seat automatic sequencer functioned correctly, resulting in a successful ejection for the MP (Tab J-2.14).

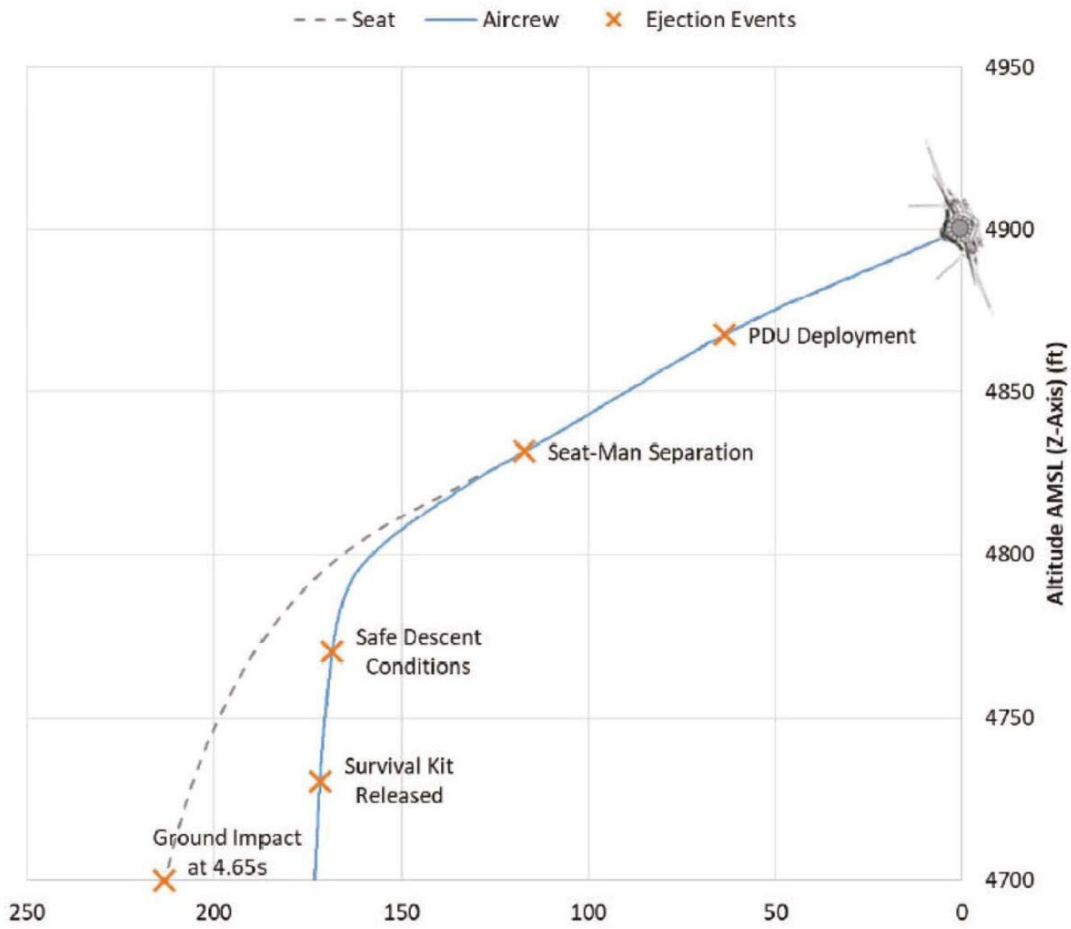


Figure 11: Ejection Trajectory (Tab J-2.10)

AIB Report.

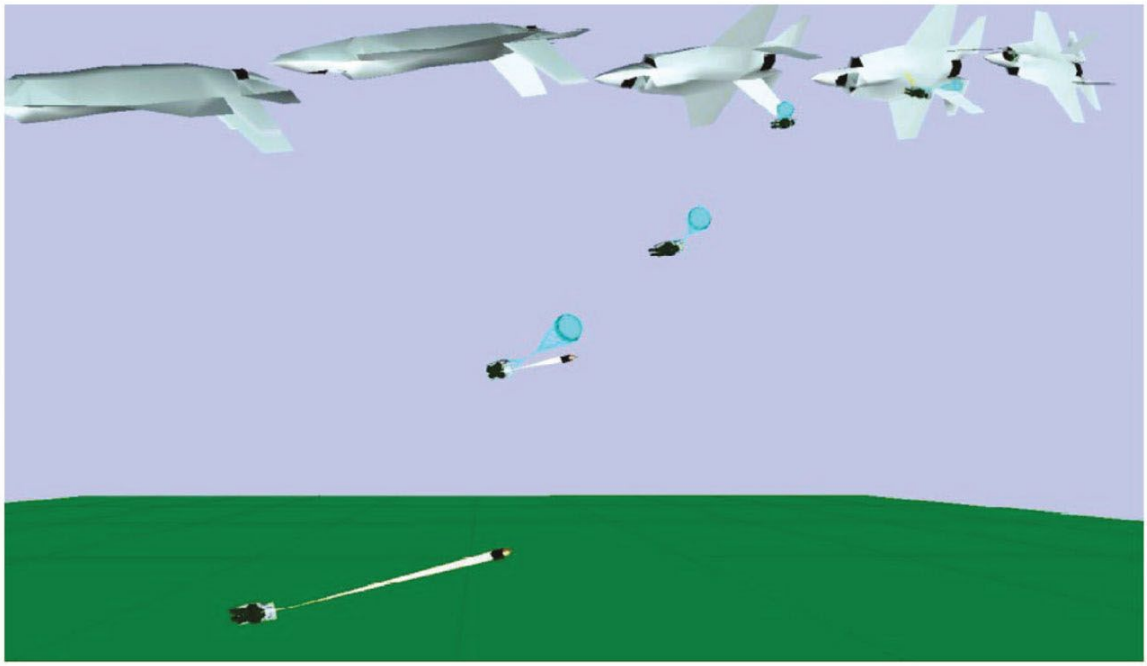


Figure 12: Representative Animation of the Stabilization Phase (Tab J-2.12)

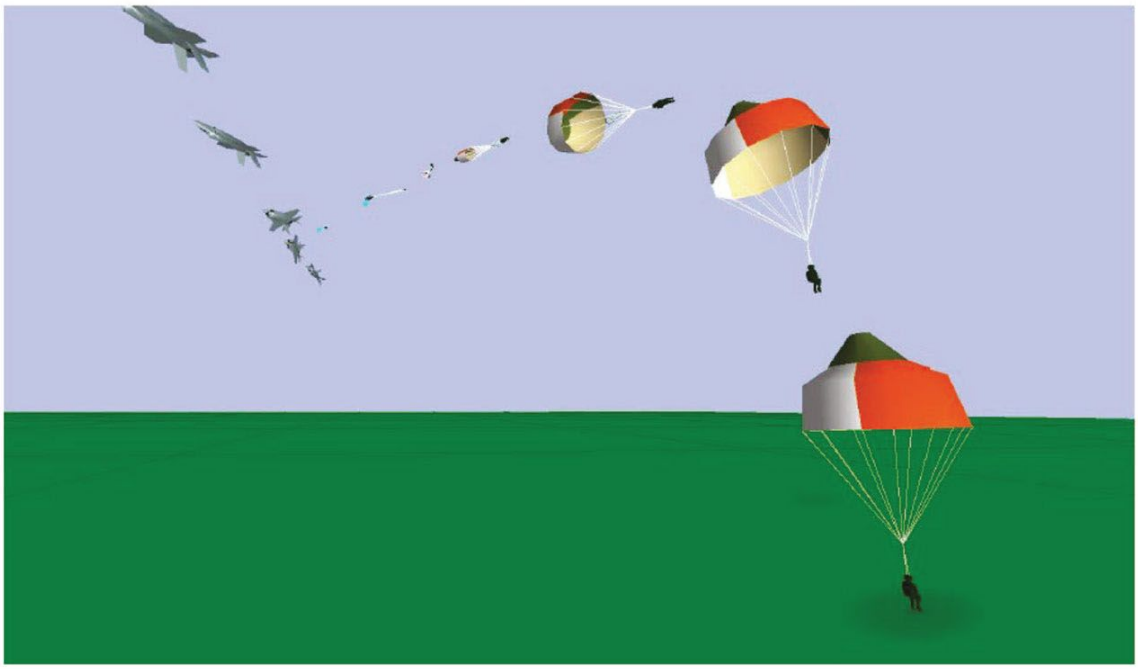


Figure 13: Representative Animation of the Recovery Phase (Tab J-2.12)



AF-27 seen here during its first flight from Fort Worth. (*Lockheed Martin*)

That was roughly how the pilot must have experienced the incident on take off from the cockpit. It was soon recognised that the engine was the cause of the accident. The F-35A's Pratt & Whitney F135-PW-100 turbofan engine is made up from five modules. The engine produces 43,000 pounds of thrust and consists of a 3-stage fan, a 6-stage compressor, an annular combustor, a single stage high-pressure turbine, and a 2-stage low pressure turbine. In the report it stated that the initial engine malfunction occurred in the fan module which is the forward most section of the engine. The fan module consists of Inlet Guid Vanes (IGV) and three stages of rotors. The third stage rotor is commonly referred to as R3. A pair of plate seals encircles the forward integral arm of the third stage rotor. A foam strip mounted to the second stage stators aligns with the seals to improve airflow efficiency in the fan sections. Stators are stationary pieces affixed to the outer engine casing that encircle the integral arm seals to improve airflow efficiency.



AF-27 in service at Eglin AFB. (*USAF*)

The R3 integrally bladed rotor (IBR) is a single piece that includes the rotor disk with blades as well as the forward integral arm. This integral arm was missing from the mishap aircraft and it had ejected itself and punctured itself through the top of the engine fan case, three hydraulic lines, severing partially a pressurised fuel transfer tube and severing a fuel siphon tube completely located over the engine in a fuel tank and exited the fuselage through panel 3331 at the 11 o'clock position if looking forward from the tail end of the aircraft. The engine was examined after the mishap and was found with a hole the size of 3 x 11 inches (7.5cm x 27.5cm). The hole in panel 3331 was 7 x 10 inches (17.5cm x 25 cm).

The F-35A uses hydraulic power to extend and retract the landing gear, open and close various external doors, and provide braking and steering during ground operations. The three hydraulic lines were from hydraulic system B and caused the system B hydraulic reservoir to be empty within 17 seconds according to the black box or the more official name crash survivable memory unit (CSMU). Hydraulic system A functioned normally to provide redundant power to the wheel brakes to allow the pilot to stop the aircraft.

The cause of the engine failure was according to the AIB report was a material failure of the third stage Integrally Bladed Rotor forward integral arm. The mishap was caused when the third stage rotor (R3) of the fan

module fractured. This fracture occurred on the R3 forward integral arm and was caused by high-cycle fatigue following a hard tip rub event on the aft plate seal of the integral arm. The aft plate seal experienced heat damage from a hard tip rub against a strip of foam material attached to the second stage stator. Evidence of this hard tip rub was observed on the recovered segments of the R3 integral arm, found north of the runway approximately just before halfway of the runway. This included thermal and physical damage consisting of temper decolourisation (heat tinting), metal smearing, and heat check cracking. This heat damage eventually caused a fracture to occur axially through the forward integral arm. Subsequent fracturing occurred circumferentially between the forward and aft plate seals and between the aft plate seal and the R3 disk.



Shortly after the accident. The fire damage is obvious and the AF-27 had sustained significant damage. (*USAF*)

As these pieces of the R3 forward integral arm fractured and separated from the rotor assembly, they damaged sections of the second stage stator assembly, which in turn damaged the airfoils of the second and the third stage rotors and high pressure compressor (HPC). The integral arm fragments then punched an exit hole in the fan case that was coincident with the radial plane of stator 2. As the fragments continued on their outward trajectory, they penetrated an internal fuel tank where they completely or partially severed fuel and hydraulic lines. The integral arm fragments

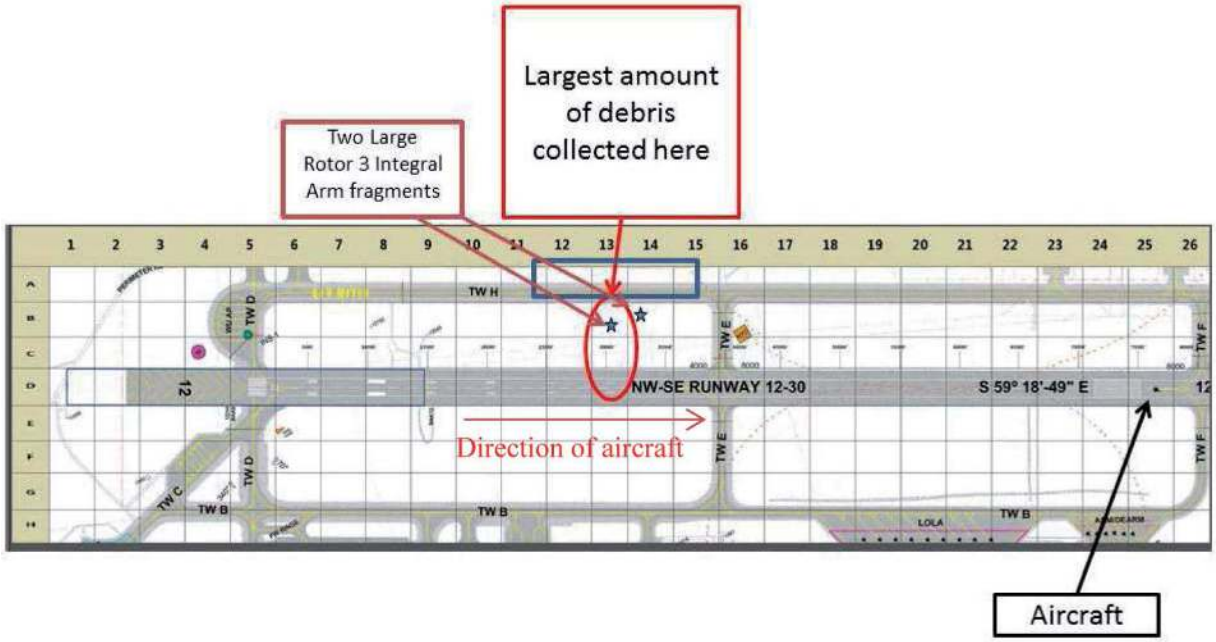
finally exited the aircraft at the forward inboard corner of the panel directly above the fuel tank causing a hole with the composite plies/fibres splayed outwards.

The GAO reported by April 2016 that the programme officials had identified a design change to address the technical problem that resulted in the engine fire. This design change has been validated and incorporated into production. Programme and engine contractor officials had identified 180 engines that would need to be retrofitted, and as of September 2015, sixty-nine of those retrofits had been completed, including all of the test aircraft. The engine contractor, Pratt & Whitney, was paying for the retrofits.

The damage to the plane was so extensive that it was a complete write-off. However, the Joint Program office (JPO) found a use for the damaged aircraft. The JPO has made significant progress in verifying joint technical data (JTD) for sustaining the aircraft's low observable signature, primarily by completing verifications on the damaged F-35A. As of September 2016, the programme had verified approximately 83 per cent of all JTD modules, but just over 50 per cent of those associated with support equipment.



A fragment of the R3 forward integral arm was found beside the runway at Eglin AFB. (*USAF*)



A graphic description of debris location after the failure in the engine. (*USAF*)

It was decided to re-purpose the jet as a maintenance trainer and test bed for developing new aircraft battle damage repair (ABDR) procedures and technologies. For this purpose the jet was acquired by Hill's Aircraft Battle Damage Repair (ABDR) Programme Office in 2019.

'Transporting AF-27 to Hill required the wings to be cut off in order to fit inside transport vessels since – unlike any other fighter in the Air Force's inventory – no provisions exist for detaching or reattaching the wings,' said First Lieutenant Sam Sentongo, chief of Hill ABDR Engineering.

The aircraft was delivered to Hill's 309th Expeditionary Depot Maintenance Flight by a C-17 military transport aircraft, a first for the F-35 programme.

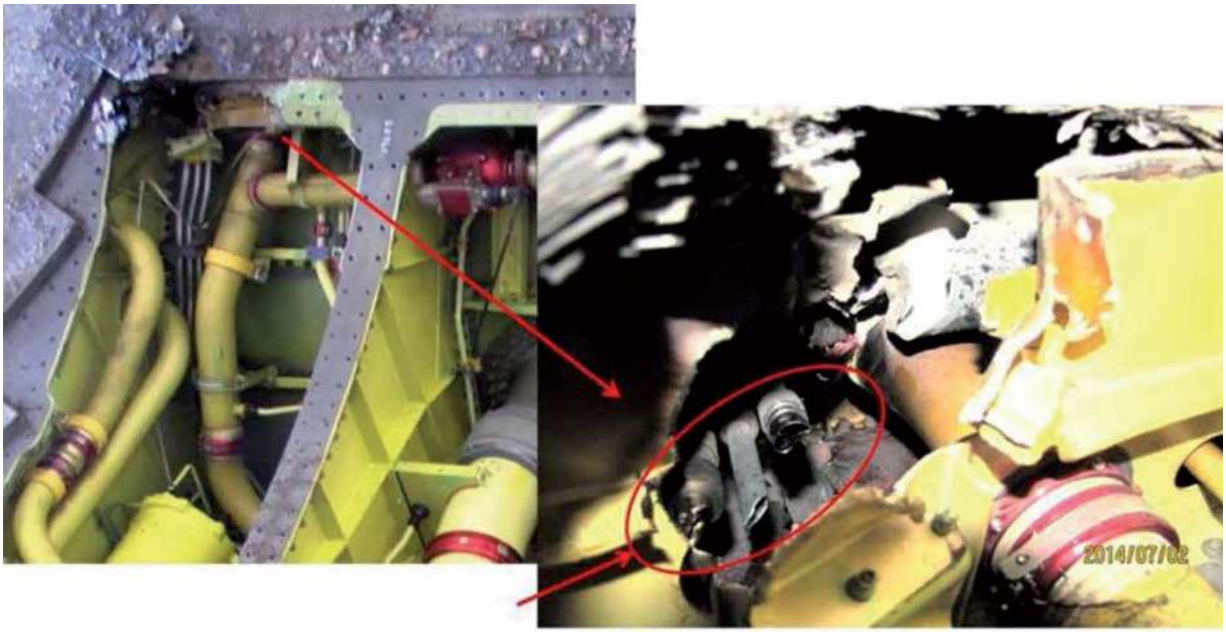
'The F-35 programme is in the throes of developing an ABDR manual for the three aircraft variants and AF-27 will be critical in helping develop and validate ABDR tasks,' said Dan Santos, 309th Maintenance Group heavy maintenance programme manager. 'AF-27 will be used to provide critical training to technicians in the accomplishment of assessing battle damage.'

F-35A AF-63 12-5052 23 September 2016 USAF

On 23 September 2016 an F-35 from the 61st Fighter Squadron from Luke AFB which deployed to Mountain Home AFB was damaged by fire during start up. After engine start up the aft end of the aircraft caught fire which forced the pilot to evacuate from the aircraft. No one was injured but as a precautionary measure the pilot from 61 Fighter Squadron and four 61st Aircraft Maintenance unit airmen, all from Luke AFB, and three airmen from the 366th Maintenance Group from Mountain Home were transported to the base medical centre for evaluation. Or so at least it was reported at the time. Seven aircraft from Luke AFB were deployed there from 10 September 2016.

The pilot initiated an aircraft engine start on the parking ramp at Mountain Home AFB, ID, by placing the engine switch on the mishap aircraft to RUN at approximately 08: 52 local time. The integrated power package (IPP) started and performed normally up through the beginning of engine start. The IPP provides electrical power to the Integrated Converter/Controllers (ICCs), which in turn provide and regulate electrical power to the engine mounted starter/generator (ESG). Twenty-four seconds after engine start IPP inlet temperatures rose. The only sources of hot gases were the IPP exhaust and the engine exhaust from the mishap aircraft that were blown by the wind back to the front of the aircraft. A direct tailwind of 30 knots or greater was present during engine start. The other five aircraft in line had not started up yet so these could not amplify the hot gas being ingested. Twenty-four seconds later, hot gas was ingested into the Integrated Power Pack (IPP) inlet causing a corresponding increase in the IPP exhaust gas temperature (EGT). Too high exhaust gas temperature is an indication of unsafe IPP system operation. Interestingly on the F-35A the IPP inlet and IPP exhaust are only approximately 3.5 feet from each other, the separation of the IPP inlet and the F135 engine exhaust is approximately 10 feet. An IPP FAIL integrated caution, advisory, warning (ICAW) occurred nineteen seconds later as the IPP performed an auto-shutdown due to an EGT over-temperature. The power and thermal management system (PTMS) monitors the IPP and performs certain tasks to get the IPP back up to full speed. The PTMS reduced electrical output to the Integrated Converter/Controllers (ICCs) and increased fuel flow to the IPP motor, the PTMS will continue to do so until the condition ceased to exist or as in this case unsafe IPP operation is reached, which was recognised by the high EGT. The PTMS reduced the energy levels and increased fuel flow for 17

seconds until the threshold for an IPP exhaust gas temperature overheat was reached. The IPP FAIL ICAW was followed four seconds later by a FIRE GEAR ICAW, which indicated fire detection sensors located in the main landing gear wheel wells detected fire. The detection of fire in the wheel wells by optical fire detectors was the first indication of fire 47 seconds after the pilot switched the engine switch to RUN.



Hydraulic and fuel line damage at the fragment exit point. The insert shows the 3 severed left-hand side main gear tubes. (*USAF*)



AF-27 burning on the runway. (*USAF*)



The R3 made it through the engine housing (*USAF*)

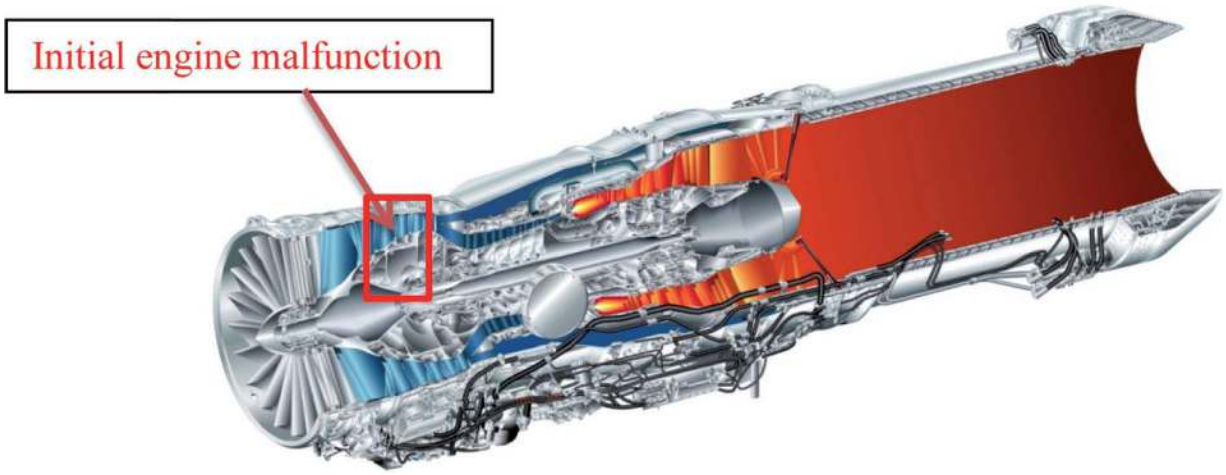


… and the aircraft like a knife through butter. (*USAF*)

Both the IPP and the PTMS worked as designed and advertised. The engine's start was normal until just after combustion was initiated. Approximately 24 seconds after start initiation, acceleration of the engine began to slow because power to the ES/G decreased due to increased IPP inlet temperature. Approximately nine seconds later (33 seconds after start initiation), increased fuel was added to the engine because of the slowed acceleration. At approximately 39 seconds after start initiation, the ICCs stopped providing power to the ES/G. At this time, the aircraft engine rotation was powered by combustion alone, which was insufficient to support engine acceleration, resulting in engine speed deceleration. Increasing fuel flow to the aircraft engine continued until approximately 62 seconds after engine start initiation.

The F135 engine, like all combustion engines, has a fire in it while running. Under normal circumstances, the fire is contained in the combustion section of the engine. During this mishap, however, the fire became uncontained due to the increased amount of fuel added while the engine rotation speed was slowing. Once the uncontained fire started coming out the aircraft exhaust, the tailwind carried it rapidly along the exterior surfaces of the jet.

Many outer surfaces of the aircraft on the aft two-thirds of the aircraft's centre fuselage section exhibited varying degrees of fire damage. The majority of the damage occurred on the aircraft's aft-most surfaces, mainly along the centre portion of the jet, including the top, sides, and underneath portions of the aircraft. However, minor damage was noted on some surfaces even forward of the cockpit. Exterior damage had been found not only on the surface of the aircraft, the wheel wells and the weapon bays which had been open which is normal operating procedure during engine start up. This allowed the fire to damage panels, wiring cables and multiple unidentified system components. The main landing gear fire detectors indicated fire was present for 20 seconds. The fire caused damage to multiple landing gear surfaces, surrounding areas and components in the left and right main landing gear wheel wells.



Location in the engine of the R3 forward integral arm. (*Pratt & Whitney*)



The exercise at Mountain Home AFB was the place for the following incident with the F-35A. This was one of the aircraft deployed there. (*USAF*)

The pilot was made aware of the fire by the ICAW but also by the ground crew. the initial news that he egressed without injury was not entirely correct. He was taken to the hospital with minor burns to his head, neck, face and ears, which all completely healed. The burn injuries indicate that the fire was rapidly moving forward and that the pilot was in duress and to egress from the aircraft was rightly his priority. The USAF Aircraft Accident Investigation Board (AAIB) reported that the pilot had not switched off the engine during his egress check list. Considering that the fighter was loaded with fuel for his mission it was only natural that fear of all this fuel exploding should encourage him to speed up his evacuation from the aircraft and not linger to switch the engine off. His helmet sustained fire damage and the remainder of his flight suit was also a write off due to possible contact with fuel. Interestingly pilots were not trained on tailwind engine start procedures and were not aware of any specific concerns related to tailwinds. Additionally, they did not have knowledge of specific limits or engine parameters to monitor during engine start, other than simply identifying that the aircraft displays were green/yellow/ red. The FADEC eventually shut off the fuel flow. All in all damage was

estimated to be in excess of 17 million USD but the aircraft was not written off.

It was only by April 2017 that planning for moving the aircraft to a repair depot was initiated. The aircraft was moved to the F-35 Depot at Hill AFB, Utah, with the help of the 366th Equipment Maintenance Squadron crash and recovery team. 'Our role as crash recovery started as first responders when the aircraft had an emergency last September,' said Master Sergeant Shane Mitchell, 366th EMS crash and recovery repair and reclamation section chief. 'We have since been involved in the various stages of planning to get it from here to Hill AFB.'



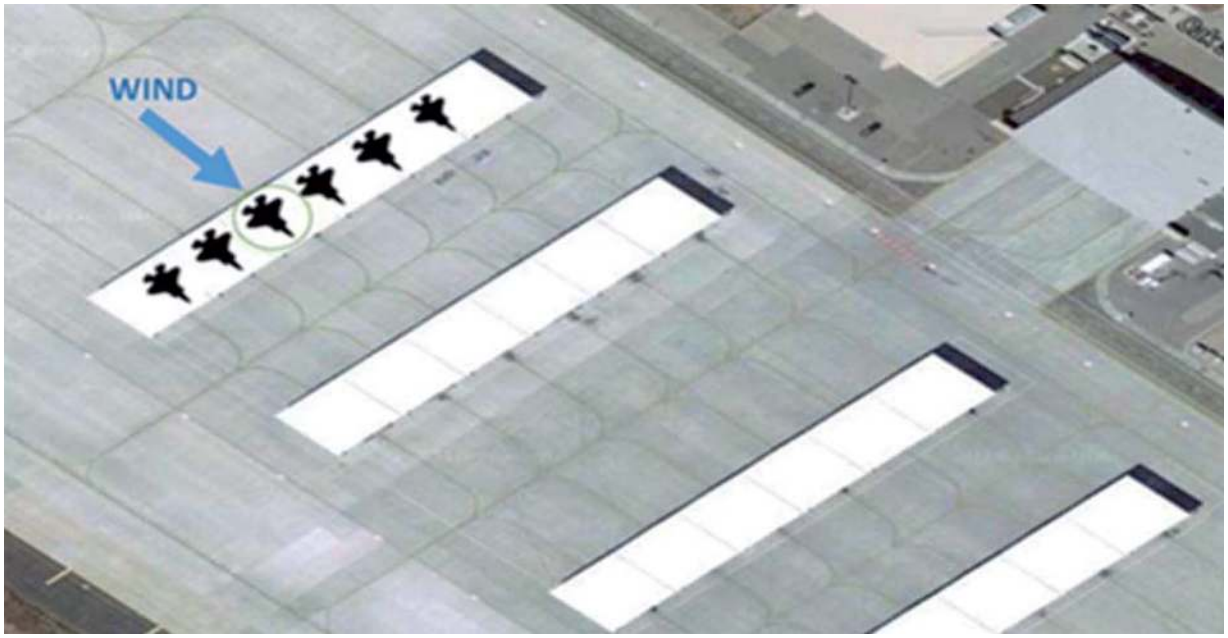
The mishap aircraft was seen here ten days before the mishap. The aircraft was seen departing Mountain Home AFB. (*USAF*)

'366th Crash Recovery (an F-15 unit) was the first to do an actual lift on an F-35,' said Daniel Santos, 809th Depot manager at Hill AFB. 'What's even more remarkable is Mitchell and his crew have no F-35 experience (or) training and using F-35 tech data, they performed a flawless lift.' Previously, a lift like this was only performed by the engineers at Lockheed Martin. The organization for the move started in April of 2017, where delegated tasks ranged from assisting with route and site surveys, to the actual lifting of the aircraft on to the specialized trailer used for transport.

The main concern was getting the aircraft to Hill's F-35 depot with no more damage than already sustained. According to Fox, the ultimate goal is to get it back to mission ready or use its parts in other aircrafts. The aircraft arrived at Ogden Logistics Centre on 2 November 2017.

F-35B BF-06 168057 27 October 2016 USMC

Fire was spreading through the fleet. Or so it seemed. One F-35B operating out of Beaufort caught fire during flight. A fire was detected in the weapon bays and the pilot managed to fly back to Beaufort, land safely and vacate the cockpit. No one was injured during the incident. Damage was, however, more than USD $2 million which made the classification of the accident automatically a Class A incident. The fire was caused by a faulty bracket issue, which was known as a potential hazard by officials of the F-35 programme and the services. The fire scraped electrical wiring near hydraulic lines. A fire erupted when an electrical short ignited a small hydraulic leak. No further information was forthcoming about this incident. The only information that was made available in May 2018 that it was not financially viable to repair the aircraft so it became the first production aircraft to be written off.



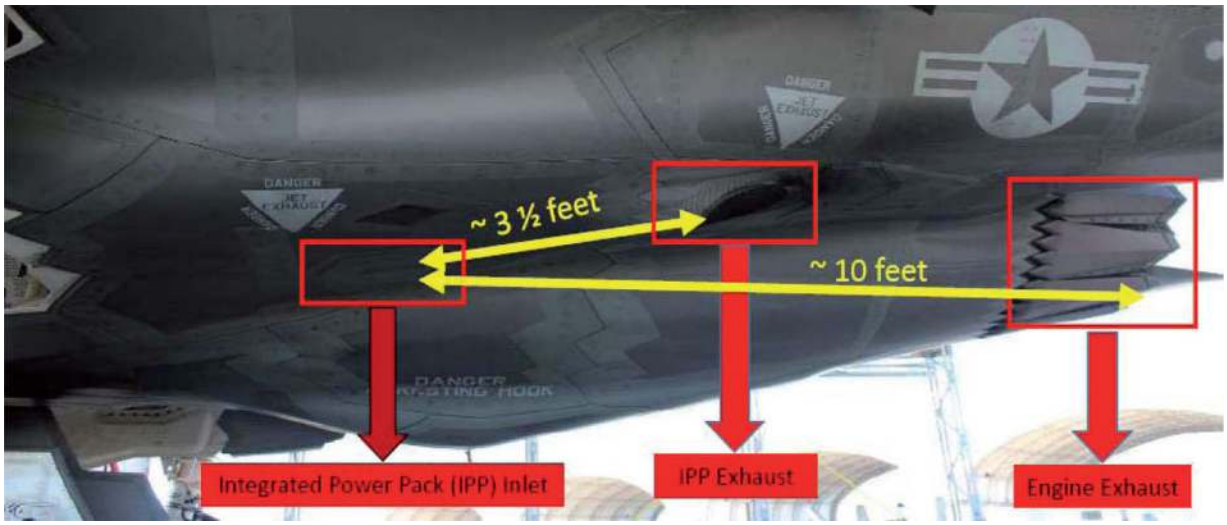
The wind played a major role in the incident as it was directly pointed at the tail, the exhaust nozzle. (*USAF*)

F-35A AF-106 14-5105 30 November 2017 USAF

Whether one can really call it a mishap is up for discussion but it caused some small damage and the flight had to be cut short since the stealth features had come undone. One panel had come loose and was lost during flight. The panel in question was the maintenance interface panel behind which are hinges on the upper edge; it is located among other systems communication connections, fuel and an IPP start switch. It happened to one of the aircraft from 34th Fighter Squadron deployed to Japan. The aircraft involved was AF-106 (14-5105) and the pilot landed without any problem. The incident took place over the Pacific Ocean as it was one of the twelve aircraft deployed from Hill AFB to Kadena, Japan. It was not made clear if the maintenance interface panel caused any further damage to the airframe as it became loose and fell off the aircraft.

F-35A 22 August 2018 USAF
Collapsed landing gear on an F-35 landing at Eglin AFB. It was the second F-35A from the 58th Fighter Squadron involved in a mishap. The pilot walked away from the incident without suffering any injuries. The amount or value of the damage to the aircraft was not given.

F-35C 22 August 2018 US Navy
A bad day in the office for the F-35 as two incidents occurred in one day. One was at sea while flying from the USS *Abraham Lincoln* (CVN-72). During an aerial refuelling mission the F-35 was flying behind an F-18C to receive fuel when things went bad. Debris of refuelling basket was ingested by the F135 engine. The F-35C landed safely back on the USS *Abraham Lincoln* but it was immediately classified as class A mishap because it was clear that the damage was more than $2 million USD. The F-18C returned to NAS Oceana where it landed safely, damage incurred by the F-18C was less than $500,000 USD and was considered a mishap class C. The thing that will have been noticed by the US Navy is that the F-135 was able to survive ingestion of hardware and survive and bring the single engine aircraft back to land safely.



The distances between the main nozzle, IPP nozzle and IPP location on the F-35A. (*USAF*)

F-35A August 2018 Israeli air Force 140Sq

Birdstrike, damage extent unknown also alleged by Iran and Syria that the aircraft was struck by their air defence systems. No other information available.

F-35B BF-21 168719 28 September 2018 US Marine Corps VMFAT-501

The first accident with an F-35 in which the Martin Baker US16E ejection seat was used. The pilot became ejectee 7585 from all lives saved by a Martin-Baker ejection seat. The aircraft crashed on an island near MCAS Beaufort where the F-35B is stationed. The F-35B was operated by the VMFAT-501. Shortly after the accident fuel tubes of the F135 engine on all aircraft were going through inspection and it was announced on 15 October 2018 that 80 per cent of the fleet had been inspected and returned to flying status. There was utter silence as to the serial number lost for a long time.



The mishap aircraft at Luke AFB, its home base before the accident. (*USAF*)



An F-35 with its internal ladder extended. An interesting shot. (*USAF*)

F-35A AX-05 15-5158 9 April 2019 Japanese Air Self Defense Force 302 Hikotai

On 9 April 2019 it was reported that a Japanese F-35 based at Misawa Air Base had disappeared from the radar. As the F-35 was over the sea at the time the Japanese send out ships to look for it. The first news noted that it was 135 kilometres from the coast, a search and rescue operation would start for the pilot and as the disappearance took place over international waters it would be important to salvage the remains of the aircraft or at least look into it if the remains would be too deep for a salvage operation. This was the first foreign-operated F-35 that was lost and as a result the remaining twelve Japanese F-35s were grounded. The accident happened shortly after the declaration of IOC by the Japanese Self Defence Force. The F-35 in question was AX-05 (15-5158) from 302 Hikotai (squadron), it was the first aircraft coming from the Japanese Nagoya production line. It looked as if it would also be the first time the pilot was lost as the next day only tail parts were found. The US Navy helped by sending in the Boeing P-8 aircraft on rotation in Japan and a guided-missile destroyer USS *Stethem* (DDG-63). Two days after the incident the name of the pilot, a 41-

year-old major, Akinori Hosomi, was given. Although so far there was no trace of him, the search would continue. Akinori Hosomi had accumulated 3,200 hours of flying time but only sixty hours of those on the F-35. Other news broke that this prior to its fatal flight particular aircraft had experienced two precautionary landings due to technical problems according to Japanese defence minister Kenji Harada. One reportedly occurred during pre-delivery flight test in June 2017, the flight was cut short due to a cooling system alert. Lockheed replaced the malfunctioning parts after the incident and on 8 August 2018 an error with the position indicator was the cause of the flight being cut short. It was not known if these emergencies were related to the accident. The parts found did not reveal any indication as to why the aircraft was lost. The remainder of the aircraft including the black box was laying on the bottom of the Pacific Ocean at an estimated 1,500 metres (4922 feet). The missing F-35 was part of a training mission with three other F-35s, it is rather strange that the other aircraft involved could provide little or no information as the EO-DAS of the three remaining aircraft should have been able to track its position and have given some details for the initial search and rescue effort, not to mention the tactical data link.



Crash Damaged Disabled Aircraft Recovery Program training at Hill Air Force Base on this F-35B from the VMX-22. (*USAF*)

It should be remembered that the aircraft had been deliberately constructed in such a way that echo reflections would not return to an emitter, thus presenting a real problem for searchers using Sonar to find such an aircraft. The Japanese Maritime Self-Defense Force had dispatched the JS *Chiyoda* (AS-405), a submarine rescue ship, which was only commissioned a year before. The longer the search lasted the less likely it was that the pilot would be found alive. The JS *Chiyoda* is a surface vessel that besides submarine rescue missions is aimed at deep sea salvage operations.

On 25 April 2019 the US Navy stated in a press release that from 9 to 17 April, the US Navy guided-missile destroyer USS *Stethem* (DDG 63) and P-8A Poseidon aircraft joined JASDF forces searching an area spanning

approximately 5,000 square nautical miles. US Navy P-8A Poseidon maritime patrol aircraft flew a total of 182 hours.

In the same release it stated that US Navy personnel had chartered the DSCV *Van Gogh*, a multi-purpose diving support and construction vessel equipped with US Navy remotely-operated vehicles and a US Navy towed-pinger locator (TPL-25) system so that more specialised equipment would help with the search for the lost F-35A. News broke that the F-35 had been found on 30 April. This was later refuted. The black box or flight data recorder (FDR) was retrieved in a damaged state, it was announced on Tuesday 7 May 2019; the data storage unit, an integral part of the FDR, was not found. Other parts were also found on the seabed. The pilot had not yet been found.

The Japanese confirmed that MADL was a help for the accident investigation and as soon as JASDF was sure that the risk of such an accident occurring again was technically negligible they would return the unit to flying status. The remains of the pilot, Major Akinori Hosomi, had been recovered it was announced on 7 June. So at least the pilot's family could get closure.

F-35B 7 May 2019 USMC VMFA-121

An F-35B from the VMFA-121 Green Knights suffered a bird strike during take-off. The extent of the damage was not known, just that the pilot aborted the take off and taxied back. The estimation of the extent of the damage was given to be over US$2 million. No other information was given, not even if the take-off run was in STOVL or conventional mode; in the former the aircraft is more vulnerable to damage as the lift fan could have choked up the bird as well.



A lineup of F-35As. 14-5105 is the first aircraft. (*USAF*)

F-35A AF-64 12-5053 19 May 2020 USAF 58th FS

This F-35A came in for landing at 9.30pm and unfortunately it did not go well. The pilot used his ejection seat and as such became Martin-Baker ejectee 7,620, the second time that the ejection seat in an F-35 was used successfully. The only information that became available was that the pilot check-list gained one point, an obvious measure to prevent similar mishaps from occurring again prior to the publication of the Accident Investigation Board (AIB) report. The mishap aircraft was the lead aircraft of Blue Flight, departing from Eglin AFB as the combination of an instructor and student pilot. The accident occurred during landing and as the reports stated, the mishap pilot set and held 202 knots calibrated air speed (KCAS) throughout the approach and landing. The aircraft touched down approximately 50 KCAS fast, and as a result of the increased speed, was approximately 8-degree AoA, more shallow than desired. The excess energy caused the nose to be driven down at a higher rate than the MP was accustomed to, and the shallow 5.2-degree AoA touchdown caused the nose gear to contact the runway immediately after the main landing gear. This resulted in a rapid and excessive nose-high bounce. Landing roll out became increasingly unstable after the first bounce for two reasons. First, the high-speed three-point landing caused the nose gear to compress and then rapidly extend.

This forced the nose into the air at a rate inconsistent with the mishap pilot's previous landing experience. Second, the shallow (5.2°) AoA at touch down is below the recommended landing attitude of 13-degree AoA. Aircraft control logic is optimised for stability at the desired landing attitude. Landing at 5.2-degree AoA resulted in the mishap pilot managing the initial bounce in pure pitch rate as opposed to the more stable, and desired, AoA-driven rates the mishap pilot would have experienced if landing on speed. Ultimately, the high-speed landing and resultant shallow AoA culminated in an out-of-control scenario developing on landing. The mishap pilot attempted to re-establish a landing attitude after touch-down. The aircraft landing lasted approximately five seconds before the mishap pilot elected to eject. Upon touch-down the mishap pilot initially attempted to dampen the rapid rise of the nose produced by the first bounce. The mishap pilot's initial reaction was consistent with attempting to recover from a bounce and set a landing attitude. However, the mishap pilot's stick inputs quickly fell out of synch with the aircraft pitch oscillations and control cycles initiated by the weight on wheels. This resulted in multiple conflicting flight control inputs. In the presence of large and aggressive stick inputs the flight control system, based on its control law (CLAW) logic, became saturated and unresponsive, and ultimately biased the flight control surfaces toward nose down. At the two-second mark, the mishap pilot set and held aft stick to try to re-establish a landing attitude. The horizontal stabilisers trailing edges remained full deflection toward nose down despite the pilot holding aft stick. The mishap pilot was unable to overcome the nose-down bias in order to re-establish a landing attitude or execute a go-around. The mishap pilot reported feeling confused, helpless, and ignored. Three seconds of pilot flight control input was not enough time to overcome the saturation caused by two seconds of prior inputs. The flight control system failed to ientate the aircraft to the appropriate attitude for a go-around, and thus avoid catastrophic loss of the aircraft. After three seconds of attempting to go-around, and after multiple and progressively worsening bounces, the mishap pilot released the stick to eject.



The BF-6 is seen here in better times, it's a transfer flight to Eglin AFB. (*Lockheed Martin*)

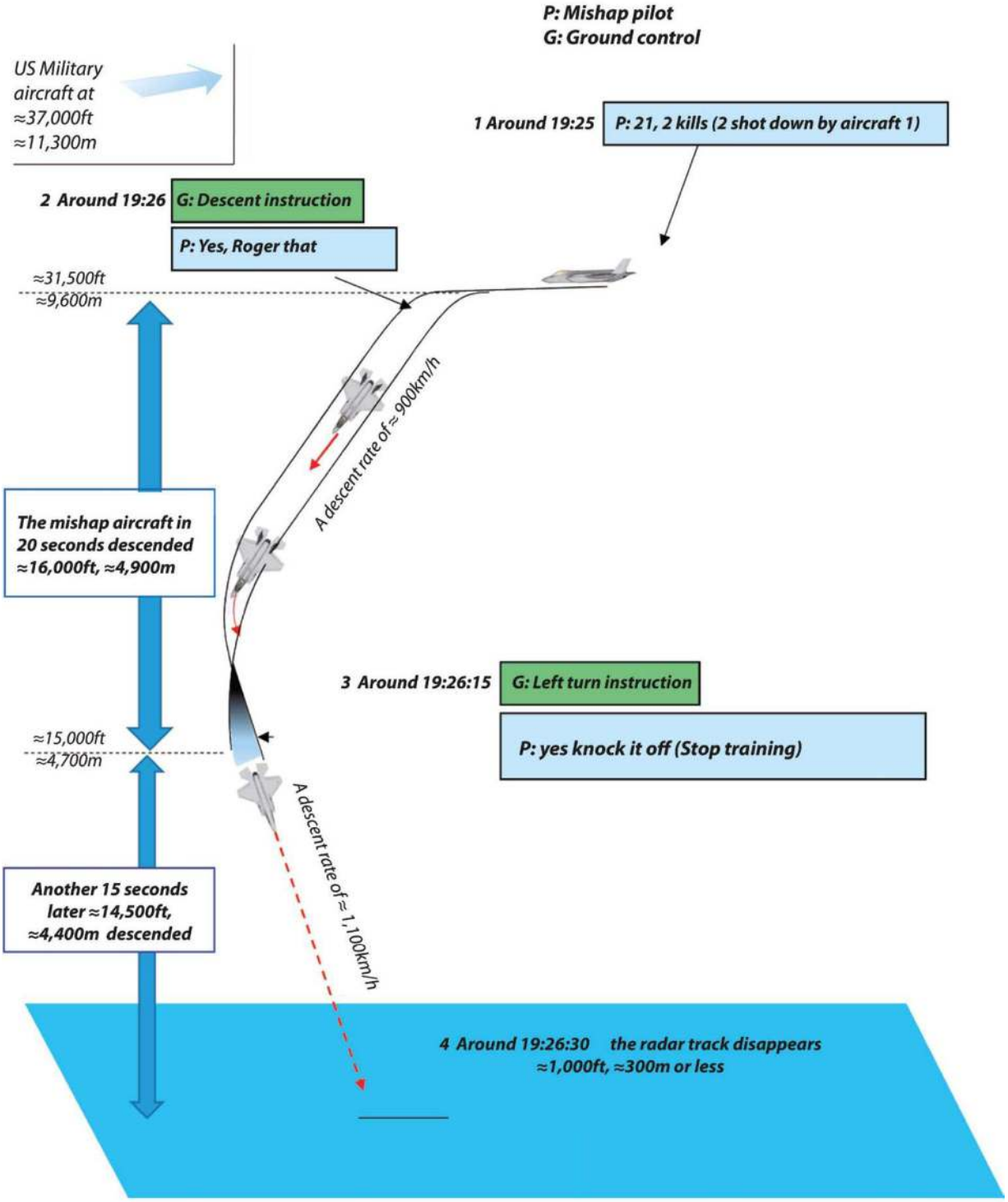


A screenshot of the F-35A 14-5105 without the Maintenance Interface Panel from a Japanese TV station posted on Twitter by @satwoon_msdf174



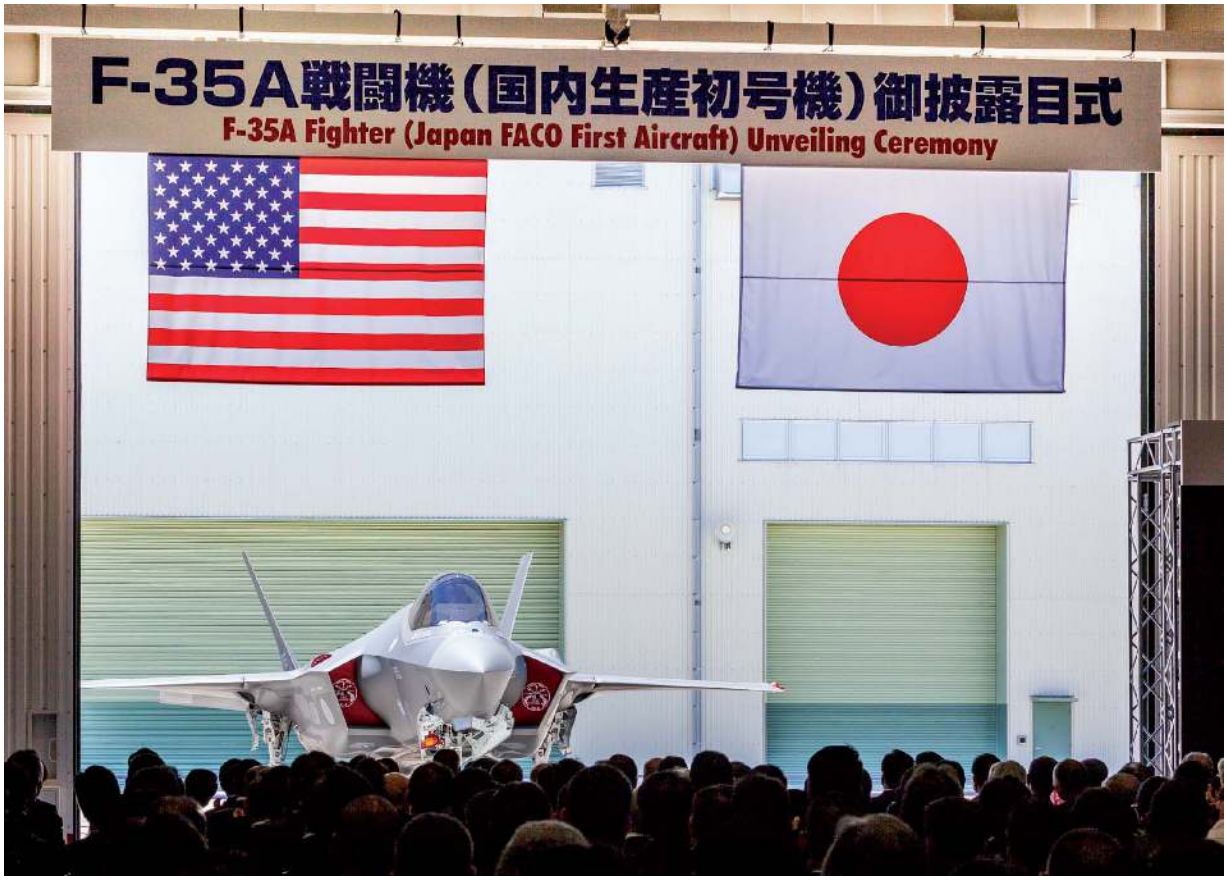
One of the first operational shots of the AMRAAM during Combat Archer 2017. (*USAF*)

The final minutes of the mishap aircraft





AF-35 found itself in this unfortunate position causing only minor damage. (*USAF*)



AX-05 was the first aircraft to roll off the Japanese production line. Unfortunately, it also got a couple of unwanted first such as being involved in the first Japanese F-35 accident and the first fatal F-35 mishap.

F-35A 8 June 2020 USAF 388th FW 421 FS

Another accident during landing occurred only a couple of weeks later but here from the outset it was clear that this could not be a case of pilot error as it was the landing gear that collapsed upon landing, damaging the plane. The pilot underwent a precautionary medical examination. Damage to the aircraft was specified but it blocked other aircraft from landing which had to divert to other airfields.

The nose of the aircraft received a bigger battering than expected but the cost of repairing was prohibitive. However an aircraft that was repurposed after an accident, AF-27, which was burned heavily at the aft and mid fuselage but did not have any damage to the front fuselage. The idea, which was revealed on November 30, 2023, was to remove the front fuselage of the AF-211 and use and mate the front fuselage of AF-27 on the AF-211. The new aircraft was dubbed the Frankin-bird. “All of the aircraft sections can be de-mated and re-mated theoretically, but it’s just never been done before,” Scott Taylor Lockheed Martin Mechanical engineer said. “This is the first F-35 ‘Frankin-bird’ to date. This is history.” It was not only Lockheed Martin involved in the creation of the Frankin-bird the other partners were the F-35 Joint Program Office, and the 388th Fighter Wing, several units in the Ogden Air Logistics Complex, including the 570th Aircraft Maintenance Squadron, 576th Aircraft Maintenance Squadron, 809th Maintenance Support Squadron, and 309th Expeditionary Depot Maintenance Flight, are among the multiple units providing direct support. To complete the work on site at Hill, entirely new, unique specialized tooling, fixtures, and equipment have been designed and built, specifically adapted for mobility. These have potential future uses abroad. “We’ve designed versatile tooling that fits neatly into a Conex box, making it transportable to various locations, including forward operation areas,” Scott Taylor said. These new mobile fixtures achieve the same results as large, stationary automated manufacturing jigs at the F-35 plant in Fort Worth, Texas, but with a new approach. The additional capability will benefit the entire F-35 program. According to the November 30, 2023 announcement the work was ahead of schedule and as such had a completion target date of March 2025.



The US services did not readily release information regarding mishaps. The F-35 as such had bad press enough as it was. (*USAF*)



The Green Knights were trailblazers. The operations of the F-35B was safer compared to previous generation fighters. (*USMC*)



An Italian F-35A and Israeli F-35 during the Blue Flag exercise. (*Israel Air Force*)

F-35A September 2020 RNLAF 308 Squadron Emerald Knights
A Dutch F-16 allocated to 308 Squadron had a severe collision with birds. The F-35A was able to return to Luke AFB. Besides damage to the fuselage there was also damage to the aircraft structure. As it was the first time that a bird-strike damage had been so severe on the F-35, it required new tools for the repair of the F-35 involved. The tools that were being developed would be of general character so that it could be used for future similar damage cases. It was expected that Lockheed Martin would perform the repairs and that the F-35 would return to flight before the end of 2021.

F-35B 29 September 2020 USMC
During a refuelling exercise an F-35B collided with the Lockheed KC-130J Hercules tanker aircraft. The collision took out two engines from the KC-130J but more importantly forced the pilot of the F-35B to eject. The crew of the KC-130J were able to perform an emergency landing in a nearby field and walked away without injury. The F-35B exploded on impact and as for the pilot, he was Martin-Baker ejectee no 7,633. The collision occurred during the weapons and tactics instructor (WTI) course 1-21. The F-35B was from the VMFA-121 Green Knights and the KC-130J was from the Marine Aerial Refueller Transport Squadron (VMGR) 352 Raiders. A recording of the communications between the tower and the pilot from KC-130J surfaced on the internet. In that recording the pilot informed air traffic control that he had lost two engines and had little control and was descending. After that communication from the KC-130J was interrupted.



An F-35 on deployment to Hickam must have provided some nervous moments with the birds flying so close to him. (*USAF*)

F-35B 12 March 2021 USMC

A pilot flying his F-35B practising its cannon (GAU-22A) over the Yuma range. Firing PGU-32/U semi-armour-piercing high-explosive incendiary-tracer (SAPHEI-T) 25mm rounds from the GPU-9/A pod under the centreline of the aircraft, one round exploded after leaving the fighter's cannon, damaging the fuselage of the F-35B. Normally this type of munition explodes after impact so that it can cause much more damage inside the target. The pilot was able to land the aircraft safely and after examination it was determined to be class A mishap – damage valued at over $2.5 million.

Other smaller incidents largely unreported

The GAO pointed out in their June 2018 report one of the most frequent breaks on the F-35 occurred on the F-35B and F-35C. It noted, from April 2014 to August 2017, a total of twenty-one incidents with the probe tip breaking off. The refuelling probe tips are meant to break in the event of stress occurring during refuelling. But the twenty-one incidents were considered excessive. The US Navy looked at the incidents and put the following actions in place to reduce occurrence:



This burned out F-35 was being repurposed for education as otherwise it would be a complete write off. (*Dvids Todd Cromar*)

1. Pilot training improvements have been completed.
2. Improved inspection of KC-10 aerial refuelling equipment has been implemented.
3. Software improvements to reduce the pilot's workload during refuelling are planned to enter flight testing in May 2018.
4. A stronger refuelling probe is in development.

F-35B 169629 BK-18 ZM152 17 November 2021 617 Squadron Dambusters RAF

HMS *Queen Elizabeth* had sailed with eighteen F-35Bs deployed which had flown over 2,000 sorties. *Queen Elizabeth* was on its way home in the latter part of its deployment sailing through the Mediterranean. Shortly after take off a single F-35B found itself in some technical difficulty. The pilot decided to ditch the aircraft, ejected safely and was returned to the *Queen Elizabeth*. It would be the 7,662nd life saved by a Martin-Baker ejection seat. The only thing clear was that it involved a British pilot flying a British jet. This accident involved the first loss of a British F-35, the second export

(after the Japanese accident) and the fourth service to suffer a write off. For the Royal Navy, however, the race was on to salvage the aircraft from the bottom of the sea, which was a reported 1,000 metres deep. The US Navy sent help to recover the aircraft. It was quite unusual after an accident for operations to continue as usual. This led to the conclusion that the cause of the accident had to be known and indeed it transpired that both the pilot and maintainers had forgotten to remove a plastic rain cover. The cover was seen floating in the sea. The Lockheed Martin provided A00020 (left) and A00021 (right) inlet cover had the letters which stated remove before flight discarded during the early part of the Carrier Strike Group 21 deployment also known as operation Fortis, because the letters were peeling off and the fear of Foreign Object Damage (FOD) was real. The FOD issue was not taken lightly and was sent back home through a Defence Air Safety Occurrence Report. The inlet covers are part of the red gear and on board HMS Queen Elizabeth The intake, exhaust and PTMS covers all part of the red gear were too large to be kept inside the issue centre, so were kept outside the compartment in a palletised stacking stowage cage known as a ‘Thatcham. In the service inquiry for this mishap it was stated that the intake and exhaust covers could be blown out by modest wind or aircraft launching nearby. For this reason a deviation was allowed for these parts of the red gear not to be mounted on the flight deck. However for port visits or even events where photographs could be taken those covers had to be installed as the F-35 is classed a special access program. This means not everybody, serving on the Queen Elizabeth was allowed near it. The passage through the Suez canal was a time when all red gear was mandatory. A video which went viral on social media showed that the F-35B did not accelerate sufficiently and even seemed to slow down before dipping over the ski ramp. The pilot ejected and shortly after the two panels of the canopy landed on the ski ramp. As the F-35B dropped in the water from relatively low height and speed the aircraft landed in the water more or less intact. Although the place where it dropped in the water is known, what is not known is how the F-35B floated down and could have displaced itself significantly while sinking to the bottom of the Mediterranean. The fact that it fell in the water mostly intact made recovery even more urgent. HMS *Queen Elizabeth* and CSG-21 did not stay on the spot but continued the voyage. The pilot who ejected landed in front of *Queen Elizabeth* and was very lucky to survive. News began spreading in early December that

the F-35B had been retrieved from the Mediterranean with the help from the US Navy and Italian Navy. This was confirmed on 7 December and the ship that helped salvage it transported the aircraft to a harbour with a nearby airport from which it was flown by C-17 back to Marham. In January an image of the F-35B appeared showing little or no damage except some missing roll-control nozzles and landing-gear doors. After investigation has been completed the aircraft might end up as a maintenance instruction frame.

Three aircraft were to be prepared for next day flying, those were BK-18 and BK-21 and BK-14 as the spare. The workload and maintenance procedure is quite interesting. There were two maintenance officers assigned to the mishap aircraft with each having separate tasks for the Post Operation Servicing and Before Operation Servicing (POS/ BOS) A maintenance officer started the engine elements of the servicing at 21: 13. At the start of their servicing they removed the right intake blank and stowed it by the aircraft while completing the engine inspection. This aspect of a POS/BOS required the maintenance officer to enter the right-hand intake to gain access to the front face of the engine. The maintenance officer was assisted into the intake by another engineer who was on the flight deck at the time servicing BK-21. On completion of their parts of the servicing, the maintenance officer collected the right intake and PTMS covers and took them down to the Thatcham which is a palletised stacking stowage cage in the hangar. On completion of their parts of the servicing, After this the maintenance officer returned the tools to a makeshift tool tidy in the crew room for second maintenance officer to use and mentioned to the second maintenance officer that his part of the POS/BOS was complete but did not discuss which blanks had been removed. As for the reason that both maintenance officers were not servicing the aircraft together it was noted that the second maintenance officer was employed with other personnel, tasked with moving some containers in the hangar. Afterwards, the second maintenance officer carried out a check of the tools issued for use on BK-18 then went for the maintenance officer’s meal break at approximately 23: 30.

Parts of the second maintenance officers servicing required the IPP to be run to provide hydraulic power to open and close doors. To run the IPP, the second maintenance officer required a task supervisor to act as a further safety observer. When the second maintenance officer went to their

supervisor to request the IPP run, they were informed that it was not permitted yet due to the raised thunderstorm warning. the second maintenance officer went back to the flight deck, collected their tools and returned to the crew room. At approximately 02: 20, the second maintenance officer requested the assistance of their supervisor to run the IPP so that the required panels could be opened. They went up to the flight deck with the required tools and carried out the IPP run. With the panels opened as required, the second maintenance officer climbed into the cockpit and from the ejection seat area completed their inspection of the lift fan and upper surface using a torch. The second maintenance officer discovered the weather on the flight deck was windy and upper surfaces of the aircraft were wet from recent rain. The second maintenance officer elected not to climb on top of the aircraft to carry out the upper surfaces inspection, considering that the protective overboots required to walk on top of the aircraft provided poor traction in the wet.

On completion of their parts of the POS/BOS, at approximately 02: 50, the second maintenance officer returned all tools to the issue centre and the exhaust blank to the Thatcham. On checking the Red Gear log at the issue centre, the second maintenance officer discovered that there was no entry for the fitting of covers to BK-18 following the last removal on 7 Nov 21, upon leaving Duqm Port. They discussed this with the issue centre custodian (ICC) and concluded that the exhaust cover had inadvertently been left fitted when all other Red Gear had been removed. The second maintenance officer then returned to the FDHOC and at 03: 29 signed for completion of second maintenance officers aspects of the POS/BOS. After confirming with the line controller that there were no further tasks that night, The second maintenance officer was released from work.

The three tasked aircraft were also required to be armed with flares for the sorties the following day. The flare loading teams had to wait until the aircraft had been flight serviced, and then proceeded to conduct the flare load on BK-14 first. Upon arriving at BK-14 at around 22: 30 they discovered all the red gear was fitted. They needed to remove the PTMS blank to run the IPP to open the flare doors. After this was completed, they replaced the cover, completing the flare load just prior to the midnight meal. They returned at around 03: 00 to load BK-18 next, then BK-21 last. They observed no Red Gear on either aircraft, finishing the last load, still in the dark, at around 05: 00.

The mishap pilot had completed flying training in 2017 and joined 617 Squadron at MCAS Beaufort for his transition training to the F-35B. The pilot had amassed 271: 05 hours on the F-35B and completed 375: 35 hours simulator flying. The mishap pilot had deployed twice to the HMS Queen Elizabeth in 2020.

When land-based, a see-off was normally conducted by one or two maintenance officers. During Op FORTIS, this team was augmented to assist with refuelling and removal of chocks and lashings, to a team of three people and a supervisor. On arriving at BK-18 and BK-21, at approximately 10: 50, the see-off supervisors determined that the aircraft canopies required cleaning due to salt deposits. When the pilots arrived at the aircraft at approximately 11: 00, the see-off teams were busy cleaning the canopies. Each pilot's walkaround31 included an inspection of both engine intakes, the exhaust, and a general visual inspection of the aircraft. Due to the noise on the flight deck, the pilots wore their helmets throughout the walkaround. BK-18's pilot noticed the undercarriage pins were still installed, removed them and handed them to the see-off team.

Once inside the cockpit, BK-18's pilot conducted a set of tests of the aircraft flight control systems known as a Built-In Test (BIT). During the BIT, fluid was seen coming from the rear of the starboard weapon bay door. The doors were opened, and the fluid examined by the supervisor who determined it to be rainwater, believed to be from the thunderstorm the night before. BK-18's BIT was subsequently completed successfully. BK-21 had a minor issue with the aircraft navigation systems which took a short time to realign. The see-off team refuelled the aircraft during the start sequence, whilst the engine was running. This was routine during Operation FORTIS, but required more workforce than had originally been planned. The two-ship of BK-18 and BK-21 were the first UK F-35B flights of the day. The pilot signalled to BK-18's see-off team to remove chocks and chains. At 11: 37, as intended, BK-18 taxied first to the runway. The queen Elizabeth was sailing at a steady speed of 5 kts, which gave 12 kts wind over the deck.

The Ship completed pre-launch checks and was turned on to a Designated Flying Course (DFC) to achieve the necessary wind over deck for launch. The readiness of the Ship to launch was relayed from FLYCO to the flight deck and the Captain of the Flight Deck (CFD) signalled this to

the BK-18's pilot. The pilot then initiated the aircraft conversion to STOVL configuration in preparation for launch.

At the moment the pilot decided to attempt to abort, the aircraft was travelling at an unkown Indicated Air Speed (IAS) and had just started up the ramp with around of take-off roll remaining. Upon electing to abort, the pilot selected the throttle to Idle, and simultaneously applied the brakes. The engine momentarily increased to 80% Engine Thrust Request (ETR) before starting to decrease, but it was still delivering a considerable amount of power and deceleration was slow. From commencing the abort to reaching the top of the ramp took 3 seconds, and the aircraft had decelerated. At this point, the pilot ejected.

Upon deciding to eject, the pilot assumed the ejection posture and grasped the ejection lever with both hands. After initiating ejection, the pilot cleared the aircraft, the seat separated and parachute deployed. Once descending in the parachute, and after initially suspecting they would land in the water, the pilot noticed the ship approaching from behind and prepared to land on the deck. A combination of the wind, the forward movement of the ship, and the swing of the parachute meant that the pilot landed on the deck, six feet to the right of the take-off ramp, three feet back from the front edge of the deck. The parachute canopy snagged on the ramp end light shroud and the flight deck nets at the right-hand side of the top of the ramp. The pilot was concerned about their parachute re-inflating, so promptly unstrapped from the harness. The Personal Survival Pack (PSP) was hanging over the front of the ship and, identifying a risk of being dragged overboard, they disconnected from it.

After falling into the sea, BK-18 floated beside the ship for a short period before subsequently sinking. Cameras were used to take images of the crash site for the investigation. One of the cameras showed the aircraft floating on the surface, semi-submerged up to the canopy, but with the wings, tail, lift fan and auxiliary doors above water level. Several witnesses saw a "large red object" pushed up and out of the auxiliary intake on top of the aircraft. The sea boat was sent to recover the debris which was subsequently identified as BK-18's left intake cover.

The pilot's Personal Locator Beacon (PLB) activated automatically during the ejection sequence. It was detected by satellite, and search and rescue co-ordination centres alerted automatically. The communication embargo delayed the Ship's survival equipment section from contacting the

rescue co-ordination authorities to inform them that search and rescue activity was not required.

BK-18 was later discovered intact, inverted on the seabed, at a depth of 2,000m (Figure 1.3.16), with a few minor parts such as the ejection seat detached but close to the airframe. A salvage operation recovered the aircraft, and all the detached items, and then transported them back to the UK.

The panel noted that UK F-35B pilots were taught that once brakes were released for take-off that there was no abort option available to them. They were expected to continue a take-off regardless of aircraft failures, and manage any problem when airborne, or eject. The trial investigated by 17 TES squadron what the outcome might have been were the pilot not to have aborted, and to have attempted to continue the take-off. The trial report concluded that with this specific failure case it was extremely unlikely that a continued take-off attempt could have resulted in sustained flight, regardless of the starting position on deck. The panel concluded that the pilot's decision to abort was appropriate given the circumstances.

The panel noted that it was standard procedure for aircraft to take-off from a position as far forward on the deck as possible, usually 350ft. The accident was reproduced in the simulator with the aircraft starting at the 500ft point. It was determined that in this scenario, had the abort decision been made after the same elapsed time, it was possible to abort successfully. Accordingly, the panel concluded that the selection of the shortest take-off run was an aggravating factor. Despite this, in the panel's opinion, BK-18's failure case was so specific that such a result should not be used to modify existing abort training. However, recognising the relative immaturity of the UK F-35B capability the panel considered that take-off distance selection should be reviewed in the light of the experience earned on Operation FORTIS.

F-35A 99-8715 AX-15 (17-5334) 8 December 2021 JASDF 301 Hikotai

A two ship from Misawa departed for an operational training flight. While flying over the Sea of Japan one of the two aircraft called an emergency and could not return to Misawa Air Base and made an emergency landing at Hakodate airport. The problem was a computer failure according to some sources; similar problems have been reported within the JSDAF. AX-15 returned safely followed by the other aircraft, (19-8725 AX-25 (19-5562)

that landed about half an hour afterwards. The emergency landing did not cause any damage and both F-35s returned to Misawa Air Base two days later.

F-35A 4 January 2022 ROKAF

One F-35A had a technical problem in flight which prevented the landing gear from deploying; it remained tucked away in the fuselage. As an emergency was called there was time to prepare the runway with foam. This reduced the damage to the airframe during the wheels-up landing. It was the first reported gear-up landing. One positive point was that the pilot was able to walk away from the incident. The damage was so extensive that this aircraft was written off. Its unknown to which unit this aircraft was assigned.

F-35C CF-30, 169304 24 January 2022 US Navy VFA-147 Argonauts NE-406

The US Navy announced that it had lost an F-35C on Monday 24 January 2022. The accident was a landing on the USS *Carl Vinson* (CVN 70) while it was operating in the South China Sea performing freedom of navigation operations. The pilot ejected safely making it the 7665th life saved by a Martin-Baker seat. The pilot was later recovered by helicopter. Unfortunately, the mishap also caused injury on the deck and seven sailors were injured; three required MEDEVAC to a medical treatment facility in Manila, Philippines, and four were treated by on-board medical personnel. All three MEDEVACs were assessed as stable. Of the four sailors treated by on-board medical, three had been released. Besides the injury physical damage to the carrier was minimal as fifteen minutes after the incident they were able to resume operations. An F-18G Growler however had also been damaged during the incident. The investigation continued but the accident is surprising in one way as the F-35C has been equipped with joint precision and approach landing system (JPALS) and integrated direct lift control to help the pilot land safely. The F-35C had fallen in the South China Sea which meant that a frantic recovery situation would ensue. Similar to the British F-35B accident, videos and an image of the accident were leaked. The F-35C had been recovered by 2 March 2022 as a photo of a packed-up F-35C shape was released by the US Navy.

The wreckage was recovered from a depth of approximately 12,400-feet by a team from 7th Fleet's Task Force (CTF) 75 and the NAVSEA's supervisor of salvage and diving (SUPSALV) embarked on the diving support construction vessel (DSCV) *Picasso*. The aircraft was recovered using a CURV-21, a remotely operated vehicle (ROV), which attached specialised rigging and lift lines to the aircraft. The ship's crane lifting hook was then lowered to the seafloor and connected to the rigging to lift the aircraft to the surface and hoist it onboard *Picasso*. The aircraft was delivered to a nearby military installation to aid in the investigation and evaluated for potential transport to the United States. The aircraft arrived at Iwakuni to be returned to the USA.



Work was done in the proper PPE clothing. (*Dvids Todd Cromar*)



After extensive work the middle fuselage had a less baked feel to it. (*Dvids Todd Cromar*)



It is not clear if only the central fuselage was repurposed. The wings were attached again but photographs released were limited to the middle fuselage. (*Dvids Todd Cromar*)

According to the mishap report this mishap was the result of pilot error. The pilot had 650.3 total flight hours with 370.7 flight hours in the F-35C. The mishap pilot attempted an expedited recovery breaking overhead the carrier, an approved and common manoeuvre, but the mishap pilot had never performed this manoeuvre before and it reduced the amount of time to configure the aircraft and conduct landing checks. As a result of the compressed timeline and the mishap pilot's lack of familiarity with the manoeuvre, the mishap pilot lost situational awareness and failed to complete his landing checklist. Specifically, the mishap pilot remained in manual mode when he should have been (and thought he was) in an automated command mode designed to reduce pilot workload during landings.

The sequence of events leading up to the mishap was as follows: At 1255L, the mishap aircraft callsign Jason 406 and his lead Jason 407 launched from the Carl Vinson CVN-70. In the first portion of the flight he performed as a part of Large Force Employment which included two aerial refuellings. The second portion of the flight, from 1522-1606L, included a

Defense Counter Air (DCA) mission after which he performed a third aerial refuelling of the flight. As he was the wingman of this flight and this flight was also to be used to gain section lead experience the mishap pilot took control of the two-ship for the final portion of the flight at 16: 28L.

What followed happened extremely fast. About two and half minutes later the mishap pilot initiated the carrier break at the stern of CVN 70 followed by the lowering of landing gear a few seconds later. At 16: 31: 25L the backup Landing Signal Officer gave the 'Right for lineup' call, followed by the Primary Landing Signal Officer at 16: 31: 26L giving a 'Little power' call. At 16: 31: 27L: CAG Paddles gives a 'Powe.. Waveoff, Waveoff, Burner, Burner, Burner.. Burner' call. The word 'power' is not completed by CAG Paddles before starting the 'Waveoff…' sequence of calls. 1631: 31.4L: mishap aircraft impacts the ramp of CVN 70 just forward of the mishap aircraft main landing gear, shearing the main landing gear, bouncing the tail of the mishap aircraft into the air with a left-wing-down, nose-down component. The mishap aircraft's station 1 (farthest left, sitting in the cockpit) Launcher (LAU)-151 catches the first arresting wire (1631: 32.3L), initiating a slight counter-clockwise rotation of the mishap aircraft. The mishap aircraft's nose gear is perpendicular to the mishap aircraft direction of movement and reestablishe contact with the flight deck just prior to the second arresting wire and begins to collapse. The mishap aircraft nose gear fully collapses on top of the second arresting wire (1631: 32.5L). Remnants of MA nose gear assembly catch the second arresting wire and it begins to payout.

The second arresting wire releases from the mishap aircraft nose gear remnants after approximately 20 feet of payout (1631: 32.65L). mishap aircraft's station 1 LAU-151 then catches the second arresting wire (1631: 32.85L). mishap aircraft's station 1 LAU-151 detaches from the left wing of the MA. First and second arresting wires release from mishap aircraft. Counter-clockwise rotation rate of the MA increases (1631: 32.95L).

The MP ejects from the mishap aircraft. Mishap aircraft is forward of the fourth arresting wire, left-wing-down, nose pointing approximately 80-90 degrees to port of the LA heading as it continues counterclockwise rotation (1631: 33.3L).

As a result of this investigation the following things were recommended and had to be changed on the F-35C:

(1) An internal indication (Helmet Mounted Display and/or audio tone) to alert a pilot that the aircraft has reached on-speed Angle of Attack (AoA) in the power approach mode without Approach Power Compensation mode (APC), Delta Flight Path (DFP) engaged. To avoid this indication during level flight, this symbology or tone should only be triggered above a given rate of descent and below a given altitude.
(2) An external indication that an F-35C is in power approach and APC/DFP is not engaged. This external indication will need to be visible to the Landing Signal Officers (LSO) while the aircraft is on final approach. This would provide the LSOs the opportunity to intervene earlier in a landing attempt, preventing a similar reoccurrence of an airplane approaching the ship without appropriate thrust.
(3) An internal indication (Heads Up Display and/or audio tone) to alert a pilot that the aircraft has reached on-speed Angle of Attack (AoA) in the power approach mode without Precision Landing Mode (PLM) engaged. To avoid this indication during level flight, this symbology or tone should only be triggered above a given rate of descent and below a given altitude.
(4) An external indication that an F/A-18 E-G is in power approach and PLM is not engaged. This external indication will need to be visible to the LSOs while the aircraft is on final approach.
(5) Update the F-35C Flight Manual to reflect that F-35C pilots shall fly APC/DFP when recovering aboard the carrier. The current F-35C Landing Checklist, Step 4 is: APC/DFP — As desired.
(6) Consult with manufacturer of F-35C to incorporate internal HMD and/or audio tone to alert pilot that the aircraft has reached on-speed Angle of Attack in the power approach mode without Precision Landing Mode PLM engaged.

F-35A 19 October 2022 421st FS HL 15-5197 W/O

An F-35A had an accident and the pilot had to eject near Hill AFB. Early reports stated that the pilot manoeuvred the aircraft away from infrastructure, thereby saving some lives prior to ejecting. He ejected safely and was on the Martin-Baker calculator number 7682 for lives saved. The accident came shortly after a grounding of the F-35A due to faulty

components of the ejection seat. The inspections had the desired outcome as the pilot ejected safely.

The Crash Survivable Memory Unit (CSMU) also known as the flight data recorder or black box was recovered. The CSMU begins recording data at engine start (or when external power is applied to the aircraft) and records continuously through the mission so was a good source for the Accident Investigation Board. CSMU data analysis and integrity checks demonstrated the following: 1) the Flight Control System operated as designed; 2) the Air Data System (ADS) hardware and its associated firmware performed as designed; and 3) the propulsion system operated nominally and without issues throughout the flight.

The mishap flight consisted of four F-35A aircraft from the 421st fighter squadron, with the mishap aircraft flying as the number 3 aircraft in the flight. The mishap flight launched with four F-35s from Hill AFB runway 14 at 16: 34: 20L. After an uneventful training sortie, the mishap flight returned to Hill AFB, in a standard tactical formation with numbers 3 and 4 in one nautical mile trail.

At 17: 55: 35L, on the return to base, mishap wingman number 4, was directed to request the current weather conditions at Hill AFB via radio. It is standard practice for only one flight member to check the weather. The winds retrieved in the weather report were from a north westerly direction at 5 knots (kts) and the supervisor of flying declared that “wake turbulence procedures were in effect”.

According to wake turbulence procedures, “supervisor of flying will declare wake turbulence procedures in effect when a light crosswind (1-5 kts), tailwind, or light quartering tailwind condition is present. When wake turbulence procedures are in effect, pilots will increase pitch-out spacing to 8 seconds for a minimum runway separation of 9,000 feet”. Increased formation spacing from the standard 3,000 feet runway separation to 9,000 ft is required in light quartering tailwind conditions to avoid the dangerous effects of wake turbulence.

At 17: 56: 26, mishap wingman number 4 relayed the weather information to the mishap flight. When mishap wingman number 4 relayed the weather, mishap wingman number 4 did NOT state that wake turbulence procedures are in effect. While mishap wingman number 4 should have relayed this information, based on the reported light winds, all pilots in the mishap flight should have known wake turbulence procedures were in effect

and landing distances increased. Pilots are responsible for wake turbulence separation when maintaining visual separation or operating under visual flight rules.

From the formation both mishap wingman number 2 and mishap pilot were not aware wake turbulence procedures were in effect. As the mishap flight announced the intention to land, the Hill AFB tower noted to the entire mishap flight at 18: 07: 29L that the current winds were at 5 knots. This is enough information for all pilots in the mishap flight to know they must increase pattern and touchdown spacing in accordance with wake turbulence procedures. Mishap wingman number 2 set the normal spacing (3,000 ft) behind mishap wingman number 1. According to available data, Mishap wingman number 2 was approximately 5,000-6,000 ft behind mishap wingman number 1. Mishap wingman number 1 and mishap wingman number 2 did not encounter any wake turbulence or atmospheric disturbances and landed uneventfully.

The mishap pilot initiated his normal landing procedures approximately 3000-4000 ft behind mishap wingman number 2. That is approximately 2 000 ft less than between wingman 1 and 2. The mishap pilot extended the landing gear at 18: 07: 23L in preparation for landing. According to the Crash Survivable Memory Unit (CSMU), the mishap aircraft experienced two atmospheric disturbances during the approach and attempted landing. The first disturbed air that the mishap aircraft encountered was at 18: 07: 44L resulted in no cautions, warnings to the mishap pilot and is roughly coincident with the maneuver by the mishap aircraft to establish spacing in the traffic pattern behind mishap wingman number 1 and 2. This disturbance was 41 seconds prior to the second and resulted in no noticeable impact on the flying characteristics of the mishap aircraft.

At 18: 08: 18L, halfway through the turn to landing, the mishap pilot engaged the approach power compensator. The approach power compensator is an additional power assist mode designed to reduce workload and to improve energy management and landing approach control during an approach to landing. With the approach power compensator engaged, the aircraft automatically controls engine thrust request to maintain desired landing conditions and reduce pilot workload. At this time the aircraft recorded winds were the same as reported by ground sensors based on the tower weather radio call from the supervisor of flying.

The second disturbance was encountered between 18: 08: 27L and 18: 08: 30L as the mishap aircraft maneuvered to land. This disturbance resulted in a large enough disruption of airflow over the sensors that the air data application, based on system parameters, excluded data from the left side Multi-Function Probe. Excluding data from the left side multi-function probe (MFP) resulted in a visual and audio AIR DATA DEGD (degrade) integrated caution advisory or warning (ICAW) to the mishap pilot at 18: 08: 29L.

The mishap pilot testified that when he rolled out on final approach, he felt a distinct “burble” or rumbling on the mishap aircraft. Based on available data, the mishap aircraft was in disturbed air, called wake turbulence, for 3 seconds from 18: 08: 27L to 18: 08: 30L. This rumbling was caused to his aircraft due to him flying through the wake turbulence from the preceding aircraft mishap wingman 2. This atmospheric disturbance resulted in erratic inputs to the air data application (ADA). This disturbance resulted from a large enough disruption of airflow over the Air Data System sensors that feed information to the ADA, based on system parameters, excluded data from the left side multi-function probe.

This, in turn, caused erroneous outputs from the air data application and resulted in a condition in which the aircraft flight controls did not respond correctly to the actual current conditions of the mishap aircraft.

The Air Data System consists of sensors that collect information from outside of the aircraft and feed it into the air data application for use by other systems and the pilot. The F-35 Air Data System consists of one left hand and one right hand multi-function probe (MFP), and one left hand and one right hand flush port module all located on the forward fuselage above the Electro Optical Targetting System (EOTS) panel. The air data application software analyses inputs from various sensors on the aircraft to provide appropriate flight control inputs to the flight control surfaces. The air data application software utilizes external pressure and movement and movement rate sensors provided by the air data system to compute aircraft parameters. The air data application also provides air data parameters to the aircraft control laws determining aircraft flight control surface movements.

The mishap pilot noted, and the CSMU confirmed this, an AIR DATA DEGD (degrade) integrated caution advisory or warning (ICAW) at 18: 08: 29L. This ICAW, with a visual and audio notification to the mishap pilot, indicated one or more air data sources were degraded and was the first

indication to the mishap pilot that there was something out of the ordinary occurring with the mishap aircraft. Excluding data from the left side MFP was the cause of the visual and audio AIR DATA DEGD (degrade) integrated caution advisory or warning (ICAW). The F-35 enterprise has over 600,000 flight hours and this is the first known occurrence where wake turbulence had this impact on the air data system (ADS).

Following the AIR DATA DEGD ICAW, the mishap pilot noted that the mishap aircraft was not responding appropriately to commanded control inputs. In response, the mishap pilot selected full after burner power at 18: 08: 30L to abort the landing and set up for another landing attempt. After selecting full afterburner power, the mishap aircraft continued to not respond as expected to MP inputs. At approximately 18: 08: 33L, 3 seconds after the MA exited the wake turbulence, the mishap aircraft banked sharply with the left-wing down. The mishap pilot re-applied full roll stick at approximately 18: 08: 35L to counter the aggressive mishap aircraft bank to the left. Based on CSMU data, the aircraft was not correctly responding to pilot inputs in the final seconds prior to ejection and departed controlled flight at 18: 08: 34. This data is evidenced in the angle of sideslip (AOSS) values at 18: 08: 34 and after, approximately 2 seconds prior to mishap pilot ejection at 18: 08: 36L

With the mishap aircraft responding erratically to the inputs of the mishap pilot, the mishap pilot released control of the mishap aircraft at approximately 18: 08: 36L to eject from the aircraft. The mishap pilot ejected at approximately 18: 08: 36L, the mishap aircraft continued into the terrain just north of the approach end of runway 14 at Hill AFB in full afterburner with the left wing striking the ground first.

The mishap pilot initiated ejection at approximately 4,900 above ground level or 200 ft above the ground. The mishap pilot initiated a successful ejection conducted at low speed and low altitude. The ejection seat automatic sequencer functioned correctly, resulting in a successful ejection for the mishap pilot.

The debris field fanned out with most of the aircraft disintegrating within airfield boundaries. Parts of the cockpit, canopy and ejection seat were located just outside the airfield boundary fence line.

F-35A October 2022, Royal Netherlands Air Force 322 squadron F-010 17-5309

A birdstrike was the cause of this mishap. The pilot had dump fuel so that he could perform a safe landing.

F-35B 1 December 2022 USMC VMFA-121 VK-00 169617
After an emergency or precautionary landing this aircraft was towed when the nose landing gear collapsed. The incident took place at Kadena AB. The pilot who was sitting still in the cockpit got a little shock but was alright. This F-35B was easily repaired and returned to service.

F-35B 15 December 2022 Lockheed Martin 170061 BF-148
Thursday 15 December 2022, a government pilot was coming in to land in an F-35B at Joint Reserve Base Fort worth. The landing seemed fast, with small puffs of smoke coming from the exhaust of the main engine but the vertical landing went without a hitch until touchdown when the F-35B jumped back up and landed heavily on its nose, the nosewheel carted off, and the F-35B tilted over onto its wingtip while turning around its axis seemingly due to higher thrust coming out of the main engine. While cartwheeling back around its axis the nose landing gear collapsed, the F-35B fell back to its main landing gear and the pilot ejected. Shortly after the ejection, the F-35B came to a standstill. The pilot was taken to the hospital for observation but reportedly OK. The flight was one of the acceptance flights of the F-35B as it had not yet been handed over. It was the 7686th successful ejection by a Martin-Baker seat. The F-35B had no unit markings applied. The accident caused deliveries to halt and investigations led to the conclusion that there was a problem with the F135 engine. A vibration issue was found and had to be resolved and that took until 6 March 2023 when flights could be resumed. Production had continued so there was a healthy backlog for the pilots. As a result of the accident delivery targets were not met in 2022. As a result of the BF-148 mishap on 15 December 2022, the program paused delivery acceptance and flight operations until the program could be assured that delivered engines were able to support safe F-35 operations. While the mishap is still under investigation, our team has identified a rare harmonic resonance phenomenon between the Main Fuel Throttle Valve (MFTV) and the CP12 fuel tube that causes the CP12 tube to fracture. Since the mishap, F-35 JPO, Pratt & Whitney, Lockheed Martin, Naval Air Systems Command (NAVAIR), and Air Force Lifecycle Management Center (AFLCMC)

personnel have been working tirelessly to understand the root cause and develop mitigations for this harmonic resonance phenomenon, and to implement a path forward for safe flight operation of the F135 stated Program Executive Offer Michael J. Schmidt for the House Armed Service Committee.

This Government and industry collaboration will ensure incorporation of multi-stepped mitigation efforts that will fully address this rare phenomenon in F135 engines. Meanwhile, root cause identification and analysis of this failure mechanism will continue. One of the mitigation steps is the installation of an orifice which reduces the impact to loss of engine control if the CP12 tube fractures as a result of the harmonic phenomenon. In February 2023, Airworthiness Authorities from the U.S. Navy, Air Force, and industry approved and released orifice install instructions and updated flight operations manuals for the Joint and International fleet. Incorporation of the orifice, which is currently ongoing, reduces fleet risk. An immediate action Time Compliance Technical Directive (TCTD) for highest-risk assets, along with a ninety-day routine compliance TCTD for the rest of the fleet, has been approved and released. The orifice install is a simple process that can be accomplished at all maintenance locations and maintenance levels in four to eight hours for engines on-wing. The orifice mitigation enabled resumption of engine deliveries from Pratt & Whitney on 17 February 2023, and the resumption of aircraft deliveries from Lockheed Martin on 14 March 2023. We forecast all backlogged deliveries will complete by May 2023.

F-35A March 15, 2023 USAF 14-5103 AF-104 62 Fighter Squadron LF

It is not often that during an aircraft a mishap or accident that a pilot is not involved. This was such a case that the damage occurred during maintenance. The accident with BF-148 (170061) on December 15, 2022 resulted in a Time Compliance Technical Directive (TCTD). As was explained in the accident investigation report TCTD are issued to provide instructions to operators to accomplish one time changes, modifications, or inspections of equipment, or installation of new equipment. The purpose of this TCTD was add a metering plug between the augmentor throttle valve pressure tube assembly (CP12) and the main fuel throttle valve. The TCTD should mitigate the change of this occurring again and for this reason was to be applied to every F-35 manufactured.

On March 15, 2023 the TCTD was planned to be executed on AF-104 (14-5103) which was assigned to the 62nd Fighter Squadron and after the installment of the metering plug a test would have to performed to see if there were any leaks which meant that the F-135 engine had to be engaged. A maintenance team of three was assigned to the task with one of them qualified as engine run crew chief so able to perform the required engine test run. The other two maintenance staff completed an aircraft exterior inspection to ensure that it was safe for maintenance and innitiate the TCTD. After completion of the TCTD and the metering plug had been installed the crew continued to check the tool inventory to make sure no foreign objects were left in and around the mishap aircraft.

The crew chief completed the Engine Before Operations Servicing (BOS) Inspection checklist and conducted the inlet inspection. At 21: 31, crew chief began the Engine Operation – Idle procedure. The aircraft was started with no abnormal indications. At 21: 38, the aircraft's inlet and exhaust debris sensors recorded debris. Following the metering plug installation, the engine must be run at idle for at least 5 minutes to conduct a fuel leak check. During the engine run, crew chief did not receive a notification of foreign object ingestion from the mishap aircraft. At 21: 44, crew chief initiated shutdown of the aircraft following the engine run with no cockpit indications of a foreign object damage to the engine. During the shutdown, the maintenance team reported hearing abnormal noises as the engine was spinning down. Following the shutdown, crew chief completed the post operations servicing inspection and identified damage to the blades of the engine. crew chief reported the engine damage to the maintenance expeditor and stated, "I believe I just ingested a flashlight."

The mishap aircraft engine sustained damage to the 2d stage rotor, 3d stage rotor, 5th stage rotor, 6th stage rotor, fuel nozzle, bypass duct, high pressure compressor (HPC), high pressure turbine (HPT), and fan inlet variable vane (FIVV). The foreign object, a handheld flashlight, damaged the $14,000,000 engine beyond local repair, The estimated engine damage is $3,933,106.

F-35B 31 March 2023 RAF/Royal Navy 169698 BK-19 ZM153

This was a relatively small incident. On 31 March 2023 BK-19 rolled off the runway. Details as to why were under investigation. The nosewheel had disappeared in the mud and for this reason recovery would take more time.

No one was hurt during the mishap and amount of damage at first sight was limited to the landing gear.

F-35B September 17, 2023 USMC VMFAT-501 Warlords write off
An F-35B from the VMFAT-501 Warlords operating in South Carolina from Joint Base Charleston crashed after the pilot ejected. The pilot ejected safely and landed in a residential area of North Charleston. His wingman landed normally. According to Martin Baker this F-35B pilot was the 7702nd pilot saved by a Martin-Baker seat. Initially the where abouts of the crashed fighter was unknown as it is a coastal area the fighter could fallen in any of the lakes and or the nearby sea. Recovery of the mishap plane is important for the accident investigation.

Personnel from Joint Base Charleston and Marine Corps Air Station Beaufort, in close coordination with local authorities, have located a debris field in Williamsburg County." "The debris was discovered two hours northeast of Joint Base Charleston. Teams from Joint Base Charleston, Marine Corps Air Station Beaufort, the 2nd Marine Aircraft Wing out of MCAS Cherry Point, Navy Region Southeast, the FAA, the Civil Air Patrol, as well as local, county, and state law enforcement across South Carolina have been working together to locate the U.S. Marine Corps F-35B."

F-35A December 18, 2023 USAF 18-5369 AF-260 356th FS
A similar incident as F-35A (AF-106 14-5105) on November 30, 2017 from 34th FS which lost a Maintenance Interface panel when it was deployed to Japan. On December 18, 2023 an F-35A (AF-260 18-5369) deployed from Alaska to Kadena in Japan lost its Maintenance Interface Panel and returned to base without it.

F-35C January 26, 2024 USMC CF-89/170109 VMFA-311
Two F-35C from the USMC VMFA-311 landed at NAS Fallon after an uneventful flight without any problems. Once one of the pilots was climbing out of the cockpit down the ladder the nose landing gear started to retract. Once it was approximately half way down it collapsed and the F-35C with tail number WL-04 landed on its nose coming to a rest on the EOTS window.

F-35B May 28, 2024

An F-35B on its way to Edwards AFB from Fort Worth landed Kirtland Air Force Base, Albuquerque to refuel. After the refuel the F-35B employed its lift fan for a short take off. Shortly after taking off from Kirtland Air Force Base, Albuquerque the F-35B crashed. The pilot ejected but was injured and was transported by first responders to the hospital. The cause was off course something that had to investigated. Martin Bakers US-16E seat had saved 9 lifes sofar and in total it 7722 lives saved by all Martin Baker seats. The Joint Program Office stated that it was an aircraft that had been handed over to the government in september 2023. It had recently undergone modification to add aditional test equipment. The pilot was from the Defence Contract Management Agency (DCMA). From this we can assume that it was a TR-3 equipped test aircraft, which could cause the test program further delays.

Export Countries

STOVL was the original purpose of the programme in which the UK partnered with US for the ASTOVL programme. When the CALF programme was started the UK was a partner from the outset and it was clear that the UK was a partner the programme leadership needed; international programmes were thought to be more survivable under budget constraints.

Export was important for the survivability of JSF programme so export countries were contacted early in the development phase, to see if they wanted to participate. Initially only a few European countries joined as associate members with only the United Kingdom joining as a full member, first of all teaming with McDonnell Douglas since they had experience together working on the Harrier. When it was clear that the McDonnell Douglas team was out of contention, BAE Systems (then British Aerospace) chose Lockheed as a partner in the JSF effort after evaluating both Boeing and Lockheed proposals.

The other countries were offered participation as well, but European production lines were out of the question. The F-16 offers some parallels with the JSF programme as both tried to establish partners early in the programme. Partners in the F-16 programme, however, did not mind paying more for their F-16s if that meant European production. The higher cost of European F-16s was related to the longer production time required in Europe; by the end of the seventies production of the F-16 was planned to take twenty-six months, but in Europe it would be thirty-six months. Europe was willing at the time, seeing it as a good investment. This time around the JSF programme office made it clear that all the extra cost of the second production line would have to be carried by the nation that wanted a final assembly and check out (FACO) facility. It was, however, not only the cost of the establishment of the FACO but also the related costs of reduced efficiency on the original production line.



The AV-8B Harrier was the reason for cooperation between the UK and USA. (*US Navy*)



The USMC soon put the F-18 also on the list of aircraft to be replaced by the CALF programme. (*US Navy*)

There were three levels of joining the JSF programme:

- Full collaborative partner

- Associate partner
- Informed customer

During the CDP the US knew it needed more security in gaining export orders and thus allowed other countries that were interested to join the programme even those unable to pay the minimum amount required for the lowest level. It was rather obvious that countries willing to invest money for information on the programme during development would not like to lose money and, at a later stage, also invest money in buying the aircraft.

Another level besides the three levels already mentioned was created, called the major participants.

A full collaborative partner was entitled to:

– full access to programme data and structure, including the representative personnel within the programme office
– ability to influence requirement definition and performance characteristics
– The UK was the only participant at this level, committing $200 million for the concept demonstration phase

An associate partner was entitled to:

– Limited access to data and limited requirements influence
– Representative personnel resident within the JSF programme office
– All aspects of participation are negotiated with the JSF programme office
– Denmark, the Netherlands and Norway formed a group and paid a total of $30 million to participate at this level.

An informed customer is entitled to:

– Limited access to programme information with representation within the programme office
– No influence on requirements
– Canada and Italy have committed $10 million each to participate at this level

Major participants

- category created after demand was found for other ways of participating, also referred to as FMS or foreign military sales participation, or fee for service
- negotiate directly with the programme office for specific JSF programme information (e.g., cost and operational performance trade processes and modelling and simulation studies)
- no representative personnel resident within the JSF programme office
- Singapore, Turkey and Israel were participating at that level.



The fact that the JAST programme was seen as an F-16 replacement enticed a lot of F-16 operators to join. (*USAF*)



The McDonnel Douglas/ BAe systems / Northrop Grumman US Air Force offering with a similar canted tail as the YF-23. (*McDonnel Douglas*)

Parallels can be drawn again with the F-16 programme. When the LWF programme was initiated, and the F-16 selected, the five partner nations (US, Belgium, Denmark, Netherlands and Norway) committed to the General Dynamics F-16. Partnership in the F-16 programme was, however, possible only at one level. Again, commonality was the thread line throughout the programme to maintain low cost. At the time the F-16 was only seen as a part-fulfilment of the USAF requirement and the total requirement for the partner nations including the USAF was set at 1,763 aircraft. But, similar to the JSF, the F-16 had other customer nations waiting almost impatiently, including Iran, which had signed a letter of intent to buy 160 F-16s, and Israel that had requested pricing on a total requirement for 250 F-16s. The difference was that the partner nations joined later in the programme compared with the JSF. Another parallel can be drawn: both the F-16 and F-35 were expected to be the last manned fighters at the time of their introduction.

The times are changing and one clear sign was that on 11 July 2000 an Antonov An-124 Ruslan arrived at Lockheed Fort Worth to pick up a full-scale mock-up of the Lockheed JSF destined for display at the Farnborough Air Show.

After the fly off of the Lockheed-Martin X-35 and the Boeing X-32, the urgency of joining the JSF programme increased for foreign countries. The JSF programme office told countries 'Your industries will get a return on investment on a competitive basis if you join now.' Buying off the shelf at a later stage was not being recommended since no offset deals would be offered. This was not expected to have a negative effect on future export sales. Joining the JSF programme as a level 1, 2 or 3 partner in the SDD phase was only possible until 15 July 2002. For Australia an exemption was made because it was a new partner and assured a bigger market.

Partner countries' investments

Country	Date of Entry CDP at Level	Amount in Million US Dollars	Date of Entry SDD at Level	Amount in Million US Dollars
Australia	N/A	N/A	31 October 2002 Level 3	$172
Canada	2 January 1988 Level 3	$10	7 February 2002 Level 3	$150
Denmark	10 September 1997 Level 2	$10	28 May 2002 Level 3	$110
Israel	Level 4	$0.8	Level 4	$150
Italy	December 1997 Level 3	$10	24 June 2002 Level 2	$1,000
Netherlands	16 April 1997 Level 2	$10	10 June 2002 Level 2	$800
Norway	16 April 1997 Level 2	$10	20 June 2002 Level 3	$122
Singapore	Level 4	$3.5	16 March 2004 Level 4	$50
Turkey	16 June 1999 Level 4	$8	11 July 2002 Level 3	$175
United Kingdom	20 December 1995 Level 1	$200	17 January 2001 Level 1	$2,000

Stealth technology is a political matter as well as a technical one and is guarded closely by the Americans as they have a technological advantage.

The idea of transferring that technology freely to other nations met the usual reluctance but was inevitable if export customers wanted to maintain their own aircraft, which is common sense.

There were some options to choose from:

- Downgrade stealth for export customers
- Remove all sensitive technology for export customers
- Not exporting JSF (not a real option)
- Downgrade stealth standard across the board (not a real option)

The political side effects included nations becoming angry at being sold second-rate equipment. Instead of buying inferior products, such foreign governments might decide to go for an altogether different option. That would affect the cost of the American aircraft and prices for spare parts and upgrades cannot be shared over so many customers. Politically, this would also mean losing influence. The US counted, however, on offering a better plane at a better price than the competition was able to do and on foreign states swallowing their pride. The F-22 and the JSF were being advertised as the only fifth-generation fighters around. Stealth is not only the materials but also the systems. Important systems that the US wanted to remain 'US only' were packed in 'do not tamper' boxes. For such boxes maintenance was possible only in the USA.

The stealth technology and integrated avionics suite are very difficult for the general public to comprehend. Since the F-35 was not going to outperform the F-16 in its flight envelope since both were capable of 9g turns, the F-35 would not be able to outperform the F-16 as the F-16 had outperformed the F-4 when it was introduced. Thus 'selling' the F-35 to the general public was much harder and the price tag associated with a modern fighter was not making it any easier.







Although Brazil is not mentioned in this publication the F-18 Hornet was offered by Boeing that in the future they could count on development work on the Boeing JSF and buy it as a follow-up. (*3x Boeing via Ron Downey*)

Operational side effects would occur during coalition efforts when commanders would have to be aware of the differing capabilities meaning that not every unit could be used for the same task. Stealth technology is supposed to increase survivability of the crew even in harm's way. (Keep in mind the example in Afghanistan where Dutch, Danish and Norwegian air forces shaped one unit with F-16s but could fly with American units in the same mission). If the export version would be downgraded or without the sensitive technology it would mean that non-US coalition aircraft would be running a higher risk during the same mission or would have a higher probability of giving away the position of the strike package.) A US DoD report to Congress stated:

Operation ALLIED FORCE highlighted a number of disparities between US capabilities and those of our allies, including precision strike, mobility, and command control and communications capabilities. The gaps in capabilities were real and they had the effect of impeding our ability to operate at optimal effectiveness with our NATO allies.

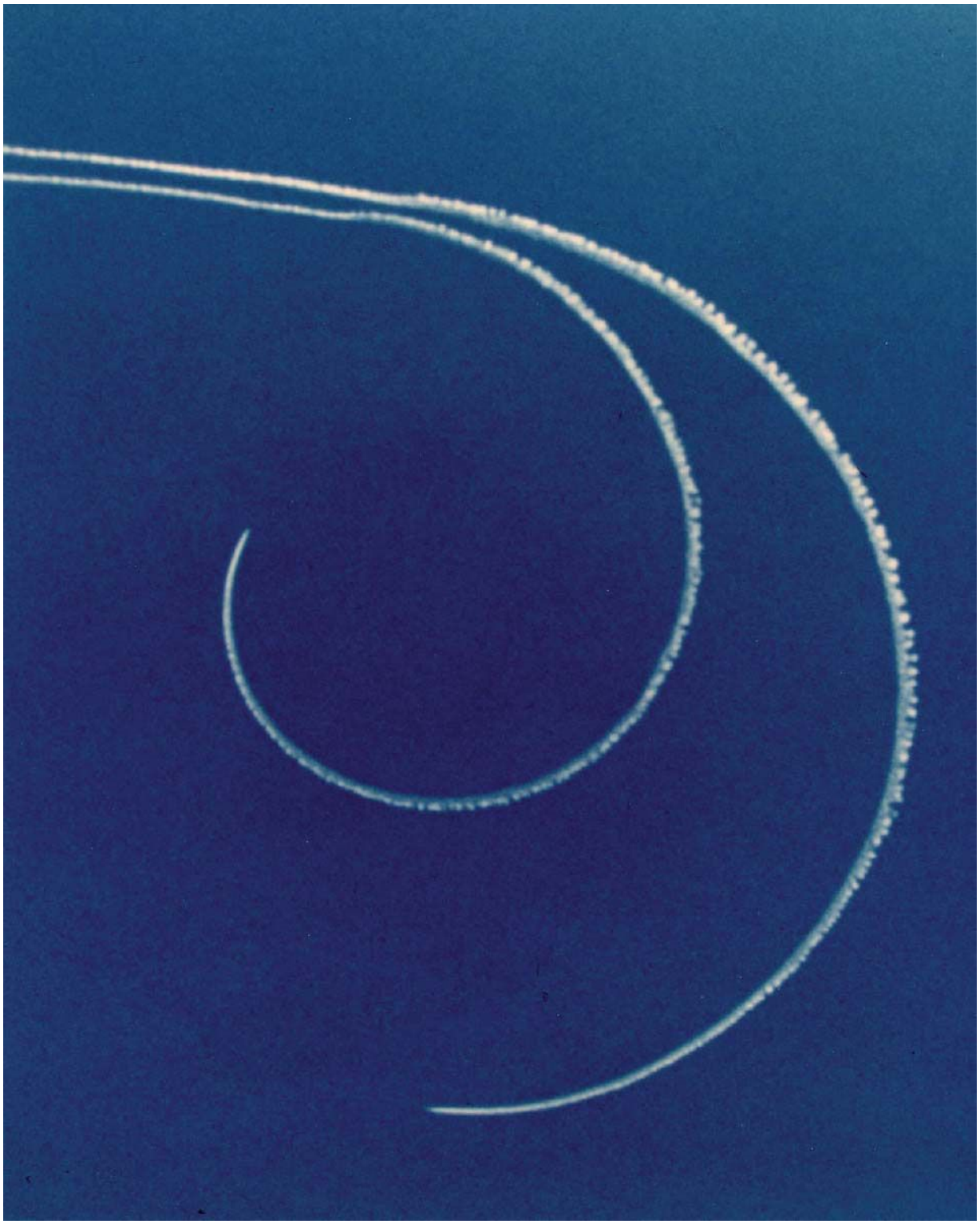
NATO allies were credited for major contributions in total sorties and strikes but limited inter-operability constrained effectiveness. In fact the JSF was advertised as being the answer to all problems by bringing commonality to all services, including those of partner nations. It was very early during the SDD phase that the outlines of a fourth version of the JSF were coming to light but were not advertised by any of the parties involved. A contract modification on 15 February 2008 to perform international commonality trade studies and conduct necessary design work directly related to the Joint Strike Fighter Air System Design meant that not only different requirements, such as a brake chute for the Royal Norwegian Air Force, but also stealth technology could be hidden under this contract.



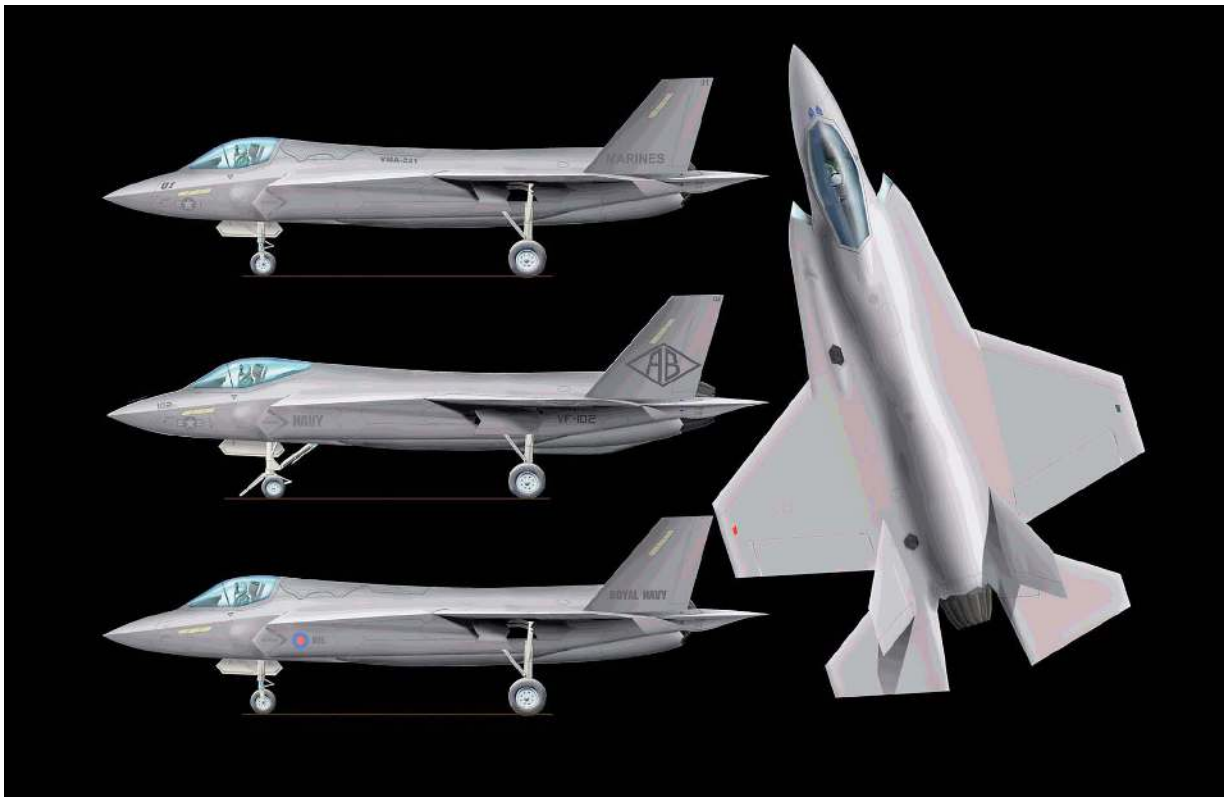
This Israeli Air Force F-16 seen during Blue Flag. Israel was one of the first, if not the first, to use the F-16 in anger. (*IAF*)

Some countries, however, were so eager to join the JSF programme that they were not in the least bothered that they would buy a downgraded version of the F-35; they accepted that they would get an F-35 in line with the US National Disclosure Policy (NDP). In fact, on 10 November 2003, Lockheed received a contract with the aim to design, develop, verify a delta version (D version) and test that version of the JSF air system that is as common as possible to the US air system within the National Disclosure

Policy (NDP). The value of the contract was $602,594,580 and the work connected with this modification was expected to be finished by April 2012 in time for the required deliveries.



The YF-16 out turning the F-4 Phantom sold the F-16 easily. The Lockheed Presentations never made any mention of a D-version in fact it was mostly denied. (*Lockheed Martin*)



The Lockheed presentations never made any mention of a D-version, in fact it was mostly denied. (*Lockheed Martin*)

The advantages of joining the SDD phase could still be given up. One more document had to be signed to proceed beyond 2006. It was, however, questionable if all would sign up since there were countries that were unhappy with the industrial co-operation. Participation in the SDD phase allowed countries from partner nations to compete for contracts on a best-value basis. The competition was hard and some politicians had hoped that some sort of offset could be attained. The new document to be signed was called the Production, Sustainment and Follow On Development contract and Lockheed Martin hoped that all partner countries, except Israel and Singapore, would sign by December 2006.

The quality, or rather the standard, of the aircraft would depend on each nation's own operational requirement document (ORD). Commonality was sacrificed. From this it was obvious that the UK would get the same quality of aircraft as the US as they had signed the JORD from the outset. Other partner nations would not. Each partner nation would also need to solve the problem with software coding and operational independence, so that their

aircraft could be maintained and repaired and overhauled locally. This was, however, difficult since the US was afraid of technology being transferred.



The Lockheed X-35A demonstrator is a lot bulkier and heavier than the F-16. Weight comes at a cost. (*Lockheed Martin*)

Signature of the PSFD MoU.

Country	Date	Estimated procurement Amount
Netherlands	14 November 2006	85
Canada	11 December 2006	80
Australia	12 December 2006	100
United Kingdom	12 December 2006	138
Turkey	25 January 2007	100
Norway	31 January 2007	48
Italy	7 February 2007	131

Denmark	27 February 2007	48

In the PSFD MOU, the F-35 JSF partners agree to an industrial participation approach with two key features:

- Companies from the partner countries can compete for design, production and sustainment contracts on the F-35 JSF Programme. This competitive approach helps to ensure that the programme has access to the best technologies at the best prices.
- In order to achieve best value through the competitive approach, the partners agree that 'no requirement will be imposed by any Participant for work sharing or other industrial or commercial compensation in connection with this MOU that is not in accordance with this MOU'. This commitment precludes the application of what are known as 'offset policies'.

All partner nations had thereby committed to the delta version of the JSF. This was later confirmed by another contract where it was specifically stated that the delta version was for the partner nations. That contract, issued on 15 November 2007, had a value of US$134,188,724 and was a modification to a previously awarded contract; the modification was to continue the design, development, verification, and test of Joint Strike Fighter (JSF) Partner Version Air System development under the JSF Delta System Development and Demonstration Effort (Delta SDD). The purpose of the Delta SDD was to develop a version of the JSF Air System that met US National Disclosure Policy, but remained common to the US Air System, where possible.

All partner nations were agreeing to conditions that would allow them to remain in the F-35 JSF programme. While the governments of partner nations were not making an irrevocable decision to forego the application of offset policy to their procurement of next-generation fighter capability, their decision to sign the PSFD MOU did imply that: if partner nations chose to remain in the JSF programme and acquire the F-35, it would do so according to the conditions of the PSFD MOU, including that offset policy would not be applied; and that if a partner nation wanted to apply its offset policy to the acquisition of the F-35, it would need to exit the JSF programme and forego preferential access to JSF industrial opportunities.

The market potential for the F-35, as seen by Lockheed Martin, besides countries already mentioned, including short-term and long-term customers, included twenty-one countries. Besides the partner nations in Europe, Belgium (F-16), Czech Republic (Saab JAS 39C/D), Finland (F-18C/D), Germany (Panavia Tornado and F-4 Phantom II), Greece (F-16, A-7 Corsair), Hungary (Saab JAS 39C/D Gripen), Poland (F-16, MiG-29, Su-22), Portugal (F-16), Spain (F-18 and AV-8B) and Switzerland (F-18 and F-5 Tiger) were assumed as being potential F-35 operators. From the Middle East Lockheed Martin expected interest in the F-35 from Bahrain (F-16), Egypt (F-16), Jordan (F-16), Kuwait (F-18), Saudi Arabia (F-15) and United Arab Emirates (F-16). From Asia, export target countries were India, Japan, South Korea, Taiwan and Thailand.



The two-contenders for the deal of the century. It remained to be seen if all countries involved would buy such a big amount due to cost. The deal would still be pretty large. (*Lockheed Martin*)

So-called partner purchase request/long-lead items were expected before contract signing. The Netherlands and the United Kingdom were the first countries to put such requests forward, both initiating the process in 2007. Contract signature for these countries was expected in 2009.

'The ongoing National Security strategy to require coalition-based operations had also exposed significant capability gaps between US and allied forces equipment,' said Tom Burbage, Lockheed Martin's executive vice president and general manager of program integration for the F-35. 'To

address these gaps, a decision was made to allow participation by selected nations in the development and procurement of the JSF. The sharing of the technology capability with allied nations implies that future coalition combat operations will be more synergistic and much less expensive from a logistics standpoint.' This statement in September 2008 was made in light of the amount of different aircraft the F-35 would replace; gaps would remain as a result of the US National Disclosure Policy.

Australia

When the announcement was made on 20 October 1981, Australia was one of the first export countries for the F-18, which was replacing the Mirage III in the ground-attack and interceptor roles. The Australian government, suffering budgetary constraints, was looking at bringing costs down when they initiated their search for a new defence system. That new system was not simply to be a replacement of the F-111 and F-18 but of the entire defence structure which was seen as being too expensive. From this requirement the AIR 6000 programme was born in May 1999.



The first flight of the first Australian F-35A. At the controls was Alan Norman, the second Australian aircraft to fly. (*Commonwealth of Australia, Department of Defence by Alex Groves*)



The Australian F-35 flew its first couple of years over the US skies to train its instructors. Once their instructors were ready they returned to Australia to set up a school at home. (*Commonwealth of Australia, Department of Defence*)

The department of future products and technology at Saab was working on different studies regarding the development of unmanned aircraft which were seen as a part of future network-centric warfare. It was foreseen by Saab that the Gripen would in the future work side by side with UAVs capable of bombing missions. This study, which had been underway for some time, was announced by Saab on 2 June 1999.

Different studies were also made as well by the Australian Ministry of Defence during 2000 and 2001. The ministry requested a total solution in its Request for Information for its AIR 6000 requirement. On 31 January 2002 Saab announced that it had answered the RFI and concluded the solution was the Gripen. It was the new network-centric-defence structure that Saab offered, in which the Gripen and unmanned air vehicles worked together. The system should have been introduced in 2012. Saab pointed out that it was much cheaper and safer even during peacetime operations. The F-18 was calculated to be withdrawn from service between 2012 and 2015 and the F-111 was to follow suit from 2015 until 2020. Other aircraft under

consideration were the Eurofighter Typhoon, Dassault Rafale, Super Hornet, F-16 Block 60, F-22 Raptor, F-15, F-35 and an unspecified aircraft from Sukhoi.

A report about the technical state of the F-111 was the source of speculation that the F-111s would be replaced sooner and that the Australian government had requested Boeing to offer them the F-18E/F out of the AIR 6000 requirement. The reports were denied by Boeing, although it admitted that it saw all current F-18 users as potential Super Hornet customers.

The Australian government ended all speculation by announcing that they had chosen to join the JSF programme by the end of June 2002, thereby ending the AIR 6000 programme. The official view was that the JSF would have capabilities none of the other contenders would possess. The only thing that could change this decision was the demise of the JSF programme which was unlikely with all the commitments from other countries. The only question remaining open was the possibility that the Royal Australian Air Force would need an early replacement for the F-111 because it was doubted that it would reach its planned end-of-service life, scheduled for 2015. Early replacement would be in the form of a lease with the JSF eventually replacing the leased aircraft. The Australian government joined as a partner in the JSF programme at level-3 on 31 October 2002, one of the few countries admitting that even level-3 partnership means that it can only end up buying the JSF. The RAAF was hoping to buy around 100 JSFs. The investment in level-3 participation was US$172 million. Australia was the only country to join the SDD phase with no prior involvement in the JSF programme.

The RAAF was considering the fact that they would like extended range for their JSF aircraft, so that the JSF would have a range to similar to that of the F-111. They wanted to achieve this by putting a fuel tank in the weapon bays. Also under consideration was the fact that cameras and other reconnaissance equipment could be placed in either weapon bay. The cost of this development would be solely for Australia as, at the time, it was the only country expressing such a requirement. As a result, the discussion about whether the F-35 was the right choice to replace the F-111 was quite heated in Australia. It was not known which F-35 version was the preferred option. The CV version with the longest range would be the most logical replacement but the connected cost was the biggest barrier; it was

questionable if the relatively small increase in range was worth the extra investment.

At the beginning of July 2004 a report was published stating that the Royal Australian Air Force should consider buying two F-35 versions; the conventional and the STOVL would both be required to fulfil RAAF requirements. The RAAF, second air force to consider a mix of versions after the USAF, indicated that they were looking into taking two versions as well. A commitment for the production, sustainment and follow on development (PSFD) was due by the end of 2006.

Although committed to the JSF programme as the only real option available, Australia was playing political hardball to get assurances similar to those of the UK regarding operational sovereignty. On the same day as the United Kingdom, Australia committed to the next programme phase when Australian defence minister Brendan Nelson signed the memorandum during a ceremony at the US State Department. 'The Joint Strike Fighter is most certainly the correct aircraft for Australia in terms of air-to-air combat and its strike capabilities.' He continued by saying that 'it will see Australia through the next thirty-to-forty years'. Only two days later news first broke that Australian defence minister Nelson was thinking about buying twenty-four Boeing F-18E/F Super Hornet outright as a stop-gap in case of delays with the JSF programme. The news was confirmed and the contract was signed relatively quickly. On 6 March 2007 Nelson announced that twenty-four Super Hornets would be acquired for the sum of Aus$6 billion.

The estimated procurement amount of aircraft per fiscal year by Australia as was determined in the PSFD document:

Fiscal Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Amount	2	6	14	15	15	15	15	15	3	100

The first Australian F-35s should arrive in country in 2015 with F-18 Super Hornets remaining in service until 2020 or, should the Australian government decide against buying a fourth F-35 squadron, Super Hornets could remain in service longer. Australia finds itself in a different position from all other partner nations. The opposition was not against buying new fighter aircraft – in fact they would like to see the government buy the more expensive but also more capable F-22 Raptor. The opposition party received the chance to show its stance on defence soon afterwards as it won the

elections and shaped the new government. The new government was not, however, sending out a clear message about what they wanted to do. According to media reports the government was considering retaining the F-18E/F and perhaps buying more and scrapping the F-35 deal. Such media reports were soon proven wrong when the first F-35s were ordered.

Participation in the programme was also brought to a different level. The JSF programme had requested the Defence Science and Technology Organisation (DSTO) to evaluate the electromagnetic environment effects (EEE), to which end a model of the F-35 was built in Australia, the model was called an Iron Bird. The F-35 Iron Bird was rolled out on 13 April 2013. Its evaluation meant the construction of an entire one-metal model that, internally, did not reflect the real structure of the F-35 but the outer mould line was emulated closely enough. Any antennae were placed on the outer skin and lightning strikes and broadcast or other electromagnetic influences were evaluated in the DSTO facility. The experiment involved surrounding the model with an aircraft-shaped mesh antenna to bathe it in electromagnetic radiation from all sides. The DSTO would then map the routing of the radiation and lightning, information which would allow for changes to be made on the real aircraft if anything proved to be a real problem. In extreme situations electromagnetic effects can knock out the computers or even release weapons. Results would be further evaluated at the EEE facility at NAS Patuxent River in the USA.



A photoshoot with the American hosts from Luke AFB. The cooperation was apparently so close that during training the crews could actually be interchanged on the aircraft. (*Commonwealth of Australia, Department of Defence*)


LF
56 FW


LF
56 FW
LF
944 FW







Above, middle and below: The permanent arrival of the first F-35s was celebrated with a beautiful formation flight with the F-18, which it was supposed to replace. (*Commonwealth of Australia, Department of Defence*)



Wing Commander Darren Clare, Commanding Officer of Royal Australian Air Force No. 3 Squadron, in front of an Australian F-35A aircraft on the flight line at Luke AFB. (*Commonwealth of Australia, Department of Defence SGT Christopher Dickson*)

The first Australian F-35 reached final assembly on 19 December 2013 with the delivery of the RAAF's first two F-35s in 2014. In an Australian Senate estimate hearing in June 2014 it was mentioned that, even though the Australian government had committed to seventy-two F-35s, only two were actually on order. What was not mentioned was that the two on order would be used for initial operational test and evaluation. The hearing queried if Australia could quit the programme; the answer was that, as only two had been signed up for, Australia had no obligation to actually buy any of the other seventy aircraft. It was also discovered that no money had been set aside to buy those aircraft and the government in place at the time of delivery would have to worry about getting the money in their budget.

The procurement plan was as follows:

Fiscal Year	2012	2016	2017	2018	2019	2020	2021	Total
Lot	LRIP VII	LRIP X	LRIP XI	FRP 1	FRP 2	FRP 3	FRP 4	
Amount	2	12	8	15	15	15	5	72

As can be seen, the Australians expected the programme to be in full-rate production (FRP) after the LRIP XI. Due to problems completing the initial operational test and evaluation this was not achieved and the entire programme was fulfilled during the procurement of LRIP XV

The first pilots sent to the US undertook their training at Eglin AFB. On 17 March 2015 Squadron Leader Andrew Jackson was the first Australian pilot to fly the F-35A. Since the Australian F-35s were based at Luke AFB, the first flight took place in an American example. Australian F-35As were to replace the F/A-18A/B Hornets at RAAF Bases Williamstown (NSW) and Tindal (NT) but uncertainty about the maturity of the F-35 slowed the acquisition programme. LRIP X was reduced to only eight aircraft, six of which were destined to operate at Luke AFB with the other two due for delivery to Australia. No. 3 Squadron was planned to reach IOC in 2020 just like the operational conversion unit (OCU), No. 2 Squadron, which was due to start its first conversion course in Australia in 2021.

Australia decided it required a similar home display of the F-35. Two F-35s, AU-1 and AU-2, arrived at Amberley RAAF base outside Brisbane on

27 February 2017. Both aircraft continued to the Avalon Air Show later in the week. The arrival was well documented but on the second day bad weather grounded both F-35s which had not been upgraded to fly in such conditions due to problems with making the fuel tanks inert. The RAAF announced that it had achieved IOC on 28 December 2020.

Belgium

Belgium was an early F-16 buyer and the only one of the original four F-16 buyers to decide against JSF participation during CDP and SDD, mainly due to budget restrictions. By December 1999 the *Belgische Luchtmacht* (BLu) or Belgian Air Force had an inventory of ninety F-16s that would require replacement from 2010. From the ninety F-16s, seventy-two were allocated to NATO. Although the BLu wanted one-to-one replacement this was unlikely for financial reasons and the number to be acquired was closer to forty, according to political leaders. Belgium's decision makers thought that the investment for participation would not pay off and, if it would buy JSF, it would probably be off the shelf. Belgium's air force reduction would mean that the total amount of aircraft required was also smaller, making the big investment a relatively expensive venture. Since other parts of the Belgian armed forces had been neglected during the previous two decades, financial investments were being made in more urgent material. By the end of 2003 it became clear that the requirement of forty aircraft was not far off as the BLu was being reduced by 30 per cent with the reduction to be complete by 2015. By that time only sixty F-16s would remain in service, forty-eight of them available to NATO. The main portion of the reduction was to be complete before the end of 2004; eighteen F-16s were retired, placed in storage and offered for sale.

At the earliest Belgium planned to initiate its replacement programme in 2015 although it was foreseen that the *Belgische Luchtmacht* would first upgrade their F-16s with a so called end life upgrade (ELu) prior to acquiring new fighters. This would mean that the F-16 would be replaced between 2025 to 2030. It would remain to be seen if an investment in a manned fighter was then still considered a worthwhile investment since UCAV capabilities would have matured, although many said that a man in the loop will always be necessary.

On 3 June 2014, two weeks after the Belgian general elections, a Request for Information was issued to five organisations:



Belgium, though not a partner probably stillwatched JSF development with interest to see what turned out to be most exported fifth-generation fighter. (*Lockheed Martin*)

- the UK Ministry of Defence for the Eurofighter
- the Swedish Defence and Security Export Agency (FXM) for the Saab JAS-39 Gripen
- the Directorate General of Armaments (DGA) of the French Ministry of Defence for the Dassault Rafale
- The Navy Integrated Programme Office (NIPO) for the Boeing F/A-18F Super Hornet;
- Joint Programme Office (JPO) in charge of the Lockheed Martin F-35 Lightning II programme

Although no numbers were mentioned in the Rf I it was expected that the number of aircraft would be around forty. The aim was to get more than open-source information so that it could be used for an informed request for proposals. The Rf I was not binding on the Belgian government. After the previous elections it had taken more than 500 days to form a government

and it remained to be seen how long the process would last on this occasion. Selection of the F-16 replacement was due by the end of 2015 or early 2016 to allow for replacement to commence by early 2020. Rumours surfaced that one of the possible Belgian requirements would automatically eliminate three of the five contenders: that requirement was the nuclear mission, which the Belgian air force had on its F-16s. The peace dividend had been spent and a wake-up call came in the form of renewed activity by the Russian air force; in the Baltic region interceptions of Russian aircraft in 2010 numbered just four. By 2014 this had risen to 150. On 27 November 2014 an office for the replacement of the F-16 was opened at the Belgian defence general staff. The Belgian F-16 replacement was called the Air Combat Capability (or ACCap) Successor programme.

The Belgian Defence Ministry allocated 3,573 billion Euro to purchase thirty-four of the next-generation fighter aircraft. The Belgian air force had fifty-four F-16s (forty-four F-16AMs and ten F-16BMs) in its inventory. On 22 December 2015 the government decided that they would be replaced by thirty-four to-be-selected multi-role aircraft; many considered the F-35 the front runner.

On 17 March 2017 it was announced that a request for government proposals was sent out to four countries from the Belgian government. The Rf P was sent to government agencies in the four countries invited to bid: DGA (Directorate General of Armament) France with the Dassault Rafale; FMV (Defence Material Administration) in Sweden with the Saab JAS 39E Gripen; the United Kingdom MoD with the Eurofighter; and the USA with the USN PMA 265 (which would offer the Boeing F-18E/F Super Hornet) and the Joint Programme office which offered the Lockheed Martin F-35. A rather unusual step undertaken was to publish the request for proposals as soon as all the agencies had confirmed that they had received the Rf P on the Ministry of Defence website. Belgium seemed to want to have a more open competition than some of the partner nations of the F-35; Denmark was even sued by Boeing due to its process. A reply to the Rf P was due by September 2017, followed by a best-and-final offer on Wednesday 14 February 2018.

The Belgian Air Force had five general roles in mind for their replacement of the F-16:

- Defensive Counter-air/Air Policing

- Offensive Counter-air (OCA)
- Air Interdiction (AI)



By not joining during the programme when the opportunity was there, Belgium missed out on the political backlash that was experienced in many countries. (*Lockheed Martin*)

- Close Air Support (CAS)
- Joint Intelligence, Surveillance and Reconnaissance (JISR)

Three roles were mentioned that would gain importance in the future and were, in many cases, seen as bridges between the other roles.

- Non-Traditional Intelligence, Surveillance, and Reconnaissance (NTISR)
- Strike Co-ordination and Reconnaissance (SCAR)
- Electronic Attack (EA)

The nuclear mission, a seemingly hot topic before the release of the RfGP was left out of the equation as it would be a fairer tender.

The Request for Government Proposals included requirements for:

- Thirty-four equipped multi-role combat aircraft, and all related support equipment;
- Support arrangements and related equipment that guarantee adequate training of the required number of aircrew, technicians and support personnel;
- Support arrangements and related equipment that enable the use of the Belgian aircraft in operations.

To prevent the Russians, Chinese or any other nation from bidding, the Belgian RfGP limited the offers only to governments that were part of either the EU or NATO. Since the acquisition was seen as very complex it would be part of one or more intergovernmental agreements. In fact the contractors would only be suppliers of a government agency of their host nation.



The Belgian Air Force used the F-16 as this example and it was doubtful that the F-35As in service with the Belgian Air Force would receive such colourful paint schemes. (*Gérard Keijsper*)



A Belgian F-16 would serve for some time to come as the F-35A would come into service for training purposes only in 2023. (*Noel Turner*)

The proposals would be evaluated over capability with a total weight of 57 per cent, followed by total cost of ownership with a weight of 33 per cent and the remaining 10 per cent allotted to protection of essential security interest. Capability was divided over partnership and military Co-operation, mission effectiveness, operational and technical support, employability and deployability, evolution and growth potential.

Deliveries to the Belgian air force were due to start in 2023, with completion by 2030. By this time FOC should be achieved. The moment from contract signature till FOC is the capability transition period, during which the Belgian government expected from the winning government agency all activities in support of:

- Initial procurement and delivery of the weapon system and its related equipment;
- Weapon system management;
- Aircrew type conversion and continuation training;
- Conversion training of all other personnel (operational, technical, support);
- Operational and technical support;
- Operational and technical sustainment, including updates and upgrades on aircraft already delivered or support systems.

The period starting on FOC or 1 January 2031 is called the follow-on period which was supposed to last twenty-eight years by which time the new aircraft would be phased out. The follow-on period would cover activities in support of:

- Weapon system management;
- Aircrew conversion and continuation training;
- Training of all other personnel (operational, technical, support);
- Operational and technical support;
- Operational and technical sustainment, including updates and upgrades of the complete weapon system.

On 19 April 2017, in a surprise move, Boeing stated that it would not participate in the Belgian tender, would not sent any delegates to Belgium (who were invited collectively with other contenders) or request more information and clear up any matters that might not be clear in the RfGP.

By July 2017 the FMV from Sweden announced that it would not offer any proposal to the Belgian government, stating that required support in the shape of a mandate from a higher governmental and political level in Sweden did not exist at that time.

Thursday 7 September 2017 was the deadline for delivery of proposals by which date two proposals had been received, one the UK MoD offering Eurofighter Typhoon and the other from the Joint Programme Office for the F-35. A letter from the French Minister of the armed forces, Florence Parly, to her Belgian counterpart Steven Vandeput, offered thirty-four Dassault Rafales in return for a deep partnership involving operational and industrial co-operation. Belgium had to look for legal advice on how to react to the highly unusual way of answering a RfGP. Logic prevailed even in this difficult jurisdictional problem and France's offer was declined as it had not answered the RfGP in a manner that could be compared to the other bidders. A selection between the remaining two bidders was due by May 2018.



Belgium was expected to join the international F-35 community at Luke AFB. The F-35A had not gone through operational testing and the negative reports coming out of the office of the Director of Operational Test & Evaluation (DOT&E) did not deter countries from signing up. (*Lockheed Martin*)



An operational test F-35A from the 422 TES with an open weapon bay and an igniting AMRAAM. (*Lockheed Martin*)

On 18 January 2018 the Defence Security Co-operation Agency (DSCA) announced that a proposed sale to the government of Belgium had been approved under the foreign military sales programme. The Belgian government had requested to buy thirty-four F-35 CTOL aircraft, and thirty-eight Pratt & Whitney F-135 engines (thirty-four installed with four spares). Also included was a package of electronic warfare systems, support and training for personnel and munitions. Similar packages were included in other national orders and a list of items and services is included in Appendix II (page 460). The estimated total value was $6.53 billion and the budget available would be one of the biggest obstacles since in Belgium the budgeted amount was €3.6 billion. Although the exchange rate was favourable, the cost seemed out of touch compared to the budget. The Belgian budget was calculated at €15 billion over the forty-year lifetime of the replacement aircraft. It was not clear from the DSCA announcement how much of the lifetime cost was not included in the immediate acquisition cost.

If the proposal was accepted, it was expected that offset agreements would be required. All offsets are defined in negotiations between the

purchaser and the contractor as reported by the DSCA, a statement that flew against statements from previous JPO leadership that offsets in the past would no longer applicable to the JSF programme or the F-35. The best and final offers were delivered to the Belgian Ministry of Defence by both the UK and US governments on 14 February 2018.



The first F-35A, FL001,with high visibility roundels on the side and tails. (*Lockheed Martin*)

During March 2018 hell broke loose in Belgium as news broke that the F-16 replacement had been pushed through parliament by withholding important information. The government had supplied wrong information to the Belgian parliament, stating that service-life extension of the F-16 was not possible. However, news also came that Lockheed Martin had provided information on 26 April 2016 that logic would admit that a service extension was possible and, of course, not as expensive as buying a new solution. The F-16s were thought to be capable of flying until 2029. Another offer from Lockheed Martin which would include more massive upgrade would make it possible for the F-16 to soldier on for another twenty years. It would remain a question if the F-16 could remain relevant for so long. The biggest part of the bombshell, however, was that the Belgian ministry had presented the replacement requirement as urgent, and parliament felt deceived. The problem was who was responsible for leaving

out such important information. The Belgian F-16 had gone through the mid-life update similar to other European F-16 operators and, as the name of the update suggests, a further update should be possible. The question of the financial wisdom of doing so is another question. Many politicians pointed out that the Belgian financial situation meant that it was probably better to perform the service-life-extension-programme, quoted at around €1 billion and defer an acquisition budgeted at four times that. The main question was: was there sufficient reason to stop the tender which had been held relatively open, to clear an advantage to any of the participants, although some accused Steven Vandeput of having a preference for the Lockheed F-35. Four military leaders had to step aside to allow an investigation into why reports from Lockheed Martin never made it to him and why the information was leaked in the manner it was. None of this made any difference since the Lockheed Martin F-35 was the Belgian government's choice, which was announced on 26 October 2018. This meant that, from the original four countries that had bought the F-16, all had selected the same replacement and for future upgrades would be able to co-operate again as they had done for their F-16 mid-life-update (MLU) programme. The time-frame for the first delivery was set at 2023 with training of Belgian pilots taking place at Luke AFB and the first aircraft due in Belgium in 2025.

Various components will begin assembly at F-35 suppliers across Europe and the US in 2022 with final assembly of the first aircraft beginning in late spring 2023 at the Fort Worth factory. News broke in July 2022 that the Belgian government would not order more F-35s in the current government's term, as had been hoped as a result of the Russian invasion of Ukraine. The Belgian Air Force would raise the question in 2024 again after the elections. Delivery of the first aircraft was planned for December 10, 2023. Even though that the Lot 15 production was planned with the hardware and related software upgrade and a delay in flight test meant a delay in acceptance flight testing and therefor deliveries the first F-35A for the Belgian Air Force had its festive roll out as planned on December 10, 2023. The milestone of it actually being transferred to Luke AFB was not clear when this would occur.

Canada

For the final stage of the CDP, Canada signed an MoU to become a partner in the JSF CDP phase on 2 January 1998, paying US$10 million. However, Canada also made clear that this was not a commitment to buy the JSF; they were the fourth and last country to sign up beside the Netherlands, Norway and Denmark.

The only neighbour of the US to join and an early customer of the F/A-18, which it was ready to replace by 2010, Canada made a relatively small investment when deciding to participate in the EMD phase on 7 February 2002. Canada was the second country to sign up but the first as a level-3 participant promising to invest $0.15 billion. Ten companies in Canada can bid for work on the JSF.

Canada was more successful than other countries in getting back its investment on business supplied on best-value basis. Pratt and Whitney Canada was awarded a contract to provide the fifth-stage high-pressure compressor integrally-bladed rotor by the end of October 2004. As Canada was satisfied with the amount of work returned, it had no problems with signing the MoU for the PSFD phase. On 11 December 2006 Canada became the second country to sign up for the PSFD. Canadian deputy defence minister Ward Elcock signed together with his US counterpart, deputy secretary of defence Gordon England. Canada plans to replace its CF-18s with eighty F-35A Lightning IIs. According to Ward Elcock Canada planned to retire its CF-18s by 2017.

The estimated procurement of aircraft per fiscal year by Canada was determined in the PSFD document:

Fiscal Year	2014	2015	2016	2017	2018	2019	2020	2021	Total
Amount	10	10	10	10	10	10	10	10	80



The Royal Canadian Air Force had been operating the CF-18 Hornet since 1982. After 30 years of operation it was thought a good time to retire them. Few expected them to soldier on for more than 40 years. (*USAF*)

From briefing it became apparent that a specific requirement from Canada was the drogue-and-probe aerial-refuelling system on their aircraft as well as the boom-and-receptacle aerial-refuelling system standard on the CTOL aircraft.

On 16 July 2010 it was announced that Canada had selected the F-35 to replace its CF-18 Hornets. Although the announcement was a positive for Lockheed Martin shortly before that year's Farnborough Air Show, it was more a declaration of intent but without contract. Contract signature was expected in 2013 and in three years much can change. The announcement caused considerable controversy and Canada had to defend its selection. The main problem was that no evaluation of alternatives had been performed. Media pressure was so strong during 2012 that the defence minister had to announce that the F-35 had not won yet and that the decision would be made at a later stage. A flurry of reports regarding the F-35 came out shortly before the Christmas holidays. In a report to parliament, Christian Paradis, Minister of Industry and Minister of State (Agriculture), stated that, as of June/July 2012 reporting, seventy-two companies in Canada had secured US$438 million in contracts. Controversy about the decision to buy the F-35 rose during the remaining tenure of conservative prime minister Stephen Harper. The JPO did not help him by sometimes stating they had a commitment when no actual contract for production jets had been signed.

In 2015 elections were planned and Stephen Harper was beaten; the opposition party, the Liberals, led by Justin Trudeau, won a majority with 184 seats in parliament and therefore not having to form a coalition with the leftist New Democratic Party, which won forty-four seats. The Conservatives held on to ninety-nine seats, while the Bloc Quebecois took ten and the Green Party one, the Conservatives becoming the main opposition party. Prior to the elections, Justin Trudeau promised:

We will not buy the F-35 stealth fighter-bomber. We will immediately launch an open and transparent competition to replace the CF-18 fighter aircraft. The primary mission of our fighter aircraft should remain the defence of North America, not stealth first-strike capability. We will reduce the procurement budget for replacing the CF-18s and will instead purchase one of the many lower-priced options that better match Canada's defence needs.

After the election Justin Trudeau immediately announced a major changeover in defence policy. The first sign of this policy change was to recall the Royal Canadian Air Force that was participating in operations against ISIL in Syria and Iraq. Although a promise had been made not to buy the F-35, Canada remained a partner of the JSF programme and Lockheed Martin confirmed that they were in dialogue with the new government. In August 2016 the F-35 participated for the first time in the Canadian International Air Show at Abbottsford. The two F-35s that participated were 13-5071 and 14-5091 from Hill AFB.

Rumours surfaced that Canada was looking into an interim fighter and the F-18E/F was touted as being the favourite because of similarities between the legacy F-18 in the Royal Canadian Air Force. Partner payments to the value of US$30 million were made quietly every year. The first year (2016), it was explained that the business gained was worth the investment; the second year there was a rift in relations between Boeing and Bombardier which soured interest in the Super Hornet. The relations got out of hand as both parties were taking hard stands in public. The interim requirement was thrown off the table amid news in December 2017 that, instead of acquiring Super Hornets from Boeing, Canada had suddenly agreed to buy F-18C/D Hornets from Australia which was phasing them out.

Canada was eager to start a new competition for its next-generation fighter, which was due to start in 2019. However, the process started before this and a conference with fighter aircraft manufacturers in Toronto was one of several small steps in that direction in January 2018; that Boeing did not participate was eye catching. The trade dispute between Boeing and Bombardier was decided in favour of Bombardier and Canadian Prime Minister Justin Trudeau showed that in politics there is no place for grudges and stated that Boeing would be invited to tender for around sixty replacement fighters for the Royal Canadian Air Force.



Canadian F-18s training at Luke AFB in February 2020 awaiting a decision whether the F-35 is going to be its replacement. (*USAF photo by Airman Brooke Moeder*)

On 23 July 2019 the Request for Proposals (Rf P) was issued with the announcement: 'Today, the government achieved a major milestone in the process. Following extensive engagement with industry and eligible

suppliers over the past eighteen months, the formal Request for Proposals has now been released to eligible suppliers.'

The following suppliers had until spring 2020 to submit initial proposals:

Sweden – SAAB AB (publ) – Aeronautics
United Kingdom and Northern Ireland – Airbus Defence and Space GmbH (with MBDA UK Limited, L3 Technologies MAS and CAE Canada)
United States – Lockheed Martin Corporation (Lockheed Martin Aeronautics Company) (with Pratt and Whitney)
United States – Boeing Company (with Peraton Canada Corp., CAE Inc., L3 Technologies MAS Inc., GE Canada and Raytheon Canada Limited Services and Support Division)

Note the omission of France and Dassault. All bidders were to be subject to the same evaluation criteria with proposals assessed rigorously on elements of technical merit (60 per cent), cost (20 per cent) and economic benefits (20 per cent). The procurement attributes one of the highest weightings to economic benefits for Canada in its history. All suppliers were required to provide a plan for economic benefits equal to the value of their proposed contract, with maximum points only being awarded to suppliers who provided contractual guarantees. In the meantime, Canada bought the second-hand F-18s from Australia as a gap filler.



The re-arming of an CF-18. Somewhat symbolic in the sense, the Royal Canadian Air Force was awaiting the replacement of the F18 which would be serving at least 40 years. (*USAF photo by Airman Brooke Moeder*)

In December 2021 the protracted decision-making was shaken up when Boeing was eliminated from the process. Eurofighter had submitted an offer because they believed that there was bias towards the American manufacturers. The decision between the remaining Gripen E and Lockheed Martin was expected shortly after the elimination of Boeing. It took until the end of March 2022 before a decision was announced. Canada selected the F-35A only fourteen days after Germany had announced its selection. It would enter negotiations with Lockheed Martin for eighty-eight F-35s. The Canadian CF-188 will remain in service until 2032.

Canada announced that it had agreed to a deal to acquire 88 F-35As on 9 January 2023. The announcement stated that this was the largest investment in the (RCAF) Royal Canadian Air Force in the past 30 years. The estimated investment for this project is $19 billion, which includes

associated equipment, sustainment set-up and services, as well as the construction of Fighter Squadron Facilities in Bagotville and Cold Lake. As the rules-based international order is challenged around the world, the F-35 will be essential for protecting Canadians, enhancing Arctic security and national sovereignty, and enabling Canada to meet its NATO, NORAD and other obligations well into the future. The first delivery is planned for 2026. Full operational capability is to be reached between 2032–2034. This should sign closure on a very protracted acquisition process. The first sixteen F-35s are scheduled for delivery as follows: 4 for delivery in 2026, followed by 6 in 2027 and 2028. Pilot training is to take place at Luke AFB and should start in 2026 and continue at the PTC Pilot Training Center until the F-35 Operational Training Unit (OTU) is established at Cold Lake AB. The technical training for maintenance personnel will take place at the (ITC) Integrated Training Center at Eglin AFB starting in 2027 and continue at the ITC until the F-35 Maintenance Training Units are established in Cold Lake and Bagotville, where the training will be provided by RCAF technicians. With the recent spate of orders new customers literally will be waiting in line to get their F-35s.

Czech Republic

From the moment it announced that it was looking for a replacement for their Soviet-origin inventory, the Czech Republic was a target country for the JSF programme. Since the JSF could not be introduced to fulfil the immediate requirement, both new and old F-16s and F-18s were offered, so that they could be replaced when the JSF was available. The strategy was partly successful. When the Czechs made their final decision in 2004 they opted for a ten-year lease for the Saab Gripen for the Quick Reaction Alert (QRA) NATO role instead of the F-16 and F-18. The lease would end by 2015 from which time the F-35 would be readily available for export customers who were not partners in the JSF programme. The question of affordability remained a question in the Czech Republic which was not sure if it could afford the JSF even after ten years of beefing up their economy, just as it remained a question whether the F-35 could fulfil its cost target. Another political problem was that most countries would like to see offsets and the Czech Republic is one. This was also a consideration in accepting the Gripen lease as Gripen International offered offsets. The JSF

programme office and Lockheed Martin have been adamant that the time of offsets is over. A country could have become a partner in the programme, the only way of getting return on investment, although even this stance was slowly disappearing as competition from the Eurofighter Typhoon became all too real in countries such as Norway and Turkey, even though Norway was thought to be using the Eurofighter consortium to get a better deal out of Lockheed Martin.



The Gripen is due to stay in service till 2027. The F-35 is seen by the Czech pilots as an unrealistic option not just because of the acquisition cost but also the operational cost. The Gripen is cheap to operate and that will be difficult to beat in the cash strapped Czech Republic especially after the coronavirus pandemic playing havoc with the economy. (*Gérard Keijsper*)

The ten-year lease was approaching its end and marketing machines were started up even though the Gripen was the obvious choice because of the financial crisis which meant that the Czech government was making very unpopular decisions and reforms. It was estimated that no reforms would be required if politicians would stop stealing. The F-35 would not be ready in time to be delivered as anticipated at the end of the lease and the F-35 never entered the equation in the 2011/2012 time-frame. The Eurofighter consortium, however, was very active and presented itself actively from 2010. As defence minister Alexander Vondra stated, he wanted to negotiate a deal with the Swedish partner about an extension. According to Vondra, the extension negotiations were going badly and he gave his Swedish counterpart an ultimatum to come up with a better offer. Otherwise, he

would be forced to advise the government to extend the contract only for a short period and issue an official tender where more options would be available to him. At the time the options with the Swedish partner were a short extension of three years, a five-year extension and a ten-year one. In late November 2012, however, Vondra announced that the latest offer from Sweden was acceptable and that he would advise the Czech government to accept it. Shortly after he resigned from his post as a result of diminishing support; he was unsuccessful in the elections for the Czech Senate. His replacement, Karolina Peake, did not have time to get comfortable as she was relieved as defence minister after only eight days in office. As caretaker, Prime Minister Petr Nečas took office as defence minister until an acceptable replacement had been found, although this took longer than anticipated. The next minister was a general fired by Karolina Peake. Before he and Petr Nečas were able to conclude the deal, a political scandal involving prime minister Petr Nečas's girlfriend abusing her powers of office caused the resignation of the entire right-wing government. Although the Czech Republic was a parliamentary democracy, it was the president who installed a government of so-called specialists. Although this government never gained support in parliament it prepared the extension of the lease deal for fourteen years of Gripen use. The actual signing of the lease agreement was to take place after the general elections due by the end of October 2013. Forming the new government took longer than expected and no contract was signed by the caretaker government. The new government took office by the end of January 2014 and the contract was signed eventually by December 2014. The lease was extended to 2027 with an option for two more years.

A commission was set up in 2020 to look into options open to the Czech Air Force. It was deemed the right time to look into the options a couple of years ahead so that a realistic list could be provided. At this time Lockheed Martin had managed to get the cost of the F-35 down. Of course, the cost of operating the smaller Gripen was likely to be a difficult proposition. It was reported that four countries had been approached by the commission although they were not named. An educated guess, however, would mean that those countries were Sweden, France, the USA and one of the original Eurofighter Typhoon countries, most likely neighbouring Germany. In August 2019 Slovakia had ordered fourteen F-16s Block 70 variant (twelve single-seat and two dual-seaters). Although looking at the Gripen as well

they decided for the F-16. The cost including training and weapons was about US$1.8 billion. By 2021 news started going round that the Czech Air Force was launching the process of Gripen replacement. After a long absence, Lockheed Martin was present again at the NATO Days air show near Ostrava. The mock up of the F-35 was there with an Italian F-35A parked in the static display. *Janes* broke the news that the Czech Republic was inquiring actively about forty F-35As. This news was denied by the chief of communications of the Ministry of Defence, Jan Pejšek, since there was a valid contract until 2027 to lease the Gripen with the possibility of an option of two more years. At the time the country was enduring a third wave of COVID which created a financial situation that made the purchase of forty F-35s unrealistic. On top of all this, the country was coming out of general elections and it remained to be seen how the new government would set priorities. However, that new government made a pledge to increase spending on defence to the NATO commitment of 2 per cent of the national GDP.

During the Berlin Internationale Luftfahrt Ausstellung (ILA) J.R. McDonald, Lockheed Martin vice-president of business development for the Integrated Fighter Group, explained that Lockheed Martin had originally offered both the Lockheed Martin F-16 block70/72 and the F-35. However, after feedback from the Czech Republic, he stated that only the F-35 was being discussed with the Czech Republic. According to McDonald an order for eighteen to twenty-four aircraft was under consideration, which would still be an increase over the fourteen Gripens being leased. McDonald also stated that Lockheed Martin expected a decision before the end of the year.

The Czech Ministry of Defence (*Ministerstva obrany* ***Česká*** *Republika*) was instructed to negotiate the acquisition of twenty-four F-35s, according to a press release issued on 20 July 2022, joining a long list of countries that had selected the F-35 in 2022. Defence minister Jana Černochová stated that the Gripen had to be replaced by 2027 and, therefore, there was very little time for the acquisition process. At the time LRIP 15-17 was being ordered with aircraft from Lot 17 due to be delivered in 2025. This meant that the Czech Republic would require its first F-35s for Lot 18 as the pilots and maintainers had to be trained before being able to take the mission over from the Gripen. The reason given for the increased numbers was that fourteen Gripens were not enough for the tasks to be performed.

On 29 June 2023, the Defense Security Cooperation Agency announced that it had notified the US Congress about a possible sale of 24 F-35As with 25 engines (one spare). Air to air weapons in the deal included the AIM-120 AMRAAM and the AIM-9X Sidewinder. Air to ground weaponry included the GBU-31 JDAM and against moving targets the GBU-53/B SDB II Stormbreaker.

8 pilots from different ages and different backgrounds, that means, Aero Vodochody L-159 ALCA and Saab Gripen with different levels of maturity from the Czech Air Force travelled to Lockheed Martin Fort Worth in May 2023.Two of the pilots were Aleš “Viper” Svoboda and Colonel Pavel “Speedy” Pavlik. The Czech pilots with very little preparations were put Multi-ship Virtual Development Lab (MVDL). At first four pilots at a time later all eight together. Lockheed Martin has two of those simulators that are used as the name indicates for development labs but also allows future customer pilots to look at the current capabilities of the F-35. According to the wing commander one of the small problems to overcome was the HOTAS

On September 27, 2023, the Czech government announced that it had agreed that the F-35A will be bought. It was not announced when the buy would be confirmed by parliament and the senate. First deliveries are planned for 2029 together with training of pilots and maintenance staff. In 2031 the first aircraft are expected to arrive in the Czech Republic and Initial Operational Capability (IOC) is expected 2032. Last of the 24 aircraft to be delivered is expected in 2035. The F-35 will not only replace the 14 Saab Gripen’s in operation with the Czech Air Force but it will also replace the 24 Aero Vodochody L-159 Advanced Light Combat Aircraft (ALCA). The first 12 L-159 will be retired in 2029 so that their pilots and maintenance staff can transition to the United States for their training. The remaining 12 L-159’s and 14 Gripens would be retired in 1935. This means that the L-159 would be in service for 35 years and the Gripen for 30 years. From 2031 training should transfer from the USA to the Czech Republic and last until 2034. Czech president Petr Pavel who had the year before stated his belief that the Saab Gripen would be good enough for the Czech Air Force now stated that the selection of the F-35 was a good choice. Off set was a big thing in the previous offer by Saab and this time around the word off set was not used but an Industrial Cooperation Agreement was touted with 11 projects with Lockheed Martin and 3 projects Pratt &

Whitney were already agreed upon. Companies that were Ray service, Honeywell Aerospace Olomouc, PBS, One3D, Centrum Hilase.

On December 18, 2023, it was announced that contract negotiations had been completed. The offer was now valid until March 2024. Czech Defense Minister Jana Černochová expected the contract to be signed by the end of January mid-February time frame. Of the 24 F-35As that would be bought 12 would be delivered from the US Fort Worth production line the remaining 12 would be built on the Italian FACO in Cameri. Considering that the Czech Air Force will take its first delivery in 2029, the Czech F-35s will be fully developed block 4 aircraft, that is with the new EO-DAS from Raytheon and the new radar system the APG-85. Similar to the Royal Norwegian Air Force and the Royal Netherlands Air Force the Czech Air Force F-35As will be able to use the conformal brake chute. Included in the deal are also four Full Mission Simulators which should be able to connect with each other for training purposes at Časlav Air Force Base. The payment will be made over 11 years and the first payment is due in 2024 after the contract signature. Časlav Air Force Base is due for a complete makeover and the first step is a new runway which will begin in 2026. A group of US advisers will come over to review Časlav Air Force Base to give recommendations as to what is required. A new project manager was appointed for the Czech side and that was retired Major-General Petr Hromek. Petr Hromek was a pilot with the Czech Air Force and has flown on both the Mig-21 Fishbed and Mig-23 Flogger.

The Letter of offer and acceptance for the 24 F-35as was signed in Prague by Defense Minister Jana Černochová and US ambassador Bijan Sabet and as such becoming the 18th country to sign up to the F-35 on January 29, 2024. Greece had just three days before been given approval by the US state department which would make them contenders for the 19 place.

Denmark

Denmark was an early customer for the General Dynamics F-16 Fighting Falcon, making it an automatic customer for the JSF. Denmark, suffering like any other western European country from budgetary constraints, had already lost its Saab Drakens in December 1993 without any outright

replacement. The F-16s took over the extra role previously performed by the Draken.



Denmark was one of the original four European countries to sign up for the F-16 and was one of the countries that eagerly joined the JSF programme. (*Lockheed Martin*)



The Royal Danish Air Force had invested one of their F-16Bs and sent it over to Edwards AFB where it was involved in flying chase missions during the System Development & Demonstration phase. (*Lockheed Martin*)

The JSF programme office tried to get future export countries involved as early as possible and before the CDP started they negotiated with the first F-16 customers in the hope of securing commitments for the eventual programme winner. Denmark signed an MoU to participate in the JSF CDP on 10 September 1997 at a cost of US$10 million.

On 28 May 2002 Denmark became a member of the select few to participate in the next phase of the JSF programme, the development and demonstration phase with Denmark to invest US$125 million until 2012, giving them a seat in the programme office. Although Danish industry would benefit from the programme, it did not commit Denmark to buy the aircraft, although that was considered a certainty since no one invests so much money in a project to abandon it later and buy another plane. Denmark's total investment including the CDP was US$135 million. Fourteen companies from Denmark could become partners in the JSF programme, according to Lockheed-Martin.

Although a partner in the JSF programme's SDD phase, this did not stop the Danes evaluating other aircraft. By the end of August 2005 Denmark released a Request for Information to several aircraft manufacturers.

Eurofighter reacted quite quickly by inviting Chief of the Royal Danish Air Force Air Materiel Command (AMC) Major General Klaus L. Axelsen to fly the Eurofighter Typhoon. The Danish general visited EADS on 7 and 8 November 2005. The one-hour-and-fifteen-minute flight was not just a demonstration flight but an actual scheduled test flight.

Denmark was the last of the countries to sign the PSFD MoU on 27 February 2007. Danish Minister of Defence, Søren Gade, signed in the US embassy in Copenhagen. The estimated procurement amount of aircraft per fiscal year by Denmark as was determined in the PSFD document. Delivery would be approximately two years after contract signature. If, and that was fairly obvious, the F-35 was selected by Denmark, it would be the second aircraft in the Royal Danish Air Force to bear the designation F-35 since the Saab Draken had served in three versions, carrying the designations F-35, RF-35 and TF-35.

Fiscal Year	2014	2015	2016	2017	2018	2019	Total
Amount	8	8	8	8	8	8	48

Denmark also tried to be involved in the flight-test programme, although it did not opt to buy aircraft for the Operational Test and Evaluation. They selected another method to be involved during the SDD phase, opting to send an F-16 to support the programme with chase flights. The F-16 left Denmark on 23 October 2008 via Scotland, Iceland, Greenland and Canada with several stopovers on its way to the USA. During transit the F-16 was accompanied by a Canadair Challenger providing search-and-rescue cover and carrying a technical crew. The official handover ceremony took place at Edwards AFB on 29 October. The test pilot and aircraft supported the testing of F-35 systems using the specially-equipped Boeing 737 and Sabreliner aircraft associated with the programme. It arrived at Fort Worth for the first time on 15 December 2008. Lieutenant Colonel Casper ‘Pel’ Nielsen was one of the Danish test pilots supporting the programme with a squad of mechanics to support the F-16.

A radio report suggested that Denmark was going to leave the programme in early 2010. This was again widely disseminated on the internet as another proof that all was not well with the F-35 Lightning II programme. The Danish F-16 in the US, however, remained there and the

government remained mute, Denmark's participation continued. The reports were repeated once in a while.



The Danish investment in sending a support aircraft lasted longer than expected. Note the Deadly Jester unit badge on the tail. (*Lockheed Martin*)

While being operated by an American crew the Danish F-16 experienced an emergency landing on 23 June 2011 and was damaged. A Danish repair team was deployed to Edwards AFB, and the aircraft was ready again after eleven weeks. The aircraft was fully operational after the functional check flight on 7 September 2011. During those eleven weeks no replacement was sent from Denmark and other aircraft from Edwards AFB were used instead.

The Danish minister of defence issued a Request for Binding Information which included approximately 950 questions on 10 April 2014. Answers were received from Boeing, Lockheed Martin and the Eurofighter Typhoon consortium on 21 July 2014. The three bidders were evaluated according to four specific areas:

Military area: the ability of the bidder to successfully conduct fighter missions (Mission effectiveness), the bidder's aircraft survivability, opportunities to maintaining the bidder's aircraft operational and technically relevant within its expected lifespan (future development) as well as the risks associated with each bidder that cannot be economically quantified (Bidder risk)

Strategic area: the ability of the bidder to support or fulfil overarching Danish defence and security policy objectives, including co-operation with other countries.

Industrial area: The ability of the bidder to support significant Danish security interest through industrial co-operation with the Danish defence industry.



The Danish F-16 was integrated at Edwards AFB with the 461 Flight Test Squadron the Deadly Jesters. (*USAF*)



Seen here in 2015. It was an innovative low-risk way in which to keep an eye on the project progress and remain involved. (*USAF*)

Economic area: the estimated life cycle cost of the bidder's aircraft, including cost associated with procurement, ongoing operations, and sustainment as well as quantifiable risks.

The evaluations are based on an operational period of thirty years for the new fighter aircraft (2020-2049).

	Military	Strategic	industrial	economic
1	Lightning II	Lightning II	Lightning II	Lightning II
2	Super Hornet	Eurofighter	Super Hornet	Super Hornet
3	Eurofighter	Super Hornet	Eurofighter	Eurofighter

The cost was seen as the Achilles' heel of the F-35. The Danes explained that both Eurofighter and Super Hornet were designed for 6,000 flight hours, whereas the F-35 had been designed for 8,000 flight hours. For this reason more aircraft would be required for the same period of time resulting

in lower acquisition cost. The Danes had quantified the requirement as such that they would need twenty-eight Lightning II airframes, thirty-four Eurofighter airframes and thirty-eight Super Hornet airframes.

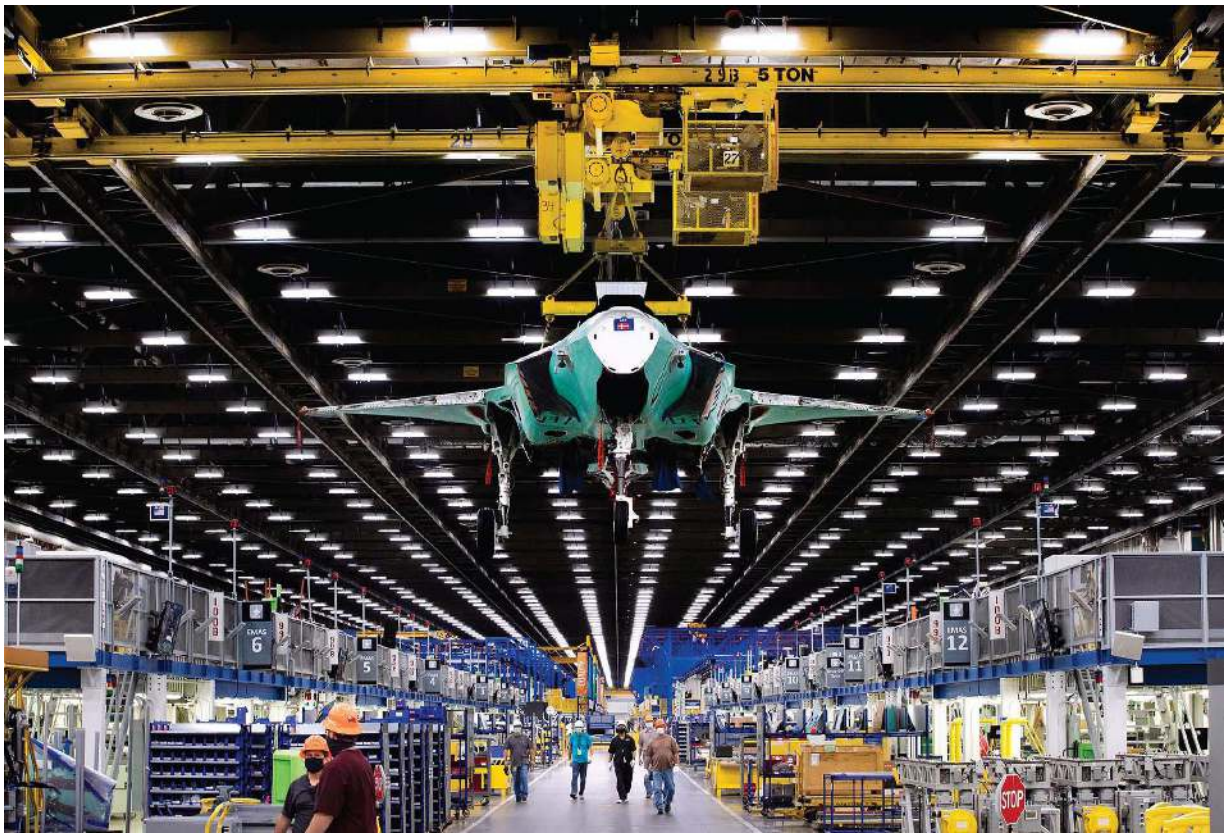
In early 2016 news came out that a fighter replacement programme (FRP) decision was to be made soon. The Danish government, a minority government, made known its selection of its next-generation fighter. From the three contenders, the Boeing F-18 Super Hornet, Eurofighter Rafale and Lockheed Martin F-35, Danish Prime Minister Lars Rasmussen announced that his government would recommend the acquisition of twenty-seven F-35 fighter aircraft. First delivery was planned for 2021 with the last expected by 2027. This was well below the forty-eight planned and it was not clear if the number was final or was a first batch. The Danish evaluation and down selection process was based primarily on information from the suppliers, i.e., MoD Germany, F-35 JPO and US Navy International Programme Office and not on the experience gained by the Danish team at Edwards AFB.



The first parts for the Danish F-35. (*Lockheed Martin Angel DelCueto*)



The first Danish aircraft in the Electric Mate and Assembly Station. The wings are already mated to the middle fuselage. Note that in the background a set of wings is already waiting to be mated to the next aircraft. (*Lockheed Martin Mikaela Maschmeier*)



The Danish F-35 lifted out of one of twelve Electric Mate and Assembly Stations at the Fort Worth plant. (*Lockheed*)



First Danish aircraft rolls out of the production line still in primer.



Ground tests of the first Danish aircraft. Note that the aircraft is being restrained with the help of its tail hook. (*Lockheed Martin Chris Hanoch*)

The Danish F-16 chased more than 600 F-35 test missions including more than 400 high-risk test missions. It was also used for other missions like air-to-air photography and proficiency flights for the assigned test pilots. The aircraft flew a total of 2,038 hours during the more than eight years it was assigned to the F-35 test programme at Edwards with the majority of them flown by 'Pel' Nielsen.

After the decision had been announced both Boeing and Airbus raised questions about how the financial part of the evaluation had been made. The Danish parliament's Committee of Defence (CoD) questioned Danish Defence Minister Peter Christensen and members of the New Fighter Program Office (NFPO). The fact that a poll showed that 59 per cent of the Danish population was against the acquisition made it unclear if the minority government had a chance of putting this through parliament. Boeing went as far as to sue Denmark for its evaluation methods. The F-16 chase aircraft was a Danish non-financial contribution to the System Development and Demonstration (SDD) phase of the programme. The

contribution was extended relative to the original commitment and discontinued as the SDD phase came to the end. The transit back to Denmark followed the same general route as the original deployment. The F-16, the Danish personnel and the Challenger arrived at Air Base Skrydstrup on 16 December 2016.



The first flight of the second Danish F-35. Note that Denmark did not select a low visualisation identification roundel. (*Lockheed Martin*)



First Danish pilot to fly the F-35 at Luke AFB.

The court case was about access to documents covering the evaluation process. As Boeing was unable to specify which documents were required, they lost their case in 2018. The Danish parliament's Committee of Defence (CoD) questioned Danish Defence Minister Peter Christensen and members of the New Fighter Program Office (NFPO). The fact that a poll showed that 59 per cent of the Danish population was against the acquisition made it unclear if the minority government had a chance of putting this through parliament. The acquisition was approved by Danish parliament 6 June 2016. The National Auditing office (Rigsrevisionen) initiated a study in December 2016. The Study published in 2017 questioned the presumption on which it calculated the life cycle cost and more importantly if the 27 aircraft ordered were sufficient for the task that they should fulfil.
The forward fuselage for the first Danish F-35A arrived at Fort Worth during the second half of January 2020

Denmark's first F-35 was due for its first flight in 2021. The F-35 was on the production line and a clear sign that it was more or less going according to plan even though COVID 19 was having a disruptive effect on the production line. Back at home a ground-breaking ceremony was held

for the construction work for the F-35 facilities that were initiated at Air base Skrydstrup 15 June 2020. The number of Danish F-35s in the US depended on the number of pilots to convert; initially it was to be seven aircraft, decreasing to six from January 2027. The first real sign that final assembly was underway was the moment that the main fuselage parts entered the electronic mate and assembly station (EMAS) on 16 July 2020. AP-1, the first Danish F-35A, left the EMAS and went into final production 15 September 2020. Once it is lifted out of the EMAS it goes to a so-called soft station. AP-1 received tail number L-001. This example would move to Luke AFB as a part of the training capability for the F-35. The first time the F-35 was in Danish air space was in 2020 when a few Dutch F-35s trained together with Danish F-16s. AP-1 was rolled out of the factory on 13 January 2021 and moved to the aircraft final finish (AFF) hall, from where, in full colour, it moved to final tests (ATF) prior to first flight on 24 February 2021. The first engine start up was shortly after, on 3 March, followed five days later with the maiden flight of the first Danish F-35.

Denmark is planning for the following implementation milestones:

- First Aircraft Arrival (FAA) at Skrydstrup Airbase by 1 October 2023.
- Initial Operational Capability (IOC) – national operations, including quick reaction alert, by 1 April 2025.
- Limited Operational Capability (LOC) – deployment in a limited mission spectrum, including air policing missions by 1 July 2026.
- Final operational capability (FOC) – deployment to the full extent of the DNK F-35 mission spectrum by 1 July 2027.

The Danish mission data files will be acquired from the US reprogramming facilities on Eglin Air Force Base, Florida. The first 6 F-35A's were delivered to Luke AFB for training purposes. The seventh F-35A was destined to fly to Denmark to become part of the operanional fleet there. On February 2, 2022 the Danish Air Force announced that the unit to receive the F-35As and operate them would be 727 Eskadrille (squadron). The first Danish F-35A was planned for arrival by October 2023 at Skrydstrup Air Base. The seventh F-35A was first delivered to Luke AFB to help with training pilot before it would transfer to Denmark. On the 14 September 2023 the first four F-35s, these included L-007 (20-5647)/L-008 (20-5648)

/L-009 (20-5649) /L-010 (20-5650), landed at Skrydstrup, This was ahead of the official aircraft introduction planned for 1 October 2023.

Finland

After the Second World War the Soviet Union gave Finland the ‘choice’ of remaining neutral or losing their sovereignty, as happened to other nations of the later Warsaw Pact. One rule was that the Finnish air force could not have more than sixty fighter aircraft, a rule, however, that was not applied too strictly.

To appease the Soviet Union, Finland had bought fighters from the West as well as from Soviet manufacturers to confirm their neutrality. Thus, they had two fighter aircraft to replace, the MiG-21 Fishbed and the Saab J.35 Draken. In 1986 it was clear that the Finnish fighter arsenal was about to be retired so, on 1 July, the USSR sent a group of six MiG-29 Fulcrums, which was also the first chance for Western press and aviation experts to have a close look at the MiG-29. Before there had been only satellite photographs and blurred pictures from Soviet publications and television stations.

In 1989 Finland wanted to replace its ageing MiG-21s and Saab Drakens. The Dassault Mirage 2000-5, General Dynamics F-16A/B, and the batch-one Saab JAS 39 Gripen were supposed to be candidates to replace the Drakens. The MiG-21s were tipped to be replaced by MiG-29s and Sukhoi Su-27 Flankers. When Finland sent out a request for quotation (RfQ) for twenty single-seat fighters and five two-seat fighters with an option for twenty more, everyone involved thought that this was only to replace the Saab Drakens for the DX requirement.

A request for quotation was sent out shortly after on 3 January 1991 for sixty single-seat and seven two-seat fighters. At the same time Finland announced that it could no longer afford to maintain two different types of aircraft and would acquire only one type to replace both the MiG-21 and the Saab Draken. Due to political circumstances, it was the first time that Finland could choose one aircraft for one requirement. The Finns immediately stated that they would also choose one of the Western fighters and had put up a requirement of a minimum of 100 per cent off-set. Due to the ever declining trade between the Soviet Union and Finland and the financial positions of the Mikoyan Gurevich and Sukhoi design bureaux this was very unlikely to be fulfilled. The fact that the Finns would choose

only one fighter was surprising so soon after the political changes in the Soviet Union. The political situation was everything except stable, as was later proven by two coups d'état.

In May 1992 the Finnish Minister for Defence, Elisabeth Rehn, called the officials of all the countries involved to give news of their decision. For the French and Swedish it was bad news. For Lockheed she also had bad news. For McDonnell Douglas, the good news was that Finland would order fifty-seven single-seat F-18Cs and seven two-seat F-18D Hornets. The letter of offer and acceptance was signed in June 1992.



The Eurofighter Typhoon was the first of the five candidates to be evaluated in Finland in early 2020.

In 1995 Finland started conversion to the F-18C/D. The first four two-seaters arrived in Finland on 7 November at Pirkkala Air Base after they had refuelled air-to-air nine times, as they were flown in straight from the McDonnell Douglas factory in St Louis. The replacement of McDonnell Douglas F-18 was thought to be a long way off, but Lockheed Martin did not hide the fact that they would target every F-18 and F-16 operator, politics allowing, with the F-35.

Fifteen-plus years later, co-operation with Sweden increased and this co-operation was expected to widen. Saab hoped that at some point its successes of selling the Super Gripen to Swizerland and Brazil meant that they could succeed where they had failed in 1992 with their original Gripen bid.

In 2014 Russian politics changed the situation in Europe when Russia annexed Krymia (Crimea) from Ukraine, supported with Russian Special Forces living in Ukraine and instigating a civil war. Russia was awakening their patriotic need to renew the power of the former Soviet Union. Everyone sat up and started discussing the need to increase defence spending. A discussion was initiated when it was suggested in Finland that it would be good for Nordic co-operation to buy the Gripen E. This suggestion was rebuffed by the defence minister, Carl Haglund, who was quoted in the *Helsinki Times* as saying 'The Finnish Air Force must get the best equipment we can afford. Our possible collaboration with Sweden must entail rational projects. This is not a question of industrial policy but of defence policy.'



The French Dassault Rafale was the second aircraft to be evaluated in Finland.

‘Although I advocate co-operation with Sweden, we should not acquire Swedish JAS fighters if we could acquire American F-35 stealth fighters for roughly the same price. Performance must take precedence in the investment,’ emphasised Haglund. On 8 June 2015 a preliminary assessment for replacing the capabilities of the Hornet fleet was published.

In the report the situation in the surrounding countries was summarised as follows: the air forces of Finland’s neighbouring countries were presently implementing significant aircraft replacement programmes. Sweden would procure sixty Gripen E fighters; a planned additional procurement may increase the number by ten more fighters. While Norway would replace its F-16s with fifty-two F-35 fighters, Denmark’s fighter programme was still incomplete. Russia had undertaken a massive modernisation of its air force and air defence equipment. The Baltic States had no fighter programmes; their air defence was largely based on NATO’s air-policing mission and the provision of assistance as per Article 5. The bases used in the Baltic Air Policing operation were Šiauliain in Lithuania and Ämar in Estonia. The presence and activity of NATO countries’ air forces had grown in response to the events in Ukraine. So far, no announcements regarding permanent US reinforcements in Europe or expanding NATO’s action in the Baltic States had been made.

The study came with the following recommendations regarding the implementation of the fighter replacement programme:

1. Adhere to the Hornet fleet’s original service life because, as per the preliminary assessment, there are no grounds for extending its service life.
2. Replace the Hornet’s capabilities with a solution based on a multi-role fighter.
3. Launch the HX programme no later than autumn 2015.
4. Set up an HX Steering Group, an HX Programme Co-ordination Group and an HX Programme Secretariat, and establish their tasks, competencies and compositions.
5. Implement the acquisition process in a normal manner: promulgate the request for information in 2016 and the request for quotation during 2017–2018.
6. Make use of the derogation of the EU Defence and Security Procurements Directive, permitted by Article 346 Treaty of the

Functioning of the European Union (TFEU), because the procurement processes pursuant to the directive are not suitable for this acquisition.

7. Draw up a defence industrial strategy and establish the project-related requirements for an independent capacity and security of supply.
8. Establish the need and possibilities for external auditing (quality assurance).



Saab sent over two Gripen for the evaluation. One was the NG demonstrator 39-10.



Boeing sent over three different aircraft EA-18G Growler, F-18E single seat, and the F-18F two-seat. Furthermore they arrived with a tanker from Omega Finnish Air Force 2x.




LF



Two F-35As arrived at Pirkkala Air Force Base on 9 February 2020 during darkness. The two F-35s were from Luke AFB. (*Finnish Air Force, Ville Tuokko 2, Joni Malkamäki*)







The F-35s were in Finland for the HX evaluation and fulfilled all requirements in the time given, as did all other competitors. Like the other candidates candidates they found time for a photoshoot. (*Finnish Air Force*)

The Hornet replacement was called the HX programme, the H standing for Hornet replacement and X for the yet unknown aircraft that would be procured. Whatever defence minister Carl Haglund's personal opinion, when Finland announced the start of the acquisition process for the F-18 replacements, the invitation for request for information would be sent out for seven aircraft: in alphabetical order the Boeing F-15 Eagle, Boeing F-18E/F Super Hornet, Dassault Rafale, Eurofighter Typhoon, Lockheed Martin F-16 Fighting Falcon, Lockheed Martin F-35 Lightning II, and Saab Gripen. A tender was being prepared. Service life of the F-18C/D fleet was calculated at thirty years and as procurement of those aircraft had taken place in the 1995-2000 timeframe it was concluded that the F-18C/D would be retired in 2030. The eventual Hornet replacement was expected to remain in service until 2060.



The F-35 was developed to replace the F-18, and just like Australia showed the F-35A was a good replacement. Finland was one of the last classic F-18 Hornet buyers. (*Finnish Air Force*)



Luke AFB became the base where most of the representative work deployments originated from. This was only logical as they had the instructor pilots. One F-35 at the ILA Berlin 2016. (*Lockheed Martin*)

The HX fighter replacement Rf I was sent to four governments during spring 2016 which they sent to their respective industries by November 2016 to send the answers to the Rf I. Information was requested on fighters, weapons systems, command and control, related training equipment and training, maintenance arrangements. To be able to compare the different information received, the aircraft manufacturers were also asked about the cost of acquisition, operations, and maintaining including their calculation methods. The manufacturers were allowed to offer a mix of aircraft. From the four countries five aircraft were offered: Boeing F-18E/F Super Hornet, Dassault Rafale, Eurofighter Typhoon, Lockheed Martin F-35 Lightning II, and Saab Gripen.

After thorough evaluation of the information received, a request for quotation (RfQ) was sent out to the four governments on 27 April 2018 so that they could forward it to the respective aircraft manufacturers. At the time Defence Minister Jussi Niinistö decided that 30 per cent of the contract value had to be re-invested in Finnish industry. The fact that the RfQ was sent was a signal that Finland was serious about acquiring a replacement for

its fleet of F-18C/D Hornets. Replies to the RfQ were due by the end of January 2019.

The military capability assessment was made using five scenarios: Counter-Air, Counter-Land, Counter-Sea, Intelligence, Surveillance and Reconnaissance (ISR) and Long-Range Strike. The candidates' capability to adapt to the air force's agile combat support at different types of operating bases in dispersed locations was also assessed.

An evaluation was required of all the candidates in Finland and would take place from Pirkkala Air Force Base. The timing was during the Finnish winter so that the evaluators could see if the aircraft would function as advertised in the harsh winter conditions of Finland.

The HX Challenge test periods were:

- Eurofighter Typhoon: 9-17 January 2020
- Dassault Rafale: 20-28 January 2020
- Saab Gripen E: 29 January-6 February 2020
- Lockheed Martin F-35A: 7-17 February 2020
- Boeing F/A-18E/F Super Hornet: 18-26 February 2020

The F-35s sent to Finland for the HX challenge evaluation were: 13-5066 (AF-72) flown by Paul 'Hat' Hattendorf, 15-5189 (AF-164) flown by Andrew 'Bundy' Soundy, 15-5125 (AF-116) flown by Billie Flynn and 15-5182 (AF-157) flown by Scott 'Shark' McLaren. They arrived in a staged manner as two were delayed by a combination of tanker availability and weather.

After each evaluation a press brief was given. During the Gripen briefing it was confirmed that the Global eye was part of the package on offer to Finland. Since some reports say that the F-35 is a better tool than the E-3 AWACS, it makes Gripen E seem less attractive. An air-launched decoy missile was announced as part of the electronic-warfare system for the Gripen during a briefing at the Kauhava Air show.

The Finnish Defence Forces Logistics Command issued the request for best and final offer for the HX Fighter Programme on 29 January 2021 with the deadline for finalised tenders as 30 April. This would give the evaluation team the time to recommend its findings to the government and for the government to make its decision by the end of 2021.

News reports in early December 2021 announced that the F-35 had been selected. No official denial was forthcoming but, on 10 December, it was confirmed by Lockheed that they had been selected for the Finnish Air Force requirement. Since the process had been quite intensive, with most of the negotiations done beforehand, the agreement to acquire sixty-four F-35A fighter aircraft was soon a reality. The letter of offer and acceptance was signed on 11 February 2022. On the same day as the Canadian announcement, the Ilmavoimat announced on Twitter that the type code of Finland's future F-35A Lightning II fleet is JF. The designation is derived from the English words Joint Fighter. The fleet is numbered per aircraft, starting with code JF-501 and ending with code JF-564. The F-35As will sport the wisent and lynx of the fighter units HÄVLLV 11 and 31 respectively.

Germany

The German Air Force, or Luftwaffe, was a partner country in previous European fighter projects. The last one, the four-nation Eurofighter Typhoon, was still entering service and the previous European project was the tri-nation Panavia Tornado, due to remain service until 2035. The Luftwaffe Panavia Tornado is also responsible for the nuclear mission, which is carried out with the B-61. The Panavia Tornado was a strike aircraft by design and Germany, if at all possible, would prefer another European co-operation programme, but it was questionable if it could find any partners for such a project, especially with the F-35 entering service in the 2020s in Europe. Previous partners in the Eurofighter Typhoon and Panavia Tornado projects, with the exception of Spain, were all in the process of acquiring the F-35. This meant that the only partner nations left for a development programme in Western Europe were France and Spain. Germany had co-operated with France on its operational trainer, the Dassault/Dornier Alpha Jet, so there was a precedence of co-operation with France. Germany did not want to close the door on a development programme for its future air combat system (FACS) or 'Command Fighter Advanced' (CFX) but asked the US for detailed information about the F-35, including a classified briefing. This was revealed in May 2017 and confirmed at the Paris air Show at le Bourget. The F-35 option would increase inter-operability with the Eurofighter services buying the F-35 as

well. Apart from Germany, Austria and Spain were the only European Typhoon operating countries not committed to the F-35. A decision on whether to develop a new aircraft or buy an already developed model was expected in 2018. Austria, it was reported, was even thinking about retiring its fifteen Eurofighter Typhoons because of the operating costs. If Germany wanted to go with a new fifth-or sixth-generation aircraft to give its industry a technology share, it would join a growing group of developers of fifth-generation fighters such as Russia/India (T-50), China (J-20), Turkey (TFX), South Korea/Indonesia (KF-X/IF-X) and Japan (X-2).

By November 2017 news got out that Germany was taking the F-35 as the benchmark for its Panavia Tornado replacement. Requests for information had been sent out and were due back by March 2018. It was deemed that a new European development would be too late. A solution was to develop a European replacement for the Typhoon. German industry was expressing the same fear as the French had been, pointing out that the F-35 would kill European industry.

The first chance for the Luftwaffe to get a real close-up look came with the *Internationale Luftfahrt Ausstellung* (ILA) in Berlin in 2018. Two F-35s from Luke AFB (11-5040 (AF-51) and 12-5054 (AF-65) were at the show. Besides the F-35, Lockheed presented the Sikorsky King Stallion. Early the following year, in January, news broke that the F-35, which was rumoured to have been the favourite among Germany's Luftwaffe leadership, was not selected for the Panavia Tornado replacement. The two types that made the selection were the Eurofighter Typhoon and the Boeing F-18 Super Hornet. There was a strong reaction from the US, and from France a counter-reaction to the so-called outrage with Minister of the Armed Forces, Florence Parly, stating that 'it's called Article 5, not Article F-35,' referring to Article 5, the pledge that all NATO members take to come to each other's defence if the alliance declares it necessary. The French were worried that acquisition of the F-35 would put co-operation between France and Germany on the next-generation fighter in financial jeopardy. This new fighter was supposed to have a technology demonstrator flying in 2025 with service entry in 2040. It was even rumoured that some of the Luftwaffe senior officials' careers were shortened due to their open support for the F-35. The 'Future Combat Air System' had been announced in 2017 and was confirmed at Farnborough 2018. Spain signed up as an observer for the FCAS although it was not clear what that would entail in the future.

The situation went quiet, elections took place in autumn 2020 and long-time Chancellor Angela Merkel retired from politics. Finland and Switzerland had selected the F-35 and a broader change in the coalition allowed the military to question earlier announcements. Suddenly the door for Lockheed Martin and the F-35 was swung wide open again and the Luftwaffe might get what they wanted from the outset, the F-35. On 24 February 2022 Russia decided to invade Ukraine which came as a surprise to many, even after its annexation of Crimea in 2014. The invasion sent shockwaves through the German political world which reacted three days later when Chancellor Olaf Scholz announced that Germany would spend €100 billion on defence. At the same time he promised to increase defence spending to 2 per cent of gross domestic products (GDP). This was followed by news on German television on 14 March that Germany had selected the F-35. Germany intends to buy thirty-five F-35s to replace the Panavia Tornado for the nuclear mission. One of the reasons for a change of heart about the F-18E/F was the fact that the US DoD had decided against employing and therefore certifying the B61-12 nuclear bomb on the F-18E/F meaning that the cost of doing so would fall to the German Ministry of Defence. The F-35 had the nuclear capability certified ahead of schedule.

On 7 May 2022 Luftwaffe Lieutenant General (*Generalleutnant*) Ingo Gerhartz announced that the F-35 would be based at Büchel Air Base, the current home of *Taktisches Luftwaffengeschwader* 33 (Tactical Air Force Squadron 33) equipped with Panavia Tornado IDS, responsible for the nuclear role, which did not come as a total surprise. At the Berlin Internationale Luftfahrt Ausstellung (ILA) 2022 the F-35 was exhibited beside a Panavia Tornado from *Taktisches Luftwaffengeschwader* 33.

Also at ILA 2022, J.R. McDonald explained how Lockheed Martin was in intensive talks with the German government so that they would understand the exact requirements for the Luftwaffe and could provide the right package. The German government had made it crystal clear that they wanted German industry involved and Lockheed Martin was examining how to do this. The government was in a hurry since they planned to hand over the package to parliament before the end of the year.

On 28 July 2022, the Defence Security Co-operation Agency (DSCA) announced that Germany had expressed an interest in acquiring thirty-five F-35As, thirty-seven Pratt & Whitney F135-PW-100 engines (including spares), 105 AIM-120C-8 AMRAAMs, four AIM-120C-8 AMRAAM

guidance sections, seventy-five AGM-158B/B2 joint air-to-surface standoff missiles-extended range (JASSM-ER), two AGM-158 Inert JASSMs with test instrumentation kits (TIK), two AGM-158 JASSM separation test vehicles (STV), 344 GBU-53 small diameter bombs (SDB-II), three GBU-53 SDB-II guided test vehicles (GTV), eight GBU-53 SDB-II captive carry reliability trainers (CCRT), 162 BLU-109 2000LB hardened penetrator bombs for GBU-31, 264 Mk 82 500lb GP bombs for GBU-54, six Mk 82 inert filled GP bombs, thirty BLU-109 inert 2,000lb hardened penetrator bombs, 180 KMU-557 JDAM tail kits for GBU-31, 246 KMU-572 JDAM tail kits for GBU-54, seventy-five AIM-9X Block II+ tactical Sidewinder missiles, thirty AIM-9X Block II Sidewinder captive air training missiles (CATM), fifteen tactical AIM-9X Block II+ Sidewinder guidance control units, and five AIM-9X Block II Sidewinder CATM guidance units. Also included are AIM120 control sections, propulsion sections, telemetry systems, warheads and containers, AIM-120 CATMs; AIM-9 active optical target detectors and containers, FMU-139 joint programmable fuses, DSU-38 LaserIlluminated Target detectors for GBU-54, AN/PYQ-10 simple key loaders, common munitions built-in test reprogramming equipment (CMBRE) and ADU-891/E adapter group computer test sets, KGV-135A embedded secure communications devices; cartridge-actuated devices/propellant-actuated devices (CAD/PAD), impulse cartridges, chaff and flares; full mission simulators and system trainers; training missiles and components; electronic warfare systems and reprogramming lab support; logistics management and support systems; threat detection, tracking and targeting systems; contractor logistics support (CLS); classified software and software development, delivery and integration support; transportation, ferry, and refuelling support; weapons containers; aircraft and munitions support and support equipment; integration and test support and equipment; aircraft engine component improvement programme (CIP) support; secure communications, precision navigation, and cryptographic systems and equipment; identification friend or foe (IFF) equipment; spare and repair parts, consumables, and accessories, and repair and return support; minor modifications, maintenance, and maintenance support; personnel training and training equipment; classified and unclassified publications and technical documents; warranties; and US Government and engineering, technical and logistics support services, studies and surveys, as well as

other related elements of logistical and programme support. The estimated total cost is $8.4 billion.

As Germany was not a partner in the JSF programme, it had to go through the Foreign Military Sales programme of the Defence Security Co-operation Agency. If the German parliament would agree to order the F-35, it would be the first Lockheed Martin built fighter aircraft since the F-104G Starfighter and the first American fighter in the German inventory since the McDonnell Douglas F-4F Phantom II retired on 29 June 2013. On 14 December 2022 Germany confirmed that it would be acquiring 35 F-35As with the related equipment. First deliveries are planned for 2026 and the first F-35As to land at Büchel Air Base are expected in 2027.

Greece

Greece is in a strange position. It is a NATO member and its air force, the Hellenic Air Force, defends itself and fulfils duties for NATO but tangles often with fellow NATO member and ally Turkey. The two countries have their own ‘cold war’ with the potential of going hot. The Hellenic Air Force operated many versions of the Lockheed Martin F-16, Dassault Mirage 2000, Vought A-7 Corsair II and McDonnell Douglas F-4 Phantom II. Unlike its neighbour Turkey, Greece did not become a partner in the Joint Strike Fighter programme. A tender to replace the Corsair II and Phantom II was initiated.

On 12 February 1999 Greek Defence Minister Akis Tsohapoulos confirmed that Eurofighter had won the competition and were the preferred bidder for the long-term fighter requirement. Greece would start negotiations to join the Eurofighter programme and was expected to buy between sixty and eighty Eurofighters. On 8 March 2000 Greece announced the intention to buy sixty Eurofighters with an option for thirty more, a deal hailed as the first export success for the Eurofighter consortium.

Signature was postponed due to financing difficulties for the Olympic Games to be held in Athens during summer 2004 and the contract signing was postponed until after the Olympics. A change of government in December 2004 resulted in a decision to re-initiate the tender instead of accepting the previous administration’s work, which was a blow to the Eurofighter consortium. The last new fighters to enter service with the Hellenic Air Force were the F-16 Block 52 Advanced in 2009. Since then,

the worldwide financial has hit Greece harder than many other countries. The Vought A-7 Corsair II was retired without replacement in 2014.

Greece could not afford to buy new fighters but nor could it afford not to. In 2019 an interest was declared in buying the F-35. Shortly afterwards, the idea of acquiring the Turkish planes was floated. In August 2020 an order for eighteen French Dassault Rafales was announced, the first being delivered to the Hellenic Air Force in July 2021. This, however, was a separate deal and would not affect the Hellenic Air Force's interest in F-35. The speed of the deal depends on the duration of the financial payments required – the longer the better for Greece. On 30 June 2022 Greece, according to Prime Minister Kyriakos Mitsotakis, officially ordered twenty F-35s. Speculation that Greece wanted these aircraft quickly and would acquire machines originally intended for Turkey was not confirmed in official communications. Tensions with Turkey had increased in recent years. It took a little over one and half year for the negotiations to be complete for the Defense Security Cooperation Agency to announce that a possible sale of 40 F-35A's was approved by the US State department. The sale would have to confirmed by the US senate and then would be followed by final negotiation between the two countries. The sale would also include 42 engines. It is not clear if all of the 40 would be ordered in one go and some anticipated that the 40 F-35A's would be ordered in separate batches for financial reasons. Previous F-35 FMS buyers had also included a weapons package this was however not detailed in the announcement.

India

Although developing its own light combat aircraft (LCA), India had a requirement to replace its MiG-21 Fishbeds and had approached Dassault for Mirage 2000s and Gripen International for the Gripen. Considering that BAE Systems had sold the Hawk to India, a foot in the door was already there, with a repeat of the South African double anticipated. However, India would request to have the chosen fighter license-built by their indigenous manufacturer, Hal. An estimated requirement for 120 aircraft existed. The Indian Air Force, with a total of 380 MiG-21s, had ordered the LCA to replace all of them but delays forced a new option to be considered. However, although the Indian Air Force had been buying Russian Su-30,

the fact that its trainer aircraft were Russian gave Gripen International confidence that dual sourcing was an option with the Indian government.

Gripen International was not alone in noticing the intention to replace the MiG 21s. Dassault was already involved with India, having delivered a version of their Mirage 2000 to the Indian Air Force. In autumn 2004 the IAF had encountered technical problems with their Mirage 2000s when three of the type crashed. However, this was seen as the time to upgrade the aircraft already in service, for Dassault to renew their connections and get, as well as an upgrade contract, a contract for newly-produced Mirage 2000s to replace the MiGs.

On 17 November 2004 the Vice Chief of Air Staff, Air Marshal Sunil Kamar, stated that the requirement was real and that there would be no restrictions for companies supplying the new fighters which would replace the MiGs until the much-delayed, home-developed LCA became available. Aircraft that would come into contention, according to Kumar, were the Lockheed F-16, Dassault Mirage 2000-5, MiG-29 and the Gripen from Gripen International. However, every company would have to meet one requirement: that there would be a continuous supply of spare parts even if there were sanctions. That would be difficult to promise for Gripen International and Lockheed, giving the French Mirage and the Russian MiG a clear advantage. Selection was expected by the end of 2006/early 2007.

Not surprisingly, Boeing was also seeking approval to sell its Boeing F/18E/F Super Hornet to India which had become a reliable partner in the war against terrorism and therefore entitled to receive consideration for Super Hornet exports. This was also noticed by Lockheed's JSF programme office which began pushing the F-35 as another option. The F-18E/F would be sold with the full Navy shipboard capability but the Indian Navy stated that the F-18E/F was not compatible with their ships since the Indian carriers had a ski jump from which the F-18E/F was not designed to take off.

Delays are not only a feature in aircraft development programmes but also of procurement programmes. The Indian programme was a point in case since selection had not been made in early 2009 and there was no sign of getting closer to the end of the tender.

When the selection was made a shock wave was sent throughout the industry. The two remaining contenders were the Eurofighter Typhoon and Dassault Rafale. The Rafale was selected as the winner of the tender but it

took a very long time to reach an agreement. The major problem was the transfer of technology. In the media it became clear that, instead of the 120 originally planned, the order would be reduced to thirty-six aircraft. The delays, however, made the Indian Air Force requirement more urgent. Those delays were thought to be going to help the Eurofighter consortium. However, during the Farnborough Air Show, Lockheed Martin floated the possibility of an F-16 final assembly line. Although the Lockheed Martin F-16 line was close to ending, upgrade work was thought sufficient to maintain the skilled work force available to re-open production in the near future if required.

Shortly after the news arrived that the remaining Sea Harriers in service with the Indian Navy were to be decommissioned during 2016 and replaced by the MiG-39K, which was also capable of taking off using a similar ramp. STOVL capability would, however, be lost by the Indian Navy. By 2017 the Indian Navy initiated a tender for fifty-seven multi-role carrier-borne fighters (MRCBF). In January 2022 the Dassault Rafale was invited for tests at the Indian Navy Air Station (INS *Hansa*) near Goa. The tests were regarding compatibility with INS *Vikrant*'s ski-ramp; the carrier would be commissioned later that year. Similiar evaluation was planned for the F-18E/F later in the year and Boeing had already had trials with an F-18E at NAS Patuxent River taking off from a ski ramp in August 2020. The Sea Gripen may also be evaluated but no previous testing has been reported although Saab has been talking a lot about design work being done. The fourth contender is the MiG-29K.

Israel

One of the US's most reliable customers, buying regularly to update their forces out of need to prevent extinction, is Israel. From the moment of its inception as a state Israel has been under attack by its neighbours. Israel prevailed in those wars thanks to support from nations such as France and, since the 1960s, from the US. In American eyes, the Israeli Defence Force Air Force (*Heyl Ha'Avir*) has a perfect record and is considered a trustworthy ally.

The Heyl Ha'Avir has large numbers of F-16s and F-15s that need replacing with the JSF the perfect replacement for the F-16. It took longer

than thought before Israel actually committed itself to the JSF programme and when it did it was surprisingly at the lowest level.

Although Israel signed up late under the Foreign Military Sales (FMS) programme it requested something not considered by any other country. It wanted a two-seat version of the JSF which could prove extremely costly since Israel is the only country requesting it. On the other hand the Hey Ha'Avir has had more operational deployment than any other air force, although the United Kingdom and the United States were slowly catching up on the experience front, as a result of the several no-fly zones and the war against terrorism. The JSF had been deliberately designed and developed from the outset as a single-seat fighter but it would be interesting if other countries follow suit or if the need arises should new multi-role tasks be required from the JSF. An option is to replace the lift-fan of the STOVL version with a cockpit seat instead of a fuel tank but this relatively easy option would still be costly since the outer design would change with cockpit and structure, and weight and system distribution also being affected.

The Heyl Ha'Avir seemed to let go of this requirement but wanted to receive F-35s fully modified to its requirement meaning that the aircraft could go straight from the manufacturer to the operator, as was the case with the F-16L. After the USAF had announced plans to buy the STOVL version for the CAS mission the Israeli Brigadier General Zeev Snir, head of the air force material directorate, stated that the HH'A was not only evaluating the CTOL/CV version, but was in discussions about the STOVL version and its capabilities with interest growing within the air force material directorate. Studies to integrate unique Israeli capabilities were underway during the first quarter of 2005 at Lockheed-Martin. One special study in preparation was the STOVL weapon-bay weapon evaluation fit. The Israelis have their own air-to-air and air-to-ground weapons and therefore a funding estimate requirement was requested on 14 March; the proposal with contract statement of work was due by 28 April 2005.



The first flight of the first Israeli F-35 with Lockheed Martin chief test pilot Alan Norman at the controls. (*Lockheed Martin*)



The F-35 with nose number 928 seen here during exercise Blue Flag held in Israel. For a country permanently challenged by its neighbours, finding time for exercises is in itself a tour de force. (*Israeli Air Force*)

Israel's dealing with China was considered problematic by the USA. The Chinese PL8 missile is based on the Python 3 technology, if not a straight copy. The Chinese J10 aircraft has a clear resemblance with the IAI Lavi. It was this that made the US wary about Israel concerning release of the new technology involved in the JSF. It went rather far since, for a short period in 2005, Israel was denied access to the programme. Only after the Ministers of Defence ironed out the problems and the US was re-assured about Israel's export policy was Israel again given access. Israel had every reason to maintain its high defence requirements even though Syria was now the only country bordering Israel with which it had no peace agreement. Iraq was moved off the threat map by the US-led invasion in 2003 but Iran was considered a security threat with its nuclear programme. If it was only the nuclear programme then Israel would not be so worried, but the call made by freshly elected Iranian president Mahmoud Ahmadinejad 'to wipe Israel off the map' was not taken so lightly.

That Israel was on its toes was made clear by an air strike that received relatively little attention. Israel attacked some facilities in the Syrian desert in September 2007. Syria did not comment at first, the countries that cried foul play being North Korea and Iran.







The Blue Flag 2019 was a major exercise involving participants from Germany (Eurofighters), Italy (F-35 and Eurofighters), Greece (F-16), USA (F-16) and Israel with for the first time F-35s and F-15 Baz, and F-16I Sufa units. (*Israeli Air force*)




927



The Blue Flag exercise was held from the UVDA Air Force Base (AFB). The most modern technology was on display from all participants except maybe the USAF. (*Israeli Air Force*)

The only sign out of the area that came up was from Turkey since during their exit the Israeli aircraft had breached Turkish airspace, during which incursion they had dropped their fuel tanks. Syria commented by saying that the Israelis had bombed some empty piece of desert before being chased away by the Syrian Air Force. Syria reserved the right to retaliate but would not be drawn on how or when. Syria increased its defence spending which is one reason why Israel was interested in becoming one of the first export customers of the F-35. Lockheed expected a contract signature as early as 2010. If the potential timeline worked out Israel would be the fourth customer to sign up for the F-35 and probably also be the first to deploy them.

Israel did not disappoint. On 26 September the US Congress was told by the Defense Security Co-operation Agency (DSCA) that a proposed sale of twenty-five F-35 aircraft to Israel was on the cards. This was a major vote of confidence in the F-35, especially at that time since critics were gaining ground among the partner nations' politicians. The Heyl Ha'Avir had requested twenty-five of the CTOL version. The other advantage of this

early request was that ramp for production could be covered by foreign orders. The USAF normally likes to get operational on an aircraft prior to delivering it to another nation but the number ordered by the US would not allow this to happen. In the proposed deal there was also an option for a further fifty F-35s which could be either CTOL or STOVL. The deal, if all options were taken up and the more expensive STOVL version included, would be worth in excess of US$15.2 billion. No engine selection had been made but it was doubtful that the F-136 would be in the initial batch. Other aircraft systems stated to be included in the price were: electronic-warfare systems (it was not stated if this was the BAE Systems or an Israeli system), command, control, communication, computers and intelligence/communication navigation and identification (C4I/CNI) system, again of unidentified origin. Other systems are related to performance-based logistics included in the deal: autonomic logistics global support system (ALGS) and the autonomic logistics information system (ALIS), an unspecified weapons employment capability, flight mission trainer (FMT), F-35 unique infra-red flares, unique systems or unspecified sovereign requirements. The most interesting part of the request was the re-programming centre hardware/software in the loop laboratory capability also included in the quoted price. Also included were the software development/integration, flight-test instrumentation, aircraft ferry and tanker support, support equipment, tools and test equipment, spares and repair parts, personnel training and training equipment, publications and technical documents, US Government and contractor engineering and logistics personnel services, and other related elements of logistics and programme support.

Even though the F-35 has a good internal fuel load the Israelis still wanted external fuel tanks which pointed in the direction of a requirement for a pre-emptive strike on Iran. Although only speculation on the part of the author, Iran is acquiring a nuclear capability similar to Iraq's where the Israelis also used their freshly-delivered F-16s to attack the nuclear facility. The fuel tanks could be used for the initial part of the flight and dropped prior to entry into Iranian air space. The stealth features would mean that the F-35 could remain undetected until too late for the Iranians. Israel had gained recent experience with a similar attack on Syria. These speculations notwithstanding, the DSCA advised that Israel was a vital partner in the Middle East for the US and, therefore, it was in the interest of the US to

allow the sale as it would ensure that Israel remained self-sufficient and able to defend itself while the Middle East would be a more stable place than without it. Israel also delayed its decision slightly from its original plans, due in part to a general election in 2009. For the negotiations Israel was holding with the US government an interesting tool was offered in the shape of the newly-proposed F-15 Silent Eagle. The F-15 Silent Eagle was rolled out on 17 March 2009 and included interchangeable conformal fuel tanks/ conformal weapon bays. The conformal weapon bays would increase the F-15's stealth signature significantly and, with all other stealth signature features offered and the fact that deliveries could be performed from two years after contract award, made it a viable alternative to the F-35 for Israel because the conformal weapon bays could be bought as an upgrade for the existing F-15 fleet; there would be no problem integrating Israeli electronics. The F-35 was, however, very high on the wish list of the Heyl Ha'Avir and it was therefore doubtful that the F-15SE would be replacing the F-35; it would more than likely be acquired as a supplement to the F-35 fleet.



The Israeli Air Force was promoting its new asset to partner nations, at the same time sending out a message to its enemies that they had just become a bit stronger and their resolve was not diminishing. (*Israeli Air Force*)

It took quite lengthy negotiations after the DSCA announcement but the sale went through and Israel ordered twenty F-35I aircraft. From the announcement until signature of the letter of offer and acceptance (LOA) was not so long, Israeli Minister Defence Director General Udi Shani signing the LOA in New York on 7 October 2010. Israel became the first export country through the foreign military sales (FMS) system. Shortly afterwards, Israel was offered twenty more but the strings attached to the deal were unacceptable; Lockheed Martin had to wait longer for the second batch. The deal was later reduced to nineteen aircraft with Israeli pilots to be trained at Eglin a year prior to receiving the first F-35 Lightning II. The first aircraft was due to arrive in Israel in 2015 to be based at the Nevatim Air Base in the Negev. Reports of problems did not decrease the urgency for Israel with reports suggesting that they would be willing to receive their aircraft prior to the USAF reaching IOC. By April 2013 the F-35 had its Hebrew name: *Adir* (or Mighty).



The Lockheed Martin F-16 was marketed more in India than the F-35. It was seen as financially and politically more reasonable with a greater chance of success. (*Lockheed Martin*)



One way of providing political engagement was the signature of the first bulkhead by politicians on the first production aircraft. (*Lockheed Martin*)



A celebration, at a time there was little to celebrate Lockheed Martin got there heads down and worked diligently to prove a point. Israel is a happy customer. (*Lockheed Martin*)



The lightshow staged would be the envy of any rockstar. The first hand over was to be a show that the attendant customer representatives should carry in memory for a long time. (*Lockheed Martin*)

Even before the first Israeli aircraft had been rolled off the production line news broke that Israel was about to acquire more of the F-35 Lightning II aircraft with reports of an order for a further twenty, which was denied officially although talk about further orders continued. Suddenly it was announced that up to fifty of the jets would be purchased. During JSF Executive Steering Board (JESB) talks with Israel in Norway it was announced that talks on a next batch of aircraft were in an advanced stage. News that a buy of fifty was refused by the Israeli ministry of defence was followed by the news that a second batch for a second squadron had been approved. The second batch, approved by the Israeli government, included Israeli-specific equipment but was for only fourteen aircraft rather than the anticipated fifty, increasing the order total for Israel to thirty-three aircraft. However, even Israel would not get access to all systems of the F-35. Although able to do most things domestically, such as weapon integration, some would have to be performed by US personnel to prevent technology transfer. The quality of the F-35 was again brought into disrepute when it became clear that Israel had requested F-15s under a ‘make peace package’

for accepting the higher risk when sanctions were lifted over the Iranian nuclear deal. Some sources stated that the F-15 should be the Silent Eagle version.

The first F-35 was rolled out during a ceremony at the Lockheed Martin Fort Worth facility. Israel was the first FMS customer. The roll-out ceremony of AS-1 took place on 22 June 2016 in the presence of invited dignitaries, including Brigadier General Tal Kelman, IAF Chief of Staff, the US Ambassador to Israel, Daniel Shapiro, and Israel's Minister of Defence, Avigdor Liberman, who got the chance to try out the cockpit of the AS-1 during the ceremony. It took a little over a month before the next milestone which was the first flight of the Israeli F-35. That took place with Alan Norman at the controls on 25 July. The aircraft was due to be delivered to Israel by year end. Israel would be the first export country to receive its F-35s for permanent domestic basing purposes, on a par only with Italy which was due to have two F-35 aircraft in Italy by the end of 2016 as well.

Problems with the fuel lines which affected both Israeli F-35s almost put in danger their arrival. The first two aircraft due to be handed over to Israel at Nevatim Air Base to the Golden Eagle Squadron left Fort Worth on 6 December and arrived at the Lajes on the Azores on the same day after five air-to-air refuellings over a seven-hour-twelve-minutes flight. The second stage of the delivery flight was a reversal of the early Italian jets' delivery to the US, that is from Lajes to Cameri. The second stage took place on 8 December with three aerial refuellings and a four-and-a-half-hour flight. The third stage was planned for the 12th with departure scheduled for 7.00am and official arrival for 2.00pm. However, fog caused a five-hour delay and the aircraft arrived at Nevatim on the 12th around 7.00pm. This made them the second country to receive their F-35s at their home base, beaten only by the Italians by a couple of hours. Considering that Italy's AL-5 and AL-6 transferred also from Cameri to Amendola, some might say that it was Italian rules so that the Italians could beat the Israelis to the milestone. The following day the Israelis flew their first sorties, marking the first flight for two Israeli pilots as they had been in the US for pilot training but had not actually flown in the F-35. Those first sorties were flown by Lieutenant Colonel Yotam, commander of the Golden Eagle Squadron, and Major 'D', his deputy.

The next three aircraft arrived on 23 April 2017 in accordance with the aim of achieving initial operational capability by the end of 2017. These

were followed by another two examples that arrived at Nevatim on 14 September. It was reported that the seven aircraft in Israel would be sufficient to declare IOC for the Golden Eagle Squadron, with another two due for delivery before the end of the year. At that time seven of the fifty aircraft had been delivered; the last of those fifty was due by 2027.

It was with only nine aircraft delivered and just about within a year that the Heyl Ha'Avir anounced that the Nevatim-based Golden Eagle Squadron had reached IOC. 'The declaration of the squadron's operational capability is occurring at a time in which the IAF is operating on a large scale in a number of fronts, in the constantly changing Middle East,' said Major General Amikam Norkin, commander of the Heyl Ha'Avir. 'The operational challenge, which is becoming more and more complex each day, receives an excellent aerial response. The Adir aircraft's operational status adds a significant layer to the IAF's capabilities at this time.' The Heyl Ha'Avir became the third service to announce operational capability.

To reach operational capability the F-35 had been thoroughly evaluated over the year with aerial refuelling and other unmentioned integration within the air force taking place. 'The inspection examined missions and scenarios that include all of the operational elements required to fly the Adir, from the ground to the air,' shared Lieutenant Colonel Yotam, commander of 140th (Golden Eagle) Squadron, which operates the Adir. 'I am confident in the division's capability to reach operational preparedness and feel that the pressure is positive and healthy.'

There were some rumours that Israeli F-35s had seen combat over Syria but there was no official confirmation. It came as little surprise therefore, on 22 May 2018, during an international air force commanders' convention in Israel that Major General Amikam Norkin announced that Israel was the first country to put the F-35 to the ultimate test, that is combat. 'We performed the F-35's first ever operational strike. The IAF is a pioneer and a world leader in operating air power.'

'The Adir (F-35I) aircraft are already operational and flying combat missions. In fact, we have performed the first operational F-35 strike in the world. We attacked twice in the Middle East using the F-35 – we are the first in the world to do so'. He talked about operations above Syria without detailing the exact role of the F-35 in these operations. Furthermore, he showed a photograph of the F-35 over Beirut.

Italy

Italy has partnered on many projects, including the Panavia Tornado which it bought in the IDS variant. It was also a partner in the European Fighter Aircraft (EFA) which produced the Eurofighter Typhoon and, as a Harrier operator, was aware that a successor would be required. Aeritalia, a partner in the afore-mentioned programmes was not new to co-operative projects and knew that the future lay in co-operation. Thus, on 30 May 1986 the company signed a memorandum of understanding with British Aerospace on VTOL/STOVL studies. Italy was interested in joining the JSF CDP, perhaps even at a level higher than the Danish, Norwegian and Dutch. Such higher-level interest stemmed from the fact that the Italian Air Force had a greater requirement then those three states. The main aim was to replace their AV-8B Harriers and AMX A-11 Ghibli strike aircraft, the latter another result of international co-operation, this time with Brazil. (AMX International was created to develop, build and market the Ghibli, known as the A-1 in Brazilian service.)



The first Italian F-35 during its first flight over Italy. Note that the F-35 is equipped with Luneberg lenses on top and underside of the fuselage. (*Lockheed Martin*)



Italy became the first country to fly the F-35 in its own airspace. The first foreign assembled F-35. (*Lockheed Martin*)

The GE/R-R JSF team linked up with Fiatavio from Italy shortly before Italy signed the MoU in a move to strengthen their position on the European market. Fiatavio already had good ties with GE and so the move did not come as a surprise. Fiatavio would be supplying structural components for the low-pressure (LP) turbine and would participate in the development of the accessory gearbox. The GE/R-R team had previously teamed up with a Danish, Dutch and Norwegian consortium under the lead of Philips ETG from the Netherlands.

Italy, previously a provider for its own or European industry, made the first step back to the US market by agreeing to lease F-16s as a result of Eurofighter delays. The sixth country to sign up for the EMD phase, on 24 June 2002, Italy signed for level-2 partnership and planned to replace its AMX A-11 Ghibli, AV-8B Harriers and Panavia Tornados. Italy signed to invest US$1 billion for an estimated 100 JSFs.

During the first half of May 2003 Marconi Selenia Communications became the first direct Italian supplier on the JSF F-35 when it was selected

to provide the back-up radio. However, Italy also voiced its unhappiness with the amount of work received by that time from Lockheed Martin.



A couple of Italian and American pilots at Luke Air Force Base where they were trained as F-35A pilots. (*Lockheed Martin*)


AERONAUTICA MILITARE


AERONAUTICA MILITARE



Crossing the Atlantic for the first time was an entire operation involving support aircraft. The entire team involved at Patuxent River. (*Aeronautica Militare 2x US Navy*)

Italy was an original Eurofighter country and had committed to buying 121 Eurofighter Typhoons in three tranches, the first one of twenty-six, with forty-six in both the second and third tranches. The second tranche had been signed and paid for, but the third became questionable as the *Aeronautica Militare*, the Italian air force, pushed to make a case for local production of the F-35 in Italy. Furthermore, the Aeronautica Militare perceived the F-35 as more survivable because of its more stealthy design. With budgets diminishing in Europe, the hope was that the political will for the third tranche in the other nations would be diminishing as well.

Italy, a big partner in the sense that it planned to buy a significant number of aircraft, left signing the PSFD MoU late. On behalf of Italy, Under Secretary of State for Defence Giovanni Forcieri signed the MoU on 7 February in the Pentagon. Italy was close to an agreement for a final assembly and check out (FACO) facility; it had also had its own final

assembly for its F-104S Starfighters. The estimated procurement amount of aircraft per fiscal year by Italy was determined in the PSFD document with delivery approximately two years after contract signature.

Fiscal Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
Amount	6	6	14	14	14	14	14	12	12	12	12	1	131



Italy became the first export customer to buy two versions of the F-35. Here the first example of the Marina Militare also built at the Cameri FACO. (*Marina Militare*)



As a part of one of the first elephant walks at MCAS Beaufort it was interesting to see that in this show of force Marina Militare and Royal air Force were participating. (*USMC*)

Italy was originally one of three partner countries that wanted to participate in the initial operational test and evaluation (IOT&E). The three countries had to commit by early 2008 but, for both Italy and the Netherlands, this term was extended to 31 May. However, in October 2008, Alenia-Aeromacchi announced that Italy had decided against participation in the IOT&E but stood by their decision to acquire a FACO facility. A totally new facility was erected for the FACO at Cameri Air Base near Novara. The 60,000m² (646,000ft²) FACO, which includes twenty new buildings and attendant infrastructure, was planned to be operational by the end of 2012. Low rate initial production Lot 6 was to be the first time that Italy was buying into the F-35. Three F-35A CTOLs were in the announced contract negotiations and the first aircraft loaded in the brand new facility on 18 July 2013 was the first Italian F-35. Originally a ceremony was planned for the occasion by industry members but the decision to purchase the F-35 was controversial in Italy and the the ceremony was cancelled. It was a little more than a year and a half year later that the first Italian-produced F-35 rolled off the production line. At the same time it became public knowledge that the first six of eight aircraft for the Royal Netherlands Air Force would be built in Fort Worth which reduced the

possible return on investment of the Italian government in the FACO facility. By the end of August 2015 Lockheed Martin announced that the first Italian F-35, AL-1, completed ATF (acceptance test facility) where Lockheed Martin ensured that it met requirements for low observable, stealth performance. Completing ATF was one of the last hurdles before AL-1 took to the skies for its first flight in the following weeks. The team loaded the new 3iR5 software and was working through regression testing and mission systems check-out in preparation for electromagnetic compatibility (EMC) engine runs. The plan was for Lockheed Martin test pilot Bill 'Gigs' Gigliotti to take to the northern Italy skies, making the very first international flight by an F-35A. The Italians did not then have any qualified F-35 pilots, Thus Gigliotti would be stationed there for all test flying of Italian aircraft as delivery to the Italian customer would have to wait until the first Italian pilot would begin training with 62nd Fighter squadron at Luke AFB. For this reason, a few weeks earlier a milestone that seemed not so significant was passed: the first international refuelling had taken place. According to the announcement:

an Aeronautica Militare KC-767A aerial refuelling tanker successfully completed its first US Air Force F-35A boom receiver certification refuelling flight, 29 July over California's High Desert region. Italy's KC-767A is the first international tanker not operated by the USAF to undergo refuelling certification trials with a US aircraft. During the flight, the KC-767A and its military aircrew completed 25 boom contacts with the F-35A and successfully offloaded 16,000 pounds of fuel. Italy operates a fleet of four KC-767A tankers, a derivative of the Boeing 767 commercial aircraft, which are stationed at Pratica di Mare Air Base, near Rome.

This certification was important to transfer the jets over the ocean to the pilot training site at Luke AFB. The first flight of the first Italian-produced F-35 took place on 7 September 2015 and was performed by Bill Giggliotti. The first Italian pilots flew at Luke AFB in November at the time three aircraft had left the production facility at Cameri. AL-2, the second, flew for the first time from Cameri Air on 15 January 2016. Italian tanker qualification had taken place in the US during the previous summer and the first air-to-air refuelling over Italy took place between a KC-767 and AL-1 (MM-7332/32-01)

The first trans-Atlantic flight was in 2016 and the aircraft involved was the first Italian-produced aircraft, which was transferred to NAS Patuxent River. AL-1 departed Cameri on 3 February and, with the support of an Aeronautica Militare Boeing 767 and two Eurofighter Typhoons, flew to Lajes Field in the Azores where they were stuck for thirty-six hours because of bad weather. From there they departed for Patuxent River, a thirteen-hour flight. AL-1 was flown by the first Italian F-35 pilot, Major Gian Marco Di Loreta, who had accumulated fifty flight hours since November 2015 when he had his first flight at Luke AFB. AL-1 arrived at Patuxent River on 5 February and was followed a little over three months later by AL-2 and AL-3 which flew from Cameri with a stopover in Lajes; they flew to Luke AFB. AL-1 was transferred to Patuxent River to undergo electromagnetic environmental effects evaluation. After those evaluations AL-1 was transferred to Luke AFB on 24 May.

The Cameri-based FACO worked on trying not to get into the news as the production line and the acquisition of the F-35 was controversial in Italy since the economy was not one of the healthiest in Europe. Working under the radar, AL-5 and AL-6 were delivered to Amendola, Italy becoming the first nation by a couple of hours to receive its aircraft on home soil, beating the Israelis on whom most of the media attention was centred. The transfer flight from Cameri to Amendola was flown by Italian pilots, unlike the Israeli aircraft which were flown by American pilots.

The Marina Militare, the Italian navy, was also a customer for whom the first major milestone was the roll out of the first Italian F-35B from the Cameri FACO on 5 May 2017. The first Italian-built F-35B, BL-1 as it was designated, was planned to perform its first flight during August. Once everything had been evaluated properly the BL-1 would fly over to NAS Patuxent River to undergo electromagnetic environmental effects testing. Although the first flight was somewhat delayed, the significance was not diminished. On 25 October 2017, Lockheed Martin test pilot Paul ‘Hat’ Hattendorf took BL-1 for its maiden flight. Five days later, during the third flight, Hattendorf took BL-1 through all its STOVL modes and hovered over the runway. The transfer to NAS Patuxent River was scheduled to take place early in 2018. On 25 January 2018 the first F-35B was handed over and BL-1 was readied for transfer to Patuxent River.

Italy’s Defence Minister, Elisabetta Trenta, suggested not only that Italy would not buy more than the ninety aircraft on order but that she wanted to

evaluate pulling out of the deal. While the evaluation was underway Italy stopped payments to Lockheed Martin in early 2018 who stopped deliveries to the Aeronautica Militare and Marina Militare. As a result BL-02 (MM7452, BuNo 169599) from lot 10 and AL-11 (MM7361/32-11, s/n 17-5287) from lot 11 remained at the Cameri FACO.

In March 2019 it was reported that Italy would reimburse Lockheed Martin so that the aircraft could be delivered. Relations had suffered and Italy could stand to lose much work in the future. BL-2 was due to be transferred to MCAS Beaufort while AL-11 was to join the other F-35As at Amendola. On 12 March 2019, during testimony before Italian legislators, General. Alberto Rosso, the air force chief of staff, said, 'We have qualified twenty-five pilots and just under 250 maintenance specialists. It has been inserted into the air defence network, the pilots are enthusiastic about it, it has capabilities that touch on science fiction and overcome our imagination, it is a system that makes the whole air force grow. The aircraft is perfectly integrated with the systems of NATO countries.'

Japan

Since the Second World War the Land of the Rising Sun has been one of the United States' main allies. A proof of this was the largely-American inventory of the Japanese Air Self-Defense Force (JASDF) which included F-15 Eagles, Mitsubishi/Lockheed F-2s (heavily based on the F-16), and F-4 Phantoms. The F-4 Phantoms, approaching the end of their useful lives, needed replacement. The JASDF had received a total of 154 Phantoms, some of which were lost to attrition. An estimated requirement for 100 JSFs existed. It is not clear why the Japanese did not join the JSF programme during the CDP or SDD. While some expected the Phantoms to be replaced by the Lockheed Raptor, the Raptor's price tag might make that option rather expensive.

The Japanese Defense Agency (JDA) officials received briefings on the F-35 and cockpit demonstrations in Tokyo on 13-14 October 2004. One JASDF requirement that would be difficult to overcome was that of deliveries by 2011. It remained to be seen, however, if the acquisition programme would go through without any of the usual political procurement delays. In April 2005 the F-X programme was launched to replace the F-4EJ Kai (Phantom) in service. The aircraft in contention were

basically all the fourth-and fifth-generation fighters from the western world, meaning the Boeing F-15 (with the advantage that they were already in service with the JASDF), Boeing F-18E/F, Eurofighter Typhoon, Dassault Rafale, Lockheed-Martin F-35 and Lockheed Martin F-22 Raptor. The Raptor was not freed for export but, according to the JDA, Japan had been in contact with the US government about exporting it. Delivery of the first aircraft would be expected during Fiscal Year 2008/2009 which made the F-35 a relative outsider. On the other hand, such programmes normally have a delay and the in-service date could still slip.

Lockheed Martin was very optimistic about the chances of the F-35 in Japan. In a briefing given by Dale Hensley on 3 April a request for proposals was expected in 2008 with possible signature of a letter of offer and acceptance (LOA) in 2009, followed by contract signature in 2010. First aircraft to be delivered would be in 2012 but would remain in the US for training purposes. The first arrival of the F-35 in Japan was estimated for 2014. Japan, having experienced the F-22 in several exercises on its own soil, would have preferred the F-22 but the F-35 would not be a bad alternative since it would also be stealthy. More so than the F-22 it would offer a higher synergy of its sensors, avionics and stealth but would lack the super manoeuvrability as a result of the lack of thrust-vectoring. Furthermore the F-35 lacked a super-cruise capability.



The first Japanese aircraft taking off from Fort Worth. This aircraft temporarily moved to Luke AFB. (*Lockheed Martin*)

Delays continued also due to a natural catastrophe, an earthquake that caused tsunami the combination of which caused damage to the Fukushima nuclear reactor. Japan was hurting already from the world recession and this catastrophe meant that defence procurement lost importance. In 2011 the replacement programme gained speed again. The three contenders replied to a request for proposals (Rf P) in September. Boeing offered the F-18E/F Super Hornet with capabilities for future roadmap updates, most of which should be available in time if the customer required it by 2015. In relation to the Indian tender for a medium multi-role combat aircraft, in 2010 Boeing presented its roadmap to the future of the Block II F/A-18E/F. Enhancements for the Super Hornet were:



The AX-01 with Paul Hattendorf in the cockpit. The Japanese Air Self-Defense Force remained as briefly in the USA as possible to train instructor pilots and move their training to Japan. (*Lockheed Martin*)

- Conformal Fuel Tanks
- Enhanced Performance Engine
- Next generation cockpit
- A stealthy weapon pod
- IRST

The second contender, the Eurofighter Typhoon, was being offered by BAE Systems. The third was offered by Lockheed Martin, the F-35 Lightning. Lockheed Martin was quite upbeat that the IOC date of 2016 required by the JASDF could be met. Japan could become the first non-partner country to acquire the F-35. At the time that the decision was supposed to come, a damaging report called the Quick Look review was leaked which some critics of the programme hoped would have an adverse effect on the selection process. This proved ungrounded and Japan announced that it had selected the F-35 on 19 December 2011.

The DSCA notified Congress on 30 April 2012 of a possible Foreign Military Sale, for four F-35A aircraft equipped with the Pratt and Whitney F-135 engine with an option on thirty-eight more. The proposed sale also included five spare engines and electronic warfare elements plus munitions and support elements as outlined in the package indicated in Appendix II (page 000). The most interesting feature of the announcement was the apparent absence of off-set agreements in connection with this sale. The

FMS deal was closed for forty-two F-35s by June 2012 and it was generally expected that Japan would acquire more F-35s in a second deal as Russia had become more active. In 2003 the JASDF performed twenty-four interceptions of Russian aircraft which had risen to 359 interceptions by 2013. Japan had to contend that the Chinese military aircraft accounted for 415 interceptions in 2013. This was on average two interceptions per day. Considering that there were eighty F-4s to be replaced, another buy was to be expected even if the aircraft were not replaced on a one-on-one basis.

The first four, designated AX-1 to AX-4, of the F-35s were to be manufactured at the Lockheed Martin Fort Worth facility but a FACO was to be set up for the remainder of the aircraft. Roll out of AX-1 was planned for late 2016. The location and partner were announced at the Paris Air Show by Lockheed Martin's Steve O'Bryan slightly before the start of press briefing. The partner was Mitsubishi Heavy Industries and the cost of the facility was carried by the Japanese government. AX-5 was the first to be built in the Japanese FACO in Nagoya; all subsequent aircraft would be produced at the MHI facilities. Northrop Grumman announced that the centre fuselage for the first F-35 Lightning II aircraft would be assembled in Japan's F-35 FACO facility in Nagoya; completed on 5 October 2015, almost two months later AX-5 went into final assembly on 15 December. At the time AX-1 to AX-4 were at different stages of the Fort Worth assembly line. AX-5 was to join the JASDF in 2017.



A variation of the JSF programme office patch for the Japanese Air Self-Defence Force.

Without any of the usual roll-out ceremonies, the Japanese first aircraft was readied for its first flight and, on 24 August 2016, Lockheed Martin test pilot Paul Hattendorf took AX-1 for its first flight over the skies of Fort Worth. The remaining three to be produced in the US were due for first flight before the end of 2016. Lockheed Martin announced that the official roll-out ceremony of AX-1 would be held on 23 September 2016. However, a week before that, news broke that AX-1 was one of the aircraft affected by faulty insulation supply on the cooling lines; it was grounded. Even

though it was not on the programme to fly with AX-1, it was an embarrassment for the already troubled programme. By the end of January 2017, when AX-5 was towed to the fuel-test facility in Nagoya, Lockheed Martin had delivered three of the four Japanese aircraft to Luke AFB. AX-5 meant that the third FACO had assembled its first aircraft, It would built a minimum of thirty-eight aircraft.




944th FIGHTER WING



Lt. Col. Nakano of the Japanese Air Self-Defense Force at Luke AFB preparing for his first flight in AX-01 the first Japanese F-35. (*USAF by Tech. Sgt. Louis Vega Jr*)



The second Japanese F-35 in a really cool formation. From the front to the back the Fairchild A-10 Thunderbolt II, F-16 Fighting Falcon and the behind the F-35 the Boeing F-15E Strike Eagle. (*USAF*)



The AX-02 seen taking off from Luke AFB. This was one of four aircraft that was based here for a short time with Ninjas unit. Their place was later taken by the South Korean pilots within the 944th Operations group. (*USAF*)



An old marketing computer representation dating from the Concept Demonstration Phase regarding the Netherlands. (*Lockheed Martin*)

Lieutenant Colonel Nakano became the first Japanese pilot to fly the F-35 from Luke AFB on 7 February 2017. Nagoya, the third FACO, rolled out its first aircraft, AX-5, on 5 June. Rumours surfaced that Japan was looking into buying more F-35s, which was logical considering setting up a FACO facility for thirty-eight aircraft was rather expensive. Rumours had it that even the STOVL version was under consideration. The rumours gained traction as the Chinese were building islands from which they planned to deploy their military might. The Ministry of Defense published a paper that confirmed the rumours; Japan wanted another 105 F-35 Lightning II aircraft. The additional aircraft should be split according to this document: sixty-three additional F-35As were planned for procurement with forty-two F-35B STOVL aircraft that would fly from the refurbished anti-submarine helicopter carriers *Izumo* and *Kaga*. Just as Rome was not built in one day, the Japanese armed services had to build their capability step by step. For

this reason, it was announced that the Japanese wanted a second batch of F-35s to include forty-two F-35Bs. Japan would become the fourth operator of the STOVL version of the F-35. Nyutabaru Air Base in Miyazaki Prefecture had been selected in early 2021 as the favoured base for F-35B. It was envisioned that a total of eighteen F-35Bs would be delivered by March 2024. In the meantime, the DDH-183 *Izumo* aircraft carrier was being refurbished to house the F-35B as a deterrent against China's ships patrolling in Japanese waters.

On 9 July 2020, Defence Security Co-operation Agency announced the Japanese order for sixty-three F-35A conventional take-off and landing (CTOL) aircraft, forty-two F-35B short take-off and vertical landing (STOVL) aircraft and 110 Pratt and Whitney F135 engines (including five spares). Also included was a package including electronic warfare systems, command control and communications computers and intelligence/ communications, as well as equipment/support specific to the F-35 including tools and test equipment as well as personnel training and training equipment. The estimated total cost is $23.11 billion. Although the deal had not been approved at the time this was only a formality. With this order Japan would become the biggest F-35 operator in Asia.

The Netherlands

One of the first countries to buy the General Dynamics F-16 (now Lockheed-Martin) was the Netherlands. According to some publications, the Dutch decision to select the F-16 made Belgium, Denmark and Norway follow suit. The first Royal Netherlands Air Force F-16s arrived in June 1979. The F-16 was to replace the older F-104 Starfighter aircraft. A follow-on order also made the F-16 the replacement for the Dutch NF-5 Freedom Fighter. The last RNLAF F-16 was delivered in February 1992.

The Netherlands was therefore also one of the first countries to look for a replacement for the F-16. The technical lifetime of the fighters was calculated to end by 2010, from when it was important to find a replacement for the 157 F-16s of the original 213 that remained in RNLAF service with the. The RNLAF had already prolonged the lifetime of its F-16s by joining the mid-life-update programme.

After fierce lobbying from the *Koninkelijke Luchtmacht* (KLu) or Royal Netherlands Air Force (RNLAF), which saw the JSF as the only sensible

future replacement for the F-16, the Dutch government signed the same MoU as Denmark on 16 April 1997.

The Netherlands have been involved in the JSF programme together with its F-16 partners Denmark and Norway since 1997 as a limited co-operative partner which had cost them US$10 million at 1996 price levels. The then Defence State Secretary, Gmelich Meijling, saw the JSF as the only rational choice available as the JSF was cheaper and more advanced than any other available aircraft, according to him. Luckily for the other aircraft manufacturers the situation changed when Gmelich Meijling lost his post as the state secretary. The new defence minister, De Grave, and the new state secretary, Van Hoof, were not that single-minded and wanted to compare the different options more carefully; at least so it seemed to the outside world. The Royal Netherlands Air Force was, however, even more single-minded about the options available than the former state secretary.

By 1999 the Dutch parliament was notified that the RNLAF needed a next-generation fighter to replace its ageing F-16A/B aircraft. On 3 June 1999 a request for information (Rf I) was send out to interested parties. Answers to this request were due 140 days after issuing. The Gripen offer was received on 22 October 1999 with all other answers arriving by the end of October 2000.



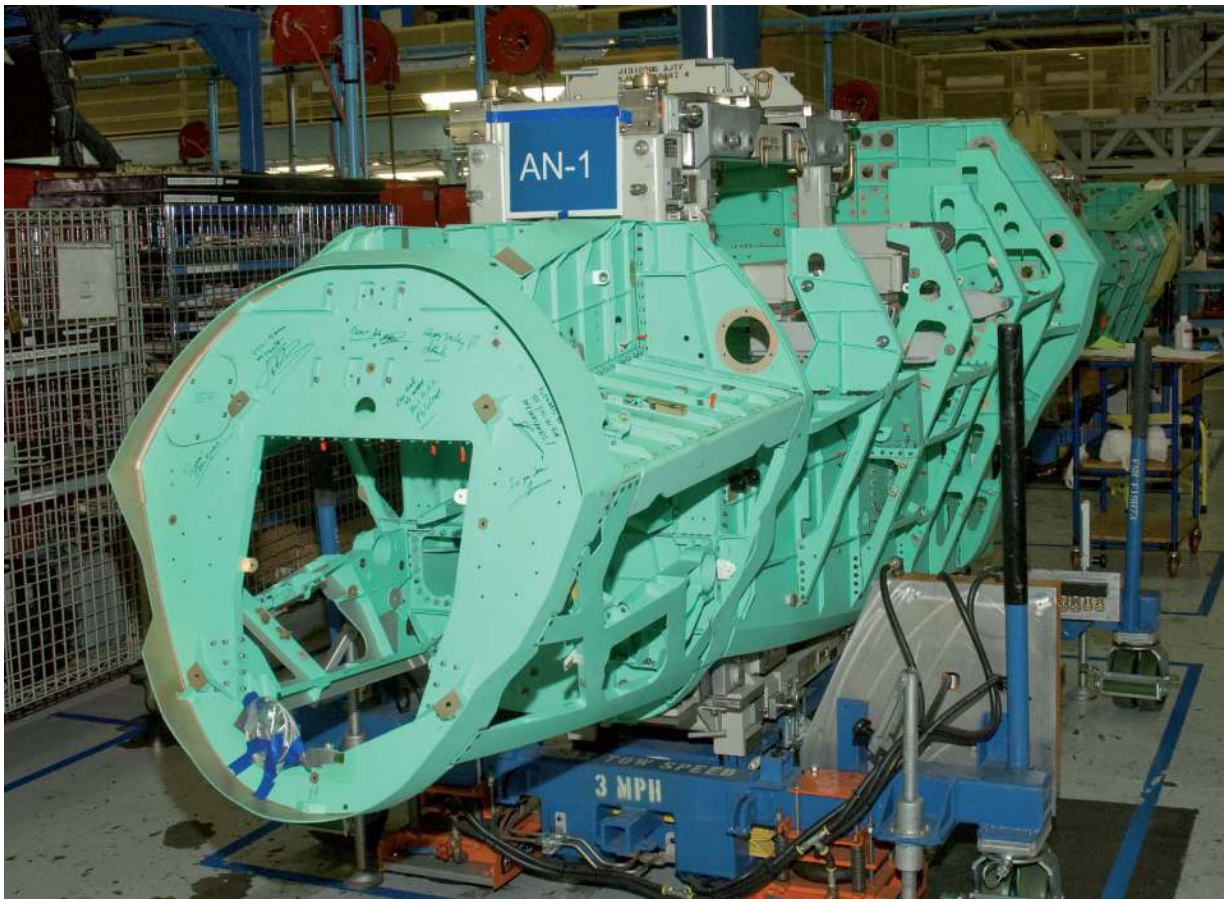
Lockheed Martin went a step further and commissioned 9 artists to paint the F-35 above a landmark in their respective countries. (*Lockheed Martin*)

On 19 November the USA officially invited the Netherlands to participate in the EMD phase of the JSF programme. The Netherlands were expected to decide by the end of 2000 as the EMD phase was to begin in early 2001. It was then expected that the first production JSF would be delivered in 2008 to the USAF and that the RNLAF would receive its first JSF in 2010, should the RNLAF choose the JSF.

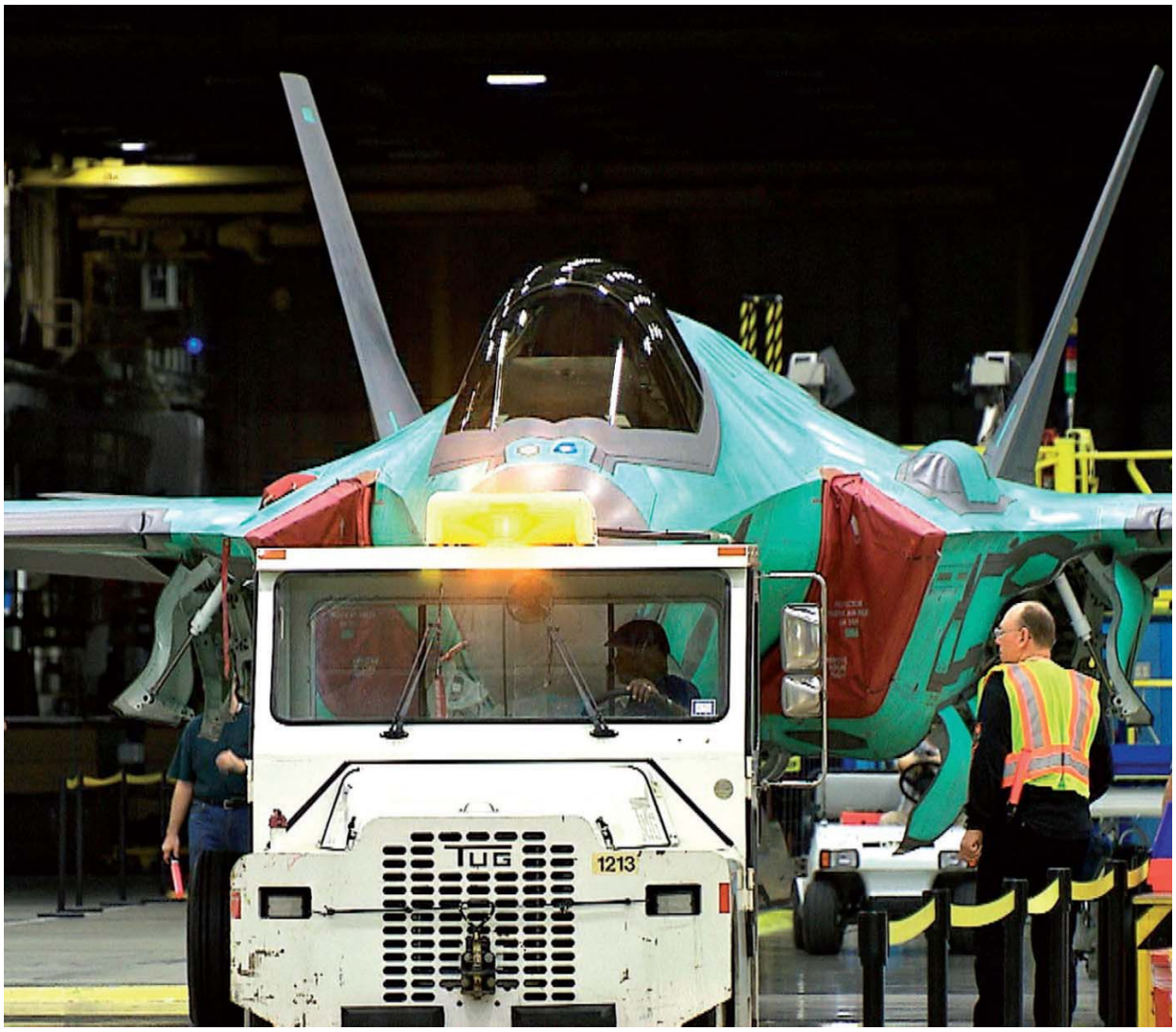
In early February 2000, one of the Dutch government parties, D66 Democraten 66 which means Democrats 66, stated that the government would buy technology off the shelf since negotiations with the Americans were not going smoothly. Their spokesman Nicky van Riet said that buying off the shelf becomes more attractive since there are no technological and financial risks.



Badge of the Project office F-16 replacement. (*Ministerie van Defensie*)



The forward fuselage for the first Dutch F-35A, an aircraft that would participate in the Initial Operational Test and Evaluation. (*Lockheed Martin*)



Buying a fighter aircraft is a political decision as well as a military decision. Politicians might not have known what their nation required. The Dutch military had exact clarity in what they wanted. (*Lockheed Martin*)

The Royal Netherlands Air Force had its mind set on the JSF but the government had to decide and therefore all possible candidates were to be tried out. A request for information was therefore sent out to the different suppliers. Options included: Dassault Rafale, Eurofighter Typhoon, MAKO, JSF and the Saab Gripen. The first step taken by the RNLAF to test the Gripen was to send its chief of staff, General Ben Droste, to Sweden so that he could fly the Gripen on 2 March 2000. A week later a Dutch delegation under the lead of the state secretary of Defence, Mr H.A. van Hoof, visited Linköping for a full Gripen briefing.

In a basic document written by the Dutch state secretary van Hoof and presented to the Dutch parliament on 15 March 2000 mention was made of the following options with a brief description:

- flying on with the current F-16A/B MLU (mid-life update); the F-16A/B MLU was an F-16 with the capabilities of a Block 52 F-16C/D without the weight increase and the loss in manoeuvrability that is paired with the F-16C/D as opposed to the F-16A/B.
- flying on with the current F-16A/B MLU with an ELU (end-life update) included, thus extending the service life of the F-16
- Gripen; two comparisons were made in the document, the first being the start weight of the Gripen was 14 tons and for the F-16 16 tons; the second was that the Gripen had fewer hard-points for weapon carriage. Both were seen in the document as a disadvantage.
- Eurofighter Typhoon
- Dassault Rafale
- Advanced F-16: the advanced F-16 was explained in this document as a Block 60+ F-16 but was thought to have little or no growth capability
- The F-18E/F Super Hornet
- JSF

The basic document also explained how the Dutch MoD saw its fighter aircraft fit into its total defence picture; Attack helicopters were ultimately for the support of the land forces (army). Ground-based air-defence systems were used mainly for defence of the airspace above own territory. Cruise missiles were only suitable for attacking static targets. Unmanned combat vehicles were in the concept stage. UAVs, unmanned aerial vehicles, were suitable only for surveillance but not for tactical reconnaissance. Satellites can give picture of the battle area but are not flexible in their timing while very few countries have the capability. Finally the combat aircraft can be used more flexibly over the entire spectrum.

Recent conflicts in which the RNLAF had participated showed the following points as really important for fighter aircraft and deciding factors for the evaluation of the future fighter:

- Reaction capability all circumstances to generate the right units with the right means

- Continuous capability to maintain this reaction capability for a longer period of time under all-weather circumstances and day and night.
- Strategic and tactical mobility: the capability to move units and material over large distances and let them move freely over the operational territory.
- Logistically self-sufficient: the ability to be independent logistically of other units
- Flexibility to operate the material for different tasks
- Ability to gain information necessary to complete the necessary mission and be able to support decisions made with the information gathered. As there is no guarantee that in every conflict all other material will be supplied, the combat aircraft is supposed to be able to work as an integrated system of systems and as a solitary system.

The Dutch RNLAF officials said that they preferred the JSF because the Gripen, Rafale and Typhoon would be 1990s technology and JSF would be based on 2001 technology. JSF had also the advantage of an internal weapon bay that the other fighters lacked and was therefore able to penetrate much denser defences. The JSF was to become more expensive due to the higher level of sophistication required; of course this was not pointed out by the same military officials.

Safety of staff and the price would be the most important factors taken into account. Safety of staff was meant the chance of the pilot returning from the battlefield. Inter-operability with its NATO partners would also be an important decision factor. A repeat of the four-nation deal with the F-16 would be appreciated. For that reason, the following comparison table was produced for the Dutch politicians as part of the basic document. Although correct at the time, it soon became out of date.

Country	Need To Replace	Replacement Chosen	Emd JSF Participant	Planned Need
Belgium	F-16	Not yet	No	48+
Canada	F-18	Not yet	3	?
Czech republic	Su-22, MiG-21	Not yet		24-36
Denmark	F-16	Not yet	3	?
France	Mirage F-1, Mirage 2000, Jaguar	Rafale	No	294
Germany	F-4F, MiG-29, Tornado	Eurofighter Typhoon	No	180
Greece	A-7, F-4, F-16, Mirage 2000,	F-16 Block 50	No	50
Hungary	MiG-29, MiG-21	Not yet	No	?
Italy	F-104, Tornado, AMX, Tornado[1]	Eurofighter Typhoon Not yet	2	121 ?
Norway	F-5, F-16	Not yet	3	?
Poland	MiG-21, MiG-29	Not yet	Yes? [2]	?
Portugal	A-7	Not yet	?	?
Spain	F-18, Mirage F-1	Eurofighter	No	87
Turkey	F-4, F-5, F-16	Not yet	2	100-150
United Kingdom	Jaguar, Tornado Harrier	Eurofighter Not yet	1	232 150
United States	F-15 A-6, F-14, F-18 A-10, F-16, F-18 Harrier	F-22 F-18 Super Hornet JSF	1	339 548 2852



AN-1, the first prototype for the Netherlands rolled out. (*Lockheed Martin*)



The first flight of the Dutch F-35A was politically sensitive at the time. Delivery to the customer took longer than usual. (*Lockheed Martin*)

Italy was replacing some of its Tornados with the Eurofighter; some might be replaced by the JSF.

Poland had indicated that they wanted to join the EMD phase of the JSF; it was not clear though at which level of participation and if they could financially realise this.

Replacing the F-16 would take from 2010 until 2025 as a result of the need to spread the financial burden. The main question was political: would the Netherlands participate in the EMD phase of the JSF or not. According to this document, participation does not automatically mean buying JSF, although it acknowledged it as the logical step.

The USA offered three interested parties three possibilities of participation in the EMD phase of the programme:

- The lowest level (3) is participation of 1 to 2 per cent of the EMD cost
- The middle level (2) is participation of 5 per cent of the EMD cost
- The highest level (1) is participation of 10 per cent of the EMD cost

The Netherlands was interested in the middle level of participation. At the initial negotiations about the EMD phase between the Netherlands and the USA, the Americans wanted the equal of 5 per cent of US$1,150 million (2000 price level), more than was planned and allocated by the Dutch MoD. The amount was still negotiable.

If the Netherlands decided not to participate in the EMD of the JSF, the process for a decision for a replacement of the F-16 was to be initiated by 2005.

The RNLAF also had Dutch industry behind it. Industry believed that if the RNLAF would choose the JSF and participated in the EMD phase, the Netherlands would gain from this because the belief was that JSF would be built in huge numbers. Some industries mentioned numbers of up to 8,000 pieces. Dutch industrial participation in such a high-tech programme from the start would see the biggest return on investment. Industry was therefore urging government to fund approximately – US$750 million to become a significant partner in the EMD phase. The JSF programme was struggling with budget overruns and was still preparing for the first flights of the technology demonstrators of both competitors Boeing and Lockheed Martin.



The first flight of the AN-01 on 6 August 2012. The transfer to Eglin AFB would take almost a year. (*Lockheed Martin*)

At the beginning of March 2000 an evaluation team left for Warton, the BAE Systems test field to test the Eurofighter Typhoon. In the evaluation team was one flight test engineer, Captain Ir. Hielke Bosma, a technical specialist, Sergeant Major Harrie Mons, and three test pilots, Major Tjebbe Haringa (head of test flying), Captain Kees Verburg (Department of Operational Research and Evaluation) and Captain Jan Post of Twenthe Air Force Base. Tjebbe Haringa took off for the first time in two-seater Eurofighter Typhoon DA4 on 10 March. The same team visited France a couple of weeks later to evaluate the Dassault Rafale, the evaluation taking place at Ystres in the South of France over the 28th to the 30th. The Boeing F-18E/F, an advanced version of the F-16 (which was not yet flying) and the JSF had been tested in simulators before but would also be test flown. The Gripen was also to be test flown. Evaluation flight dates for the remaining aircraft were not confirmed.

Dassault offered the Netherlands participation in the continued development of the Rafale. This offer, proposed on 16 June, was an invitation to join Dassault in a EMD phase to develop the Rafale for future technology. According to some sources, the offer was stated as 50 per cent partnership in future Rafale development.

A report for the Labour party, a government party, noted that during Operation ALLIED FORCE the RNLAF participated with twenty F-16s, of which sixteen had gone through the MLU programme. The Dutch F-16s flew 1,200 offensive, defensive or reconnaissance missions, averaging sixty missions per aircraft. In comparison, the Royal Air Force flew 1,600 missions with fifty-two aircraft averaging approximately thirty-one missions per aircraft. The Armée de l'Air flew 2,000 missions with eighty aircraft averaging twenty-five missions per aircraft. The high sortie generation rate (SGR), and the effectiveness of a relatively small force, was an important factor to be taken into account again for the F-16 replacement.

On 18 August 2000 the Dutch parliament could ask questions about the basic document presented half a year before by the state secretary of the MoD. The parliament was informed about the current situation on the F-16s still in service. When the F-16 was bought, its lifetime was calculated as 8,000 flight hours by General Dynamics. Since the F-16s were used under greater stress, not only in the Netherlands, than anticipated by General Dynamics, a new calculation showed that flight hours had decreased to 6,000 hours. At the time the RNLAF had 157 F-16s still available, nineteen of which were offered for sale; the remaining aircraft were either updated to the MLU standard or about to be updated. The nineteen F-16s were offered to the United Arab Emirates (UAE) who were interested in buying them and negotiations were underway between Dutch and UAE defence officials. The PVDA, the biggest government party was against selling the F-16s, believing that they could be kept as a reserve for peace-time losses that the air force was likely to endure during the next twenty years of F-16 use. The following table, again accurate at the time, gave an overview of the remaining F-16s:





The Dutch F-35A around Fort Worth during its early career. (*Lockheed Martin*)

Year of Introduction	Total F-16 Delivered	Average Flown Hours Per F-16
1981	5	2952
1982	12	2755
1983	16	2677
1984	17	2627
1985	17	2634
1986	14	2444
1987	12	2306
1988	10	2042
1989	12	2015
1990	10	1915
1991	10	1780
1992	3	1727

NATO wanted each pilot to have a minimum of 180 flight hours and recommended 240 flight hours per pilot per year if the pilot was to be proficient in his job, but the RNLAF thought that 180 flight hours was enough flying hours per year for a pilot to be proficient. Some pilots got to fly more hours due to international peace enforcement missions.

At the open days of the Royal Netherlands Air Force at Volkel on 1 and 2 September 2000, the unexpected happened. All the competitors for the F-16 replacement showed up at the show. The Eurofighter Typhoon, which could not even make it to one of the major UK air shows made it to the Dutch air show days as did the Gripen.. The Dassault Rafale and JSF were presented, the latter with a mock-up. One of the so-called advantages of the JSF was the new stealth technology in which the US had a clear advantage over the competition but it remained to be seen if stealth would keep its ‘holy cow’ status as technologies to detect stealthy aircraft were becoming more successful. In former Yugoslavia one stealth aircraft, an F-117, was shot down and another had experienced a near miss. Stealth requires a lot more maintenance which would make the aircraft system more expensive, although these arguments could be easily dispelled by two counter

arguments: first, the F-117 presented first-generation stealth technology while the F-35 would represent fourth-generation stealth technology; secondly, the USAF stated that the F-117 had been following the same route every night, which made it easier for the air defences to shoot it down.

The two prototypes of the JSF programme had taken to the air. The Dutch Ministry of Defence and/or the Dutch Government had yet to make a decision. Discussion on whether the Netherlands needed such a system as expensive as the JSF began and the Gripen grew in favour compared to the JSF with some defence officials and politicians. When, in autumn 2000, both technology demonstrators for the JSF project were flying, Saab-BAE SYSTEMS was declaring that the technologies in development for the Gripen would give it the same, if not better capabilities. Under development for the Gripen were an AESA radar system and an HMD system, among others.

On 14 February 2001 the new commander of the RNLAF, Lieutenant General Dick Berlijn, flew in the Eurofighter for the first time. The flight was from the CASA test field at its Getafe flight unit and was in the DA6 test aircraft. The test pilot flying with the Dutch general was Eduardo Cuadrado.


INNOVENTOR
J830-2 Stand 1-4
40 PSF MAX


INNOVENTOR



The progression or at least some of it of AN-2 on the production line at Fort Worth. (*Lockheed Martin*)



An-2 rolled of the production line. This plane was due to participate in the Initial Operational Test & Evaluation. Dutch participation went through a political thunderstorm and at the time the outcome looked better. (*Lockheed Martin*)

Another important statement was made by the new US president, George W. Bush who stated that it was a fair assumption that the US could not afford to buy the three fighters that the Pentagon wanted to buy. The programmes he was referring to were the F-22 Raptor, F-18E/F Hornet and the JSF. To preserve JSF and US industry, on 14 March 2001 Teal Group recommended that the F-22 and F/A-18E/F acquisition programmes be reduced to 216 and 420 aircraft, respectively. Despite the drawbacks of implementing this programme, it would allow JSF to proceed after a delay of only about two years, with no major increase over the current level of fighter procurement funding. The Teal Group foresaw a production of almost 3,000 fighters between 2001 and 2010. This number was thought to be realistic because of anticipated orders that had not been made in previous years.



The first belgian aircraft coming out of the EMAS. On the Nose one can see the places where the EO-DAS will be placed, the flush port and multi-function Probe for the Air data System. (*Lockheed Martin*)



Majoor Laurens Jan Vijge preparing for his first solo flight at Eglin AFB. The first four Dutch pilots were exclusively trained at Eglin AFB. (*USAF*)



AN-2 the second Dutch F-35 on the production line. Note immediately behind it an F-35B STOVL version on the production line.



Majoor Laurens Jan Vijge was the first Dutch pilot to fly in the F-35A, a nice coincidence was that he flew in the first Dutch F-35A. (*USAF*)





The Dutch planned for a home visit to present the F-35 to the general public. Aerial refuelling was a necessity. The required trials with the Dutch KDC-10 and pilot qualification took place at Edwards AFB. (*Defensie.nl*)

On 21 and 22 March 2001 the Dutch State Secretary of Defence, Henk van Hoof, visited the EADS Eurofighter facilities after the offer from the four Eurofighter-producing countries (Germany, Italy, Spain and the UK) to join the Eurofighter programme. Besides Mr Van Hoof, the RNLAF Commander in Chief, Lieutenant General Dick Berlijn, was also present. The offer was an equal partnership in production and design from Eurofighter Tranche 3 which was supposed to enter service in 2010. Dutch industry would then become an equal partner in the Eurofighter programme. The decision was expected late 2001.

On 3 October Henk van Hoof presented a report to parliament with the results so far, stating that the KLu (Koninklijke Luchtmacht or Royal Netherlands Air Force) with support of the TNO and NLR (*Nationaal Lucht en Ruimtevaartlaboratorium* or National Air and Space Laboratories) had evaluated all candidate aircraft. The end-life update was found to be an unrealistic option. Since Gripen did not fulfil the requirements set further evaluation was not undertaken. It made Saab's assumption that Gripen

would be as capable as JSF harder to believe. The most important factor, and only one mentioned, was that Gripen with a heavy weapon load did not have a satisfactory range. According to the report, Saab had been informed about this. Other decisions had also been taken. He further noted that there were three candidates offering participation: Eurofighter, Rafale and JSF. The Ministry of Economic affairs had requested the CPB (Central Plan Bureau) to put the figures of the offers by the three candidates in a more broad cost-and-profit balance. The figures had been inventoried by the Ministry of Economic Affairs with the help of Booz-Allen & Hamilton and the *Nederlands Instituut voor Vliegtuig ontwikkeling en Ruimtevaart* (NIVR or Dutch Institute Air and Space development) headed by Ben Droste, the former chief the RNLAF. In the report the difference of buying off the shelf or participation in the different developments was also to be compared. Negotiations with the three manufacturers were continuing. One similarity with all three candidates was that joining sooner meant profitability would be bigger. If the Dutch government decided not to participate and buy off the shelf, all options would become available again.

Early in October 2001 a press leak included details from a report from the Central Plan Bureau (CPB), a Dutch bureau for economic analysis that produced the report for the finance minister. It was mentioned that investing Dfl: 1.6 billion (US$658 million) would not result in such a big job increase as expected from the amount of investment. In fact the increase would be normally achieved as a result of economic growth. The gain was negligible and not worth the investment. Although final results of the report were not due for another month, the blow to the pro-JSF party was big since their main argument was the new jobs and technology connected with the JSF programme. One of the report's biggest critics was Ben Droste (also one of the most pro-JSF people around), stating that the CPB had ignored a government decision and investment from 1998 that would cement together the Dutch aviation industry. That this had not been achieved was not surprising, according to him, since the government had given the programme eight years to realise itself. The actual report was published on 26 October 2001.



The two Dutch F-35As finally make their way over to the Netherlands although for a short period. Seen here with KDC-10 and a Gulfstream that flew out of Leeuwarden to meet up with arriving aircraft. (*Mediacentrum Defensie*)

Eurofighter was fighting hard for the deal, but according to an official of Gripen International, the Netherlands was basically a JSF customer and it would surprise him very much if any of the other options would win. So if the shelf buy became a solution, the F-18E/F would become an option. The Gripen would, however, not have such a big chance anymore due to the fact that its growth potential would have been used up by that time. The JSF had a higher maximum take-off weight and a higher empty weight and the expenses would be higher, but these costs were not mentioned or were thought to reduce as the sophistication of the technology would impose automatically higher reliability and lower maintenance costs. This was, however, not a realistic point of view as had been pointed out years before by Norm Augustine, the former CEO of Lockheed Martin in his book Augustine's laws. The other option not thought of was that the JSF would be a middle-class fighter with Eurofighter and the Rafale for the higher end of the market and the Gripen for the lower end. This, however, would also mean that the F-16 would remain a viable product for future customers. JSF office and partners were expecting a quick decision from the Netherlands

and Italy for participation and expected it before the year ended. The Netherlands, however, were not that fast; Dutch industry came with an offer to help and share the cost involved with the Dutch government. The decision was now expected to be made on 18 January 2002. The Dutch Prime Minister, Wim Kok, stated on 1 February 2002 that the JSF programme had the best documentation and was therefore favoured by him with both the finance and defence ministers having the same opinion. The statement was, however, only that the JSF was favoured by the biggest political leaders in the Netherlands. No official decision had been made to buy any aircraft or to participate in any programme.



The fire brigade giving a wet welcome to two Dutch F-35As at Leeuwarden AFB. The welcome ceremony was transmitted live on Youtube. All this in an effort to impress the general public, which after a long time supported defence spending again. (*Mediacentrum Defensie*)



At the beginning of the part about the Netherlands in this chapter there is a computer made image of the JSF above the Netherlands. This area was the inspiration. (*Frank Crébas via Defensie.nl*)

Exactly a week later the Dutch government decided that the JSF was the best option to replace its ageing F-16s. At the same time the government decided that it would participate in the EMD phase. All other competitors were thereby eliminated. The Netherlands were thus one of the earliest European participants in the JSF programme. This was the first step for Lockheed-Martin to repeat the F-16 success in Europe. The Dutch parliament was to vote in April 2002 about participation in the EMD which would lead to an acquisition of up to eighty-five F-35s. The acquisition was valued between €5 and 6 billion. The Dutch government was under American pressure as well as facing a time limit due to the elections on 15 May 2002.

However, a parliamentary commission was called after both Eurofighter and Dassault complained that their offers were not taken seriously and that important parts were left out. In fact, inexplicable discrepancies were found in the material that the cabinet presented to the parliament. In the evaluation the JSF won 6.97 points, the Dassault Rafale came in second with 6.95 points and the Eurofighter Typhoon gained only 5.83 points. Strangely,

however, the improved version of the F-16 had gained 5.80 points. So, according to the Dutch evaluation, the modernised F-16 Block 60+ was indeed very close in quality to the Eurofighter. One would almost wonder why four nations bothered buying the Eurofighter if the difference was really so small.

In early March 2002 the *Nederlands Centrum voor Laser Research* (NCLR) or Dutch Centre for Laser Research received a contract from Pratt and Whitney to drill holes on the F135 propulsion system on condition of the Netherlands joining the SDD. The new laser-drill system developed by the NCLR is capable of drilling multiple small holes simultaneously with high precision, where other lasers are only capable of drilling one hole at a time.

On 2 April 2002 the Dutch parliament was due to discuss with the government the plans to join the EMD phase (recently renamed as system development and demonstration phase, or SDD) which would mean that the decision to buy the JSF was already taken as well. The cost of €800 million would be paid by the government, in return for which the government would be able to buy the JSF without development costs calculated in the cost price and would receive royalties on exported JSFs.

Although the elections were approaching the political debate about joining the JSF programme was being delayed. An unforeseen event fourteen days later seemed to delay the entire participation discussions: that was the early resignation of the government on 16 April 2002. The decommissioned government had only the right to handle active cases. Therefore, a delay was expected and it was thought that everyone had to wait until after the elections. This was confirmed later by the fact that the JSF office extended the term for contract signature until June. The new Dutch government was more right-wing orientated and had no big problems in agreeing to participation on the second level of the JSF programme.

When the Netherlands signed on after all the political turmoil the country had endured, it was the first country to sign on as a level-two participant but the fourth to join the EMD phase. The Netherlands signed on 10 June 2002 for participation to a value of US$800 million with plans to replace 135 F-16s by approximately eighty-five JSFs. The total committed by the Dutch government, not including support packages for the national industry, was US$810 million. According to a press conference at Farnborough 2002 sixteen companies had the qualifications to bid for work

on the JSF but had to present best-price/product combination since their work share was not guaranteed. For some Dutch companies, this was a bitter pill to swallow, as they had to commit money for the SDD phase to the Dutch government.

The increasing price of the F-35 was acknowledged in 2005 by Lockheed Martin and the programme office approached the Dutch politicians as it was not sure if the Dutch would commit to the planned eighty-five aircraft. According to some, the Dutch might order fewer and take out an option on more to spread the financial burden. The political popularity of remaining with the JSF programme and signing the JSF PSFD memorandum of understanding was dwindling fast.

The signing of the PSFD was planned for December 2006 and the closer that date came the greater was the worry of the incumbent government as opposition parties all threatened that, after elections planned for 22 November 2006, they would not sign the PSFD if they were to be elected, putting in jeopardy the investment already made. To prevent the threat becoming a reality the government decided to deal pre-emptively with the problem and signed the PSFD MoU as the first nation on 14 November 2006.

The estimated Dutch procurement of aircraft per fiscal year was determined in the PSFD document. Delivery would be approximately two years after contract signature.

Fiscal Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Amount	1	2	0	6	10	12	12	12	12	18	85



The round flight which the F-35 was to take on 7 June 2016. (*Defensie.nl*)



The F-35 on 7 June 2016, over the most impressive deltaworks ever built, located in Oosterschelde. (*Frank Cébras via Defensie.nl*)


Low-level flight testing by this Dutch F-35A in the USA proving a lot of critics wrong about its manoeuvrability. (*Defensie.nl*)



The heart and mind flights F-35 over Amsterdam city centre. (*Frank Cébras via Defensie.nl*)

The year 2008 was a strange year for the Netherlands regarding the F-16 replacement question. It was announced that the Netherlands wanted to participate actively in the IOT&E with the government planning to acquire two CTOL aircraft. Furthermore, financial commitment for these aircraft was expected the following year. In the MoU signed for the IOT&E the cost was capped by a financial part and a non-financial part. The Dutch MoD share of the financial cost ceiling was US$30 million; the non-financial cost contribution included, but was not limited to, munitions, use of two JSF Air Systems, and the services of trained personnel for IOT&E efforts.

However, the Dutch cabinet required that alternatives were again evaluated but Boeing, Dassault and Eurofighter declined to participate. Gripen International, however, did not hesitate and answered the request for information. When the answers were due in not all could have been answered due to information release rules from the US. It was there that it could be seen if the competition would be fair and open, a Gripen International statement read. Although the Netherlands government had not committed itself officially to production, only about a month later, on 2

September 2008, Pratt & Whitney received a contract for the long-lead items for several engines, amongst them long-lead components destined for two CTOL propulsion systems for the RNLAF. The cost of those long-lead items was calculated at US$2,025,000 or 2.6 per cent of the total contract value. The only other partner nation being mentioned in this contract award was the United Kingdom. This was part of the partner purchase request/long lead phase that was initiated by both countries. Although government and parliament still had to give approval in 2009, it was strange that Lockheed Martin received a similar contract on 11 March 2009, again prior to the government decision and among public reports in the local press that support for the JSF was not there in parliament. However, there was a coalition agreement by the Dutch government parties that had tied them to support the JSF programme. In advance of the political debate, Dutch defence minister Jack de Vries told the media that not buying the JSF would throw away the investment made so far by previous governments.



The F-35 over the city with one of the biggest harbours, Rotterdam. (*Frank Cébras via Defensie.nl*)



The coastal town of Scheveningen near the government city Den Haag. (*Frank Cébras via Defensie.nl*)

The coalition agreement was put thoroughly to the test on 22 April 2009 when the discussion about buying two test aircraft opened in parliament. It was during this first day that trouble rose and it was unclear if a solution could be found. The solution found on 23 April was a rather strange one: the government would not make a decision to buy the aircraft but it would provide Lockheed Martin the money to produce one aircraft. The government would make a decision in 2010 when it was thought that the political parties (mainly Labour) involved could make a better decision on the ground of information they hoped would be available on cost, noise levels and jobs that in the Netherlands as a result of the Netherlands participating in the JSF programme. If the Netherlands decided against buying the test aircraft it would get its money back minus US$20 million, said Defence Minister Jack de Vries. The decision to buy the eighty-five aircraft was, according to the current agreement, pushed back to the next government. It was further expected that the Dutch would buy their aircraft in two batches, one of fifty-five and one of thirty.

The next government became a reality sooner than anticipated as in early 2010 the coalition parties could not agree on a common policy for their commitment in Afghanistan. New elections were planned for 9 June before

which parliament voted to cancel the one IOT&E aircraft ordered. This could be overturned by the new government but the increase of cost was a well debated item in the newspapers and the fighter replacement had become one of the election topics for the national elections. The elections took place as planned but it was a couple of months before a coalition was formed. When, finally, a government was formed it had an agreement that it would retain the one test aircraft and order one more but production orders for operational aircraft would be left to the next government. This meant a delay in orders as the planned term of the new government was four years. The JSF programme, however, brought great controversy and the cost of and need for the second test aircraft was a matter of debate. Originally the government had the time to decide till March 2011 which the Americans extended until Apríl 2011; the second test aircraft was as an option taken in the fourth LRIP contract. Long-lead items, however, were already ordered but the big part of the discussions was that the cost of the engines was not known since negotiations with Pratt and Whitney had been so protracted the contract for the fourth LRIP had still to be signed in the first quarter of 2011. The Dutch government finally agreed on buying the second test aircraft with a narrow vote in parliament. The cost of both aircraft, including pilot training, was quoted during the debate as being €270 million. The first of the two aircraft ordered rolled off the production line on 1 April 2012. AN-1 was to go through fuel tests, followed by other ground tests before first flight. It was first flown four months later on 6 August. Its second flight was only four days later. However, releasing news of handing the actual aircraft over was delayed because the operational utility evaluation had to be completed so that the first Dutch pilots could be trained. They were to be trained at Eglin AFB and, since the USAF would not begin training until this evaluation, the Dutch had also to wait.



Palace Het Loo another landmark in the Netherlands. (*Frank Cébras via Defensie.nl*)



The city of Arnhem. It is mostly made famous outside the borders of the Netherlands due to a film about the Second World War based on real events which took place in Arnhem. The film was called ‘A Bridge Too Far’. (*Frank Cébras via Defensie.nl*)



The Dutch pilots busy evaluating the F-35A, were also tasked to evaluate the training facilities at Galatino/ Lecce Air Base, Italy. (*Mediacentrum Defensie*)



On 12 June 2015, the pilots were fitted out with flight gear to evaluate the M-346 training system (*Mediacentrum Defensie*)

The IOT&E was delayed. According to the MoU signed by the Dutch in 2008, the IOT&E would take place from mid-2012 until mid-2014, separated into Block 2 and Block 3. Clearly, this was not to be met. In a February 2013 letter to parliament, it was revealed that:



The evaluation included flights in the M346. (*Mediacentrum Defensie*)



The Dutch F-16 based for training purposes in the USA, would be replaced by F-35. It remained to be seen how long these would stay at Tucson. (*Mediacentrum Defensie*)

- The cost ceiling will be broken, cost of IOT&E participation will be about €54 million (US$73 million)
- IOT&E will take four years, not two
- IOT&E planning is now from 2015 until 2018 but may be a little later
- The two Dutch F-35s cannot be used until that time (2015)
- The Dutch have to pay 'parking costs' of several million a year for their two F-35s

The first point, although upsetting, was logical as the IOT&E was going to take longer. That, however, does not take away from the fact that one can change an agreement only if both partners agree. The last two points were outrageous for the simple fact that it was stated that these aircraft could not leave the US. The second reason was that the Dutch could have waited to buy the two jets and would have obtained fighters with fewer currency problems and at a lower cost. At approximately the same time the first pictures of AN-2 on the production line were released. Shortly after, on 4 April, the news was revealed that the Dutch would transfer the two aircraft

to storage in Edwards AFB and keep them in flying condition by letting American pilots fly them once in a while. Storage would last until a decision was made on the follow-on to the F-16. Other competitors such as the Boeing F-18E/F Super Hornet, Eurofighter Typhoon, Dassault Rafale and Gripen E were invited back in. It was questionable, however, how a fair evaluation and tender could be managed in a relatively short time. The Joint Programme Office Director, Lieutenant General Bogdan, was quoted as stating that the F-35 would be about 10 per cent more expensive per flight hour than the F-16. Figures quoted were that the heavier F-35A, the version selected for the *Koninklijke Luchtmacht*, would cost US$23,900 per hour to fly compared with US$21,500 for the lighter F-16s.



The weapon bays open and fully loaded. Further notice the air scoops under innerwings. (*Defensie.nl*)



Note the cooling scoop on the upperside of the inlet. (*Defensie.nl*)

The Netherlands made a decision rather soon after all the negative news about parking costs. On the Prins Day (*Prinsjesdag* is the beginning of the governmental year and occurs on the third Tuesday of September) in the Netherlands the defence minister, Jeanine Hennis-Plasschaert, made it known that the Ministry of Defence wanted to buy a total of thirty-seven F-35s. That number included the two already purchased in the third and fourth lot respectively; the next purchase was actually for thirty-five aircraft. Against the current plan of eighty-five, this was a rather large reduction. It was, however, possible that a second batch would be bought but this would be decided by the next government. According to the *Defensienota*, a defence white paper, it was stated that operational and acquisition costs were not entirely clear. The Dutch Ministry of Defence did not want to cut into other capabilities. The operating cost of the sixty-one F-16 fleet divided over three squadrons was €270 million per year and the fleet size of the F-35 was selected with a 10 per cent reserve in mind. In other words, the operating cost of thirty-seven F-35s was expected to be €240 million annually. The possibility of increasing the number of F-35s was left open but was dependent on an increase in the defence budget. A parliament

motion that the F-35 should not carry nuclear weapons, or have that capability, was approved.

A team of four pilots and about twenty maintenance staff under the leadership of Lieutenant Colonel De Smit was to begin training at Eglin AFB by the end of October 2013. The decision to continue with the F-35, as opposed to re-opening the tender to other competitors, made the decision to put the aircraft in storage superfluous. The first of the pilots was expected to fly before the year ended. The training of pilots and maintenance staff had to start by the end of October so that they could gain sufficient experience on the F-35 to be valuable members of the operational test and evaluation team at Edwards AFB where they were planned to transfer by the end of 2014. Operational test and evaluation was now planned to start in 2015. The first Dutch pilot, Major Laurens Jan Vijge, started training as planned at Eglin in autumn 2013, making his first flight in the F-35 on 18 December. Major Vijge flew from Eglin AFB in one of the two Dutch planes based there, F-001, the first Dutch plane to come off the production line. Interestingly compare this with the F-16, which Dutch pilot Major S. Heyboer flew for the first time on 21 September 1977 as the twenty-third pilot of the programme, only three years into the development programme of the F-16, which was sold as a co-operation programme but with no need to buy into the development part. During that time the Dutch pilot was actually the third foreigner to fly the F-16. Paying to be a partner in the F-35 programme, it took seven years for the first Dutch pilot to fly and he was not in the first 100 pilots of the F-35. Major Vijge received his training certificate on 24 January 2014 together with six Dutch maintenance staff. The second Dutch pilot started his training on 18 February and two more would follow during 2014. Another six technicians were undergoing training and it was planned that a total of thirty-four people would be involved in the Dutch operational test and evaluation team to be based at Edwards.



The third Dutch F-35 arriving at Luke AFB. (*USAF*)



History, the Supermarine Spitfire and the Hawker Hunter, both English products. Today, the General Dynamics (now Lockheed Martin) F-16 and the future of the Lockheed Martin F-35A, both American products. (*Mediacentrum Defensie*)

In January 2014 came news that the Dutch ministry of defence was planning to give the F-35 its nuclear capability anyway because there was a commitment to NATO. The opposition was not happy with the fact that the minister was ignoring the motion. Another party not totally happy with the

Dutch decision to acquire just thirty-five aircraft were the Italians who had been calculating on better use of their production line, the cost per aircraft for which had suddenly increased. The Italians were even further disappointed later when the F-35 buy was detailed more by the Dutch defence ministry. The first batch of eight aircraft was finally approved by the Dutch parliament and described by Dutch Defence Minister a decision of no return on 3 March 2015. Of the first eight, six would be produced at the Lockheed Martin Fort Worth facility since they were destined for training purposes and would be based at Luke AFB. It would be more expensive to have them fly from Italy to the US. So from the thirty-seven aircraft destined for the RNLAF only twenty-nine would be built at the Italian facility. Meanwhile, the first four Dutch pilots who had been trained at Eglin and were due to join the JOTT at Edwards transferred with the two Dutch aircraft on 17 January 2015 to begin their part in the operational test and evaluation. Other pilots would be trained at Luke AFB. Shortly afterwards, F-002 was transferred to Ogden Air Logistic Centre for modifications.



The first Dutch Italian-produced F-35A on its delivery flight from Cameri to Leeuwarden. Note that no unit markings were present. (*Mediacentrum Defensie*)



The cannon being filled for an Initial Operational test & Evaluation to be done by this Dutch F-35A from Edwards AFB. (*Defensie.nl*)

It was planned that the lead-in fighter training (LIFT) would take place in Italy as they had developed the Russian YAK-130 into the M-346 LIFT. In 2015 an agreement was signed that Dutch pilots would receive their training in Italy. To evaluate the state of the training and to see how much of it could be done in Italy prior to sending pilots to Tucson AFB (Arizona) or, in the near future, Luke AFB, two pilots were sent over to evaluate the training syllabus. They were none other than two F-35-qualified pilots Colonel Bert 'Vidal' de Smit and Major Pascal 'Smiley' Smaal from the Operational Test unit. The evaluation took place at Galatino/Lecce Air Base.

The two first aircraft joined 31st TES at Edwards AFB, receiving the American OT designation on their tails as they became an integral part of that unit. Major Pascal Smaal was the first foreign pilot to drop a GBU-12 LGB from a foreign (F-002) at the China Lake ranges on 18 February 2006.

After the Australians and Italians, the Dutch also wanted to have their tanker qualified to refuel the F-35. The RNLAF send a KDC-10 to the US in 2016 and, in co-operation with 418 FLTS and Dutch crews, performed

the qualification for the KDC-10. The second reason was that during summer 2016 the RNLAF wanted to bring their F-35 to the Netherlands so that they could do noise-level comparisons at Leeuwarden and Volkel. Those two locations were selected as the main bases for operational aircraft. Both aircraft would also participate at local open-door days called *Koninklijke Luchtmacht Open Dagen* on 10 and 11 June 2016. They would be the first to fly American-built F-35s over the ocean. The two F-35s transferred from Edwards AFB to NAS Patuxent River on 21 May 2016, which took approximately four hours, and two days later departed for Leeuwarden where AN-1 and AN-2, piloted respectively by Colonel de Smit and Major Smaal arrived around 8: 45pm.



The F-35A flying low through a canyon called the Death Valley. (*Defensie.nl*)



Surprise for the pilot! (*Mediacentrum Defensie*)

In the Netherlands the two aircraft initially performed perception flights at Leeuwarden and Volkel Air Bases which were considered a great success. The other evaluation that took place was compatibility with the hardened air shelters (HASs). The Dutch also planned to fly over as many landmarks and populated places as was allowable for marketing purposes but the first attempt, on 2 June, was cancelled due to low cloud. However, the second attempt on 7 June was successful. This was followed by the F-35 participating in Royal Netherlands Air Force Open Days (*KLu Open Dagen*) where a total of 208,000 people came to watch. The hardened air shelters have been in service since the KLu had Lockheed F-104 Starfighters in service and had been designed with the F-104 in mind, each housing one aircraft. As was pointed out the F-35 lacks an oxygen cylinder and instead is equipped with an on-board oxygen generation system (OBOGS). OBOGS makes oxygen from the ambient air but in the HAS this is polluted with exhaust fumes. For this reason the Defence Materiel Organisation (DMO) of the RNLAF commissioned NLR to investigate the emissions of various hazardous gases, including carbon monoxide (CO), carbon dioxide (CO2), nitrogen monoxide (NO) and nitrogen dioxide (NO2). The report, completed in early November 2016, found that even with all the differences between the F-16 and F-35 the HAS could still be

used for the F-35. The importance of this evaluation could not be underscored since other partner nations and the USAF had similar HASs.

The Dutch order would be separated in three parts. The moment the Netherlands signed up with real consequences was when it signed the consolidated procurement request (CPR), as with every partner nation prior to negotiations starting with Lockheed Martin. To have all countries on board on time, the last possible date was when the JSF Executive Steering Board convened. For the Royal Netherlands Air Force the key date was 26 March 2015. The first order for eight F-35s was signed for in LRIP 11. The Dutch government promised that if a block buy became available the Netherlands would try to become part of such a deal. The next order was a block buy. For the Netherlands a requirement for twenty-four was a part of the block buy including LRIP 12, 13, 14. There was a worry from the Dutch side that they would have a problem financing the aircraft and so they went for the following acquisition strategy: LRIP 12 eight F-35As, LRIP thirteen F-35s with an option of three more, LRIP 14 with a requirement for five F-35As and an option for three more. It depended on the financial situation by the end of 2017 if these options would be taken up. The third order would be for the last three in lot 15.



F-35 in the Death Valley or Star Wars canyon as it is also called. (*Mediacentrum Defensie*)

After the deployment of the two Dutch aircraft from 23 May until 14 June, F-001 was sent to Luke AFB for modernisation to Block 2B standard. The modification took three months and was complete by the end of August. It was to be followed by another upgrade in 2018 to bring it up to Block 3F standard. This second upgrade would bring the first Dutch aircraft up to IOT&E standard. The F-002 was to be upgraded in 2017 but immediately to the Block 3F standard required for IOT&E.

The Royal Netherlands Air Force had used brake chutes, or drag chutes as they are called officially, on their F-16s and it was confirmed on 1 December 2016 that they had paid NOK96 million to Norway as their part of drag-chute development for the F-35. As a result, a new switch would find its way into the cockpit.

Production of AN-03 to AN-08 would take place at Fort Worth and would be delivered to the 308th Fighter Squadron under which the Dutch pilots would receive their training. AN-03 was due to roll out of the Fort Worth facility in the fourth week of 2019. AN-09 would be the first to be built on the Italian FACO at Cameri. The assembly of AN-09 was officially initiated during a ceremony at the Italian FACO on 15 June 2018 when Dutch Secretary of State for Defence Barbara Visser signed a bulkhead of AN-09. AN-09 was expected to arrive on Dutch soil by 31 October 2019. The first aircraft had arrived at Luke AFB when the news broke that the cost of the flight hour had reached US$44,000 in fiscal year 2018 – quite a difference from the US$21,500 for the lighter F-16s. Norway declared that it would have to increase its budget, as this was more than it had budgeted for.

AN-09 had its first flight from the Cameri FACO on 9 September 2019, making AN-09 the fourteenth F-35 to fly out of Cameri, preceded by eleven Italian F-35As and two Italian F-35Bs. Another twenty-eight Dutch F-35s were under contract to come from the Italian FACO. The first flight was on time for the ceremony planned for first aircraft arrival at Leeuwarden. AN-09 was handed over to the *Koninklijke Luchtmacht* at Cameri on 12 September 2019 which was followed shortly with news that the Netherlands would opt to buy nine more aircraft. The decision was announced on the third Tuesday in September, called *Prinsjesdag*, when the policies of the next year are announced. The Defence minister Barbara Visser told media it was a step in the right direction to renew the air force and fight the neglect that all the forces had suffered. The nine aircraft would be for a third

squadron but the eventual missing six aircraft to complete the third squadron would be for a future decision; it was not known if that decision would be made, although it was highly likely.

The first arrival of the F-35 at Leeuwarden Air Force Base was a real celebration with all bells and whistles. Ian Knight, commanding officer of 323 Test & Evaluation Squadron, flew in from the FACO in Cameri. Knight landed and got a surprise; the fire brigade unit on the base had to give him a welcome shower but instead of water it sprayed the new arrival in firefighting foam. The first operational mission out of Leeuwarden took place on 27 November 2019.

IOC was achieved in December 2021 and preparation for the next unit at Volkel Air Base was in full progress. On 1 June 2022 it was announced that the *Ministerie van Defensie* had received approval to order six more F-35As. This was agreed quickly following the Russian invasion of Ukraine. It was believed that the aircraft had to be ordered quickly as an increase of orders from other countries was expected. Although the order for the additional six F-35s was planned, the situation on NATO's border brought it forward; the aircraft would be included in LRIP 17 for delivery in 2025. These six aircraft would go to the third squadron, allowing one long-term deployment of four aircraft or one short-term deployment of eight for one mission. Simultaneously, it would also be possible to deploy four aircraft on a second short mission.

Norway

In March 1995 the Norwegian defence ministry took the first step towards obtaining a next-generation fighter to replace its F-5 Freedom Fighters. The aircraft under consideration were Eurofighter 2000, Rafale, the F-16C/D and, of course, the JAS 39 Gripen. The F-16C/D, although a fourth-generation fighter, stands a good chance because the F-16A/B is already in the inventory of the Royal Norwegian Air Force (RNoAF). Saab retired from this bid when it transpired that the Royal Norwegian Air Force at that time preferred twin-engine aircraft. The Lockheed team remained in the bid with its F-16C/D.

The JAST office briefed Norway on the JSF shortly after March 1996 although it was doubtful that the Royal Norwegian Air Force could wait so long to replace the F-5s. The JSF would, however, be ready when the

Norwegians needed to replace their F-16MLUs, which was expected around 2010. Shortly after the briefing, Norway expressed a desire to join the programme as an informed customer, meaning that they would have to invest 0.5 per cent of the total cost of the CDP. Norway was one of the first countries, other than the UK, to express its desire to join the JSF programme.



Together with the Dutch and Danish governments, the Norwegian government invested US$30 million (one third each) to become partners in the JSF CDP, the Norwegians signing the MoU on 16 April 1997.

The financial crisis had also reached Norway. The Norwegian Chief of Defence, General Arne Solli, announced that the procurement of forty fighters was to be postponed for four years and that, due to budget restraints, the requirement had been reduced from forty aircraft to twenty-five. The fighters still in the running were the Lockheed F-16 Block 60 and the Eurofighter. The Norwegian decision was expected in late 1999.

Another programme that had suffered delay was the Indian LCA (Light Combat Aircraft). The first flight was re-scheduled and, due to the economic crisis in the region, further delays could still occur. In fact the first flight of the LCA occurred on 4 January 2001. No decision had been made by the Norwegian government until 2003.



The first visible part of the Norwegian production underway at Fort Worth. (*Lockheed Martin*)



All the fuselage parts are entered into the Electronic Mate and Assembly System. (*Lockheed Martin*)

Norway's political decision to retire the F-5 without replacing it was a big blow to the air force. The RNoAF still had fifty-eight F-16s in service but peacetime losses had amounted to sixteen F-16s by the end of 2000. Moreover, the plan was that the fifty-eight F-16s were to be replaced by forty-eight fighters. As the financial budget was so tight, it was deemed necessary to replace at least half the F-16s in the inventory from 2006 to 2009 and the other half in a second batch in another tender. This would create the possibility of again having two different aircraft types in the inventory. If the plans went as intended then, in 2003, all options would be studied including the Batch 3+ quality (international NATO compatible) Gripen for the first batch. Commander in Chief of the Royal Norwegian Air Force, Major General Tomas Colin Archer, saw the JSF as the only realistic option for the second batch.



The first Norwegian aircraft being lifted out of the Electronic Mate and Assembly System. (*Lockheed Martin*)



Weight on wheels milestones the start of the final assembly. (*Lockheed Martin*)



The final assembly of the first Norwegian F-35A. (*Lockheed Martin*)



The first Norwegian F-35 departing the final assembly.

By the end of April 2002 defence staff advised the ministry of defence that the JSF would be the best option. Earlier there was an advice from the National Civilian and Defence Technological Industry Association that again preferred the Eurofighter Tranche 3 offer, which they thought to have a far better effect on Norwegian industry then the JSF. The Norwegians signed on for level-3 participation on 20 June 2002 for US$125 million, expecting to buy forty-eight of them. The Eurofighter consortium, with EADS in the lead, seeing that they were about to lose an important customer, provided a Norwegian company with a big order for parts for the Eurofighter Typhoon. As the JSF suppliers' contracts were on a competitive basis, the off-set deals were slow in realising themselves and there were even rumours that the Norwegians would abandon the JSF programme in favour of the Eurofighter around the Paris Air Show at le Bourget in 2003. Norway remained with the programme, although voicing on a regular basis discontent with the work they were receiving in return for their investment. A decision on commitment to production of the F-35 was expected in 2006.



Standing in the facility for final finishes to be applied.



The official handover to Norwegian officials.

Although Norway decided to continue with the JSF this did not represent to them a commitment to buy. In fact, Norway was looking for similar opportunities elsewhere and was in discussion with the Eurofighter

consortium and Saab about a further development of the Gripen called Gripen N. Gripen N (N for Norway) was offered and Norway funded a part of a demonstration programme, together with Sweden. The Gripen Demonstrator, now the basis for the Gripen NG for Next Generation, was thought to be the cheaper option, compared to the F-35.



Arrival at Ørland, Norway the homebase for the Norwegian F-35.

The estimated procurement amount of aircraft per fiscal year by Norway was determined in the PSFD document. Delivery would be approximately two years after contract signature.

Fiscal Year	2014	2015	2016	2017	2018	Total
Amount	8	12	12	12	4	48

Eurofighter retreated from the tender stating that the tender process was skewed too much in favour of the JSF. The two remaining contenders proposed their aircraft and their final bids were evaluated during 2008. On 20 November 2008 it was announced by the Norwegian prime minister's office that the defence minister had recommended that the F-16 be replaced by the F-35. It was the first tender where the Gripen NG was pitted against the F-35, but the amazing part of the result was that the F-35 was the

cheaper option. It was literally stated that the F-35 was offered at a lower price than the Gripen NG. Furthermore, it was stated that the selection process was open and fair. According to the same statement from the Norwegian prime minister, this was also confirmed by unspecified independent auditors. The cost of acquiring forty-eight F-35 CTOLs would cost up to NOK18 billion; the Gripen NG was NOK6 billion more expensive. Due to their decision and explanation, the Norwegians were ridiculed since the cost of the JSF was estimated not to remain under US$50 million. In fact reports already had it at the level of US$80 million.

A more interesting fact, at least for Norway, was that in Lockheed Martin's reply to its Rf I it was stated that Norway's requirement for icy runway capability including a braking chute would be addressed as early as a Block 4 capability. When this would become available is not clear though it was addressed in the Rf I reply as notional. In the same reply, information was given that the Block 4 development was scheduled for initiation in 2010 and OT&E of Block 4 was due for completion in 2015. Norway, however, had a requirement for a drag chute or a technology that would replace it and as such the standard F-35 would not fulfil its requirement. For this reason in 2010 Norway, the Netherlands and Canada paid for a study into different options of integrating a drag chute or similar effective capability into the F-35. From this study, however, the drag-chute solution came out as the favoured option. The fact that the order for the first two Norwegian F-35s was against the original schedule brought forward. On 15 June 2012 a contract for advanced production items for LRIP 7 included funds for long-lead-time efforts required for the incorporation of a drag chute in CTOL air systems for Norway. The actual long-lead items for the aircraft were allocated five days later in a separate contract. It was two years later that the contract was again modified. Lockheed was to develop, test, and certify two drag-chute systems for the F-35 for Norway. The contract value was US$246,613,000 and work had to be completed by July 2019.



AM-08 at Fort Worth just before transferring to Ørland in Norway. (*Lockheed Martin by Angel Delcueto*)



Norwegian Air Force operating out of Luke AFB for training purposes. (*USAF*)



The early production aircraft remained at Luke AFB. (*USAF*)



Initial flying operations were performed by the Norwegian Defence Management Agency (NDMA). (*Norwegian Armed Forces Forsvarets*)

Another Norwegian initiative and requirement was the integration of the joint strike missile (JSM), which was aimed for integration into Block 5. Block 5 development was due to begin in 2012 and the completion of OT&E was due for 2017, well in time for delivery to Norway. This, of course, would depend on delays in the schedule of the initial blocks since testing of software and aircraft had also run into delays that were relatively

small compared to the F-22. This, however, changed over time; the delays became more significant and everyone initiated delays with their acquisitions. On 16 June 2011 the Norwegian parliament decided to commit to buying four F-35 aircraft to be used for training for Norwegian crews. The announcement was made shortly before the Paris Air Show where it was explained that the commitment for the operational aircraft would be delayed. Norway would stick with its decision that it wanted Block 4 capability aircraft. The first four aircraft would be a part of LRIP Lot 5 aircraft. At the 2011 Paris Air Show it was further explained that Norway expected help either from the US or other partner nations in the development of its joint strike missile. The Norwegian buy was delayed by another two lots, the first two aircraft for the Royal Norwegian Air Force being ordered under LRIP 7. The first Norwegian F-35, designated AM-1, initiated mating process in early 2015. AM-1 was scheduled for roll out later during the year. Norway was not shying away from publicity surrounding their aircraft and every milestone, however small, on the assembly line was used; weight on wheels was achieved on 26 April 2015. Roll out followed shortly after on 19 August.

The aircraft (AM-1 RNoAF serial number 5087) moved into the aircraft final finishes facility, where it received its low-observable coatings. From there it had to undergo a series of functional fuel-system checks prior to operational ground checks and first flight. In the middle of all these events the official handover ceremony was planned for 22 September. After the aircraft was accepted it would be delivered to 62nd Fighter Squadron at Luke AFB where Norwegian pilots would be joining the Australian aircraft there and the Norwegians would shortly be joined by the Italians. First flight of a Norwegian aircraft was, however, performed with the second Norwegian production aircraft AM-2, (RNoAF serial number 5088) piloted by Bill Giggliotti on 6 October. The Royal Norwegian Air Force began training of their pilots at Luke AFB and, as one of the first pilots, Major Morten Hanche was outfitted with the Gen III HMD on 16 October. Major Morten ‘Dolby’ Hanche was also the first Norwegian to fly the F-35. After the Australians and Italians, the Norwegians became the third nation to have their pilots and maintenance staff trained at Luke AFB. Major Hanche flew the F-35 for the first time from Luke AFB on 10 November. On the same day the first two Norwegian aircraft were transferred to Luke AFB, Norway becoming the second nation to have its aircraft based at Luke. A

total of five more Royal Norwegian Air Force F-35s were delivered to Luke AFB before the first aircraft were delivered to Norway. Aircraft were due to arrive in Norway on 2 November but this was delayed by a day. Three F-35s (AM-8 AM-9 and AM-10) left from the Lockheed Martin Fort Worth facility to arrive the same day at Ørland Air Base, Norway. The three aircraft, the first to be delivered to Norway, took off from Fort Worth, Texas at 6.35am Norwegian time on 3 November and landed at 3.57pm the same day at Ørland Air Base. It was the first time that US-made F-35s were delivered to Europe and Norway was the second country in Europe to receive its F-35s home-based after Italy; they were the third country after Israel and Italy to have their F-35s at home. Norway had taken delivery of its first ten aircraft. A week later an official introduction and handover ceremony was held at Ørland Air Base. The three aircraft became a part of the Norwegian Defence Management Agency (NDMA). It was all relatively quiet at the Norwegian front from then on until it was announced that the Royal Norwegian Air Force had performed the operational evaluation of the brake chute at Ørland on 16 February 2018.



The first AMRAAM firing in Norwegian air space. (*Norwegian Armed Forces Forsvarets*)

On 22 May 2018 another three F-35 aircraft landed at Ørland Air Base, taking the total number of aircraft in Norway to six. Another seven Norwegian F-35s were based at Luke AFB for the training of Norwegian pilots and maintainers. This was followed by another three aircraft on 21 September. The F-35 was due to take over some of the tasks of the F-16 once IOC was achieved in 2019. The QRA mission was due to be taken over in 2022. IOC was achieved by 6 November, being the third country in Europe to achieve the milestone. Taking into account all the services worldwide, Norway was the eighth service to achieve this milestone.

Poland

One of three former Warsaw Pact countries, but geographically the largest as well and with the greatest requirement for new aircraft since its air force was numerically the strongest, Poland was the most interesting for NATO. As with the other former Warsaw Pact countries Poland was battling with admittance to NATO and the language difference. Their military had always trained with Russians and therefore had not needed English and so their communication systems were the first to be replaced. The air force was equipped with MiG-29 Fulcrums and many older fighters, such as the MiG-21 Fishbed, that needed replacement. Poland's economic situation forced a drastic cut in its forces. In 1997 the plan was to cut the forces by 25 per cent from 240,000 personnel. On 7 March Saab-BAE announced that an eventual partnership might include final assembly of Gripen aircraft for Poland at the PZL Mielec plant with engine assembly at Rzeszow. The original number of fighters to be replaced was reduced from 250 to about 100 multi-role fighters but, in July, Defence Minister Janusz Onyszkiewicz said that this was highly unlikely to be the total of fighters Poland was likely to acquire in the near future.

On 15 April a security agreement between Sweden and Poland was signed to speed up flight evaluation of the Gripen. Swedish Minister of Defence Björn von Sydow and his Polish counterpart signed the agreement. The two ministers talked about the Gripen. Björn von Sydow stated that if the tender for the next-generation aircraft was fair then the Gripen could speak for itself. Due to this agreement, Polish pilots could have flights in the two-seater: both cockpits have the same instrumentation, information on some of which is classified. Should Poland decide to buy the Gripen the agreement opened the door for future co-operation and partnership opportunities, possibly including high-value technology transfer to Polish industry.



Some of the Mig-29s in the Polish Air Force were bought directly from the Soviet Union but some were traded for helicopters with the Czech Republic. All of them needed replacing. (*Gérard Keijsper*)

On 18 April the Polish defence ministry announced that it would issue invitations to tender for 250 new multi-role fighters in October or November with selection due in May or June 1998. The plan was to procure the first ten to twelve aircraft as soon as the winner was announced, possibly under a leasing arrangement, but the remainder would not be ordered into production until late 2002 at the earliest. Contenders were the Dassault Mirage 2000-5, Lockheed Martin F-16 Fighting Falcon, McDonnell Douglas F/A-18 Hornet, MiG-29 Fulcrum and, of course, Gripen.

General Kazimierz Dziok Chief of the Polish Air Force took to the air for the first time in a Gripen aircraft with Reino Lidvik as the back-seat pilot on 18 November, becoming the third former Warsaw Pact chief of air force to fly the Gripen. BAe/DASA/Saab submitted a joint proposal to the Polish MoD autumn 1998 with solutions divided between immediate, short-term and long-term.



This Polish Sukhoi Su-22 Fitter is the oldest fighter in Polish Air Force service that required replacement. The Su-22 Fitter is a strike fighter which makes the F-35 a logical replacement. (*Gérard Keijsper*)



The Polish Air Force was quickly transforming from a Soviet era force to a modern western equipped force. (*Via Miroslav Gyürösi*)



The Italian F-35A flown over for the contract signature by the Polish Minister of Defence. (*Via Miroslav Gyürösi*)

Immediate option 1: The Polish Air Force's twenty-two MiG-29 Fulcrums to be extensively modernised, making use of DASA's experience, to the German Block III standard (NATO communications, IFF, data transmission ability by databus).

Immediate option 2: Groups of PAF pilots to undergo an extensive ten-week course in English military aviation in the UK, to include flights with 100 Squadron, paid for by the UK government.

Immediate option 3: Pilot training at Såtenäs in Sweden in Saab Viggen aircraft, or Gripens from 2000, with up to 1,000 flying hours per year available, costs to be met by the Swedish Government.

Short-term option 1: Procurement of twenty Hawk training aircraft from BAe, with assembly taking place at the PZL-Meilec plant and Adour engine production at the PZL-Rzeszow plant.

Short-term option 2: PAF Deblin Aviation Academy instructors to undergo advanced courses at the NATO flying training school in Canada, costs to be met by Poland.

Short term option 3: Extensive and better co-operation with the Polish defence and aviation industry.

Long-term: Proposed purchase of Gripen and Eurofighter Typhoon (the latter was unrealistic considering the financial situation of Poland) aircraft in return for Polish industrial participation in major European programmes.

In May 1999 the Polish government issued an Rf I for sixty new light fighter aircraft. Since the MiG-21s in service would have to be retired before the new aircraft was available a solution for this problem was also requested. The budget for the replacement programme was set at US$1.5 billion.

By September 2000 the commander of the Polish Air Defence and Aviation Force, General Andrzej Duleba, announced that the service lives of the ninety-eight Sukhoi Su-22 fitters would be extended. That life extension would mainly be a structural life extension to keep the type in operational service until 2010-2015. The only way this would affect the fighter tender would be in the budget available.

The French Defence Minister offered to shift the production of the Mirage 2000-5 Mk 2 fighter to Poland as part of a bid to win a Polish government contract for the sixty new fighters for which Dassault was bidding. The offer was made in December 2000, and included an undertaking that, if other countries in the region should decide to buy the Mirage, production for those countries could take place in Poland as well.

Even US considered it important to obtain the Polish deal and made an attractive offer to the Polish Air Force. Should the Polish government decide to buy twenty-nine F-16A/ Bs then the refurbishing of those aircraft could be done by Polish industry instead of Lockheed Martin. This offer was made by the end of March 2001 to make the overall deal more attractive as opposed to the deal from the Gripen joint venture company which was also offering second-hand Gripens for lease.



The Green Knights F-35Bs seen here at the Singapore Air Show 2018 was a small hint of the direction of interest of the Royal Singapore Air Force. (*Lockheed Martin*)

On 17 April 2001 Defence Minister Bronislaw Komorowski confirmed the intention to replace the old MiG-21s still in service with the Polish Air Force. The request for propositions was for the purchase, lease or transfer of sixteen aircraft by 2003 with a subsequent purchase of forty-four aircraft. Poland needed the sixteen fighters before 2003 to fulfil its commitments to NATO; about sixty were needed by 2006 for the same reason. The Polish Air Force had 114 MiG 21s, ninety-nine Su-22 Fitters and twenty-two MiG-29s in service. To be able to afford this Poland was to pass special legislation for financing the deal. The cost of the deal was calculated to be 0.05 per cent of GDP and everything was to be paid for by 2015. Offers were due by the end of May 2001 so that the government could make a selection by the end of July 2001. The sixty new aircraft were to be based at Krzesiny and Malbork Air Force Bases. All aircraft were to have air-to-air refuelling capability, LGB capability and fulfil all the missions requested by NATO, including the SEAD mission. A week later, on Tuesday 24 April 2001, the new law for the fighter acquisition was passed, opening the way for the tender to continue as planned.

Finally, on the night of 26 December 2002, it was announced that the winner of the tender was the Lockheed Martin F-16C/D. Dassault was very upset and said that Poland should have bought European after being invited to join the European Union. However, the defence minister denied that it

was a political decision, since there had been a tender process to prevent politics influencing the choice.

It was expected that Poland would buy a second batch of F-16s to replace its Su-22 strike aircraft. Its ageing MiG-29s were also due for replacement and again the F-16 was thought to be the affordable solution. Poland was the first post-communist country to make it known that it was interested in a fifth-generation fighter and did so on 20 February 2014 through Brigadier General Tomasz Drewniak, deputy commander of the Polish Air Force Inspectorate. While it was said that a fifth-generation fighter was desirable, the only fifth-generation fighter available in the west was the F-35.





The official roll-out more of a ceremonial hand-over. (*Lockheed Martin*)

On 28 May 2019 defence minister Mariusz Blaszcak reported that Poland had sent out a letter of request (LoR) to the US government for the purchase of thirty-two F-35A Lightning II fighter aircraft, including logistics and training packages. Poland was the first post-communist country to be granted the possibility of buying the F-35 by the State Department. DSCA announced that it had notified Congress of the possible sale. Negotiations could begin and Poland anticipated that a contract could be signed by the end of the year. Poland requested thirty-two F-35 CTOLs and thirty-three Pratt and Whitney F-135 engines. Also included were electronic-warfare systems and other elements from the list outlined in Appendix II (page 460). The estimated cost was US$6.5 billion. Polish officials hoped for a good discount as Poland is buffer country and one of the outer border countries of NATO. The F-35A would replace both the Su-22 and MiG-29 in service. Shortly afterwards, a decision was made that the Polish F-35s would be based at Lask Air Base. Training of Polish pilots was to take place in the USA but where was not clear since Luke was reaching capacity.



Detail of the F-35 during the ceremonial hand-over. (*Lockheed Martin*)



The first production F-35A for the ROKAF in flight. Note that there is no country roundel on the intake. (*Lockheed Martin*)



At Fort Worth the only identification is the title ROKAF on the tail. (*Lockheed Martin*)



The first polish F-35 lifted up to the first station where it would stand on its own wheels for the first time. AZ-01 is due for delivery in 2024. (*Lockheed Martin*)

Some countries have expressed interest in faster deliveries since the Russian invasion of Ukraine according to J.R. McDonald of Lockheed Martin, Poland being one. However, it was not possible to speed up the first delivery because of connected investments in training and infrastructure.

As the first F-35A delivery was due 2024 it was announced on April 29, 2024 that the first polish F-35A was lifted out of the Electronic Mate and Alignment Station (EMAS) earlier during the month but that the AZ-01 had now reached weight on wheels. This meant that it was at the beginning of the mile long assembly line. The place of polish pilot training was also revealed as the Ebbing Air National Guard Base, Arkansas. The first F-35A was due to be delivered there later during 2024 but delays with the TR-3 hardware and related software which were also causing delays with the Belgian F-35As was according to some sources something that could delay delivery into 2025.

Portugal

One of the nations in Europe that operates the F-16 is Portugal. As an F-16 operator the F-35 was seen as the logical step as a replacement. Portugal did

not join the Joint Strike Fighter program as partner. Just like Belgium it remained outside the program and if it would be interested Portugal intended to buy of the shelf. Gen. João Cartaxo Alves, chief of staff of the Portuguese Air Force acknowledged November 2023 that the F-35 would be the logical replacement of their F-16 inventory but it remained to be seen when this would also be politically enacted upon. The Portuguese F-16 had received their Mid Life Update from 2003 onwards bringing it up to block 50 capability. Portugal was in the process of acquiring the Brazilian Embrear C-390 and some even thought due to the language connection Portugal might go for the Gripen E/F although this seemed far fetched.

Romania

Romania was a former Warsaw pact country that had suffered immensely economically like most Warsaw pact countries. To maintain the Romanian Air Force (Forţele Aeriene Române) credible it decided to upgrade its Mig-21 that it had in large quantities in its inventory. These Mig-21 were upgraded by Romanian industry in collaboration with Israeli Elbit systems. In 2013 the first western fighters were acquired. 12 second-hand F-16F-16 A/B Block 15 MLU fighters from Portugal entered service with the Romanian Air Force. Six years later Romania bought another five F-16s from Portugal.

Romania announced in December 2021 the decision to buy some more second-hand F-16s but this time from Norway and in larger numbers. This deal was announced at a time that the USA was warning the rest of the world that Russia was preparing to attack Ukraine, a neighbouring country for Romania. A deal was signed with Norway almost a year later, on 4 November 2022, for 32 F-16s A/B Block 20. These F-16s would replace the Mig-21 Lancers in service with the Romanian Air Force in 2023.

On 2 February 2022 the war in the Ukraine had not yet begun but this time the President of Romania Klaus Iohannis stated that Romania wanted to buy the fifth-generation F-35. On 11 April 2023 the acquisition of F-35s was approved by the Romanian Supreme Council of National Defense. Deliveries of F-35s was expected in the 2030s. The Mig-21 Lancers were indeed retired by the middle of May 2023 making the Romanian Air Force one of longest operators of the Mig-21.

Singapore

On 23 February 2003 it was announced that Singapore was considering joining the SDD phase of the JSF programme. This was seen as a slap in the face for the competition since Singapore was expecting to replace its A-4SU Skyhawks by 2007; it was now uncertain if there would be any competition at all. Besides its A-4SU Skyhawks, the Republic of Singapore Air Force (RSAF) had Northrop Grumman F-5S/Ts and F-16s but wanted to reduce the number of types in its inventory. The F-16 was thought to be in a very favourable position since the air force was to take delivery of twenty Block 52 F-16s from December 2003.

In February 2004 Singapore signed a letter of intent to join the SDD phase of the JSF and, on 16 March, signed a bilateral agreement with the US to become a partner in that phase. The letter of offer and acceptance (LOA) made Singapore a security co-operation partner (SCP) with the opportunity to buy the F-35 from 2012. In addition, the RSAF would be able to perform studies for integrating their requirements. Singapore, however, required aircraft from 2008/9 and it was unclear if it still intended to buy an interim fighter, for which it had pre-selected the Eurofighter Typhoon, Dassault Rafale and the Boeing F-15T. The RSAF selected the F-15SG as the latest addition to the inventory; it was similar to the South Korean F-15K Strike Eagle version with a different choice of radar. The Republic of Singapore Air Force F-15SG Strike Eagles were equipped with Raytheon's APG-63(V)3 active electronically scanned array (AESA).

When it was expected that the RSAF would select the F-35, it opted instead to upgrade its F-16 fleet, an upgrade involving avionics and one of the available AESA radars, SABR offered by Northrop Grumman or RACR by Raytheon. The upgrade was seen making the avionics suite as compatible as possible with the future acquisition of the F-35. The F-35 visited Singapore for the first time when two F-35Bs from the USMC Green Knights attended the Singapore Air Show in 2018. On 28 February 2019 Singapore announced that it would acquire a small number of F-35s to evaluate the aircraft against the requirements of the RSAF to replace the F-16. The version to be evaluated was not confirmed although many sources speculated that it might be the F-35B. Although it was announced that four F-35s would be acquired for evaluation, no information was given on RSAF's total requirement.

On 9 January 2020 the Defence Security Co-operation Agency announced that Singapore had requested to buy up to twelve F-35B STOVL aircraft (four F-35B STOVL aircraft with the option of another eight) and up to thirteen Pratt and Whitney F135 engines (including an initial spare). Also included are electronic warfare systems; command, control, communication, computers and intelligence/communication, navigation and identification (C4I/CNI) system as well as a package of other support systems, tools and test equipment, personnel training and training equipment.

Singapore had ordered four F-35Bs for evaluation purposes which should enter service from 2026. As the original requirement was for 12 aircraft an option for the remaining eight was taken. The fact that Singapore is one of the few nations in the area without territorial disputes makes it an exception. The country is reliant on free trade and for this reason the Republic of Singapore Air Force has quite a formidable force. As a Security Co-operation Partner since 2003, it has been following the F-35 programme but surprised many by selecting the F-35B instead of the F-35A. The evaluation will take place in the US. No other information has been divulged but it is clear that during Pitch Black, staff of the Republic of Singapore Air Force responsible for the replacement programme were closely watching the operations of both the USMC F-35Bs and RAAF F-35As. The option for the remaining eight aircraft was committed to on 24 February 2023.

The Republic of Singapore Air Force will also get 8 F-35As it was announced 28 February 2024. Training of the Singapore pilots would take place at Ebbing Air National Guard base. The training of Singapore F-16 pilots was moved from Luke AFB to Ebbing Air National Guard base and the F-35 pilots would join them there in 2026 consolidating the training of pilots in one place.

South Korea

The Korean War from 25 June 1950 to 27 July 1953 was the first war where most air battles were fought by jet aircraft. Officially the war has never ended although an armistice was signed in 1953. Ever since then the United States has had a presence in South Korea and as the main defence partner was also the principal supplier of military aircraft to the Republic of Korea

Air Force (ROKAF) which has been equipped with F-4 Phantoms, F-5 Freedom Fighters, F-16 Fighting Falcons and F-15 Eagles. The last addition to the ROKAF inventory was the F-15K under the F-X programme, an export version of the F-15E Strike Eagle. The F-X programme ran in different phases: under phase I sixty F-15Ks were procured in 2002 while phase II saw another twenty-one F-15Ks purchased. In 2012 the F-4 Phantom was to be replaced and South Korea was considering buying up to sixty new fighters under phase 3. The tender was expected to be fought out between the F-35, F-15 Silent Eagle and Eurofighter Typhoon. However, since the Japanese had committed to the F-35, many believed that South Korea would be the next F-35 customer.

The Republic Of Korea Air Force (ROKAF) operated the F-4 Phantom in different roles: 131st Tactical Reconnaissance Squadron was flying seventeen RF-4C Phantoms; 151st Fighter Squadron was flying F-4Ds and 152nd, 153rd and 156th Fighter Squadrons were flying F-4Es.

Political stability on the Korean peninsula was disturbed by the northern neighbours. North Korea's relatively fresh heir to dictatorship was trying to impress the world with wild rhetoric and a threatening posture against his southern neighbours and the possibility of war did not seem far away. North Korea went as far as to tell foreigners in South Korea to leave South Korea. Borders were closed, even the border between North Korea and China. During these times DSCA announced, on 2 April 2013, the possibility of the sale of either sixty F-15 Silent Eagles or sixty F-35 Lightning IIs. The technical descriptions in the announcements were:



Just like the Japanese pilots, the South Koreans pilots received their training with the 944th Operations group Detachment 2 the Ninjas. (*USAF*)



The first Republic Of Korean Air Force pilot flying out of Luke AFB. (*USAF*)

The Republic of Korea has requested a possible hybrid case in support of sixty F-15 Silent Eagle aircraft being procured via Direct Commercial Sales (DCS). The proposed sale will include sixty active electronically scanned array radar (AESA) radar sets, sixty digital electronic warfare systems (DEWS), sixty AN/AAQ-33 sniper targeting systems, sixty AN/AAS-42 infra-red search and track (IRST) systems, 132 ultra-high-frequency/very-high-frequency (UHF/VHF) secure radio with HAVE QUICK II, sixty-nine Link-16 terminals and spares, the Advanced Display Core Processor II, joint mission planning system, various support equipment items, GEM-V GPS airborne receiver module, and communication security; software development/integration, spares and repair parts, personnel training and training equipment, publications and technical documents, US Government and contract engineering and logistical personnel services, and other related elements of logistics and programme support. The estimated cost is US$2.408 billion.

The Government of the Republic of Korea has requested a possible sale of sixty F-35 … CTOL aircraft. Aircraft will be configured with the Pratt and Whitney F-135 engines, and nine Pratt and Whitney F-135 engines are included as spares. Other aircraft equipment includes: electronic warfare systems; command, control, communication, computer and intelligence/communication, navigational and identification (C4I/CNI); autonomic logistics global support system (ALGS); autonomic logistics information system (ALIS); full mission trainer; weapons employment capability, and other subsystems, features, and capabilities; F-35 unique infra-red flares; re-programming centre; F-35 performance-based logistics. Also included: software development/integration, aircraft ferry and tanker support, support equipment, tools and test equipment, communication equipment, spares and repair parts, personnel training and training equipment, publications and technical documents, US Government and contractor engineering and logistics personnel services, and other related elements of logistics and programme support. The estimated cost is US$10.8 billion.

The wide cost variation was the most shocking difference since the F-35 was supposed to be affordable. The difference, although breathtaking at first glance, was because Boeing’s bid not include the aircraft itself, at an estimated US$100 million each which would add about US$6 billion to the

$2.408. Boeing had reason to think that it had a good chance to win the competition with its F-15 Silent Eagle bid since there was still a 20 per cent cost advantage. A comparison of life cycle cost (LCC) was on the side of the Lockheed Martin F-35 although, at the time, it was stated that the F-35 life cycle cost (LCC) was higher than the F-16 or F-18. Both variants were thought not to alter the basic military balance in the region. The South Korean government set a financial ceiling and contenders had to comply with their bids to have a chance to win phase 3 of the F-X programme. Three bids were received but, since the F-35 bid did not come under the ceiling, it was eliminated, as was the Eurofighter Typhoon, leaving the sole contender as the Boeing F-15 Silent Eagle. South Korea, however, did not want the Silent Eagle and the process to procure it altered. It was decided instead that forty F-35s would be acquired. On 24 September 2015, South Korean Minister of Defence Han Min-koo had a meeting with DAPA to approve the acquisition of forty F-35A fighters. South Korea wanted the aircraft delivered between 2018 and 2021. A letter of offer (LOA) and acceptance with South Korea was signed on 30 September. South Korea wanted technology transfer in the deal, but was denied by the US government. South Korea required the technology as they wanted to develop their own stealth fighter, the KF-X, which would be delayed since the technology would have to be bought elsewhere or developed in house. The technology transfer was related to:

1. The active electronically scanned array (AESA) radar,
2. Infra-red search and track (IRST),
3. Electro-optical targeting system (EOTS)
4. Radio-frequency (RF) jammer

All are considered critical in the development of high-tech fighter jets. The request was reiterated and again denied, fuelling criticism in South Korea about the selection of the F-35.

The decision to acquire the F-35 was evaluated since corruption was insinuated with Korean Aerospace Industries raided by investigators as widespread corruption was suspected. It was not only the F-X III programme that was under scrutiny but some other high-tech programmes, such as development of the KFX fighter and the KUH-1 Surion utility helicopter programme.

The Korean peninsula was going through some difficult times with North Korea trying to flex its muscles by firing intercontinental missiles, performing nuclear tests and threatening countries as far away as the USA with extinction. Tensions were high and the added problem of the corruption investigations made it necessary to send a positive message, for which reason two F-35s from Hill AFB departed for the Seoul Aerospace and Defense Exhibition (ADEX) Air Show at Seoul International Airport. The first Korean F-35s would be delivered under LRIP 1; six of the total of forty were due for delivery under LRIP 10.

Although none of the F-35s ordered by South Korea had been delivered, it was announced that South Korea was already looking into expanding its F-35 fleet. A major reason for this was heightened tensions between the USA and North Korea as in 2017 international sanctions were mounting on the latter. The first South Korean F-35 had its maiden flight on 20 March 2018 from Lockheed Martin's facilities at Fort Worth. Eight days later there was a ceremonial roll out as the beginning of a new era was celebrated at Fort Worth with invited guests from the US and South Korea. F-35s would arrive in South Korea in 2019 at ROKAF main operational base at Cheongju.

However, the first aircraft moved to Luke AFB, where it joined 944th Fighter Wing Det 2 where the next milestone for ROKAF took place when their first pilot, Major Kiyun Jung, flew his first solo flight in the first ROKAF F-35 on 20 July 2018. Major Kiyun Jung had prepared for the flight through months of intensive academic, simulator, and hands-on training with the 944th Det. 2 and 56th Fighter Wing.

'I felt so excited for this flight, and because of my instruction, this aircraft felt familiar and I was able to have a smooth experience,' said Jung. 'This is my job and it felt great to finally take off and work on becoming the best F-35 pilot I can be. My goal moving forward as an F-35 pilot is to lead and teach my fellow pilots in Korea to become the best in the world.'

It did not take long as the first two ROKAF aircraft were delivered to South Korea. ROKAF tail numbers 18-005 (15-5225) and 18-006 (15-5225) arrived on 29 March 2019 at Cheongju, 140 kilometres south of Seoul, at 2: 35pm local time, delivered by two American pilots from 944th Operations Group Detachment 2 'Ninjas' who departed Luke AFB on Friday 22 March to arrive in South Korea a week later. The South Korean air force base became the seventeenth base in the world to receive the F-35 and another

eight aircraft were to be delivered during the same year which seemed aimed at an IOC in 2019. North Korea stated that the procurement of the F-35 risked putting the peace process between the two countries in jeopardy. The National Assembly Audit that took place on 7 October 2019, however, announced that South Korea were interested in acquiring another twenty F-35s as well as continuing to develop their own fifth-generation stealth fighter, designated KF-21.

Spain

Although not a partner in the JSF programme, Spain was seen as an inevitable JSF customer for the simple reason that it operated EAV-8B Harriers, or Matadors as they are called in the Spanish Navy, in its inventory as well as the F-18 Hornet. Spain was, however, like Italy, also a partner in the Eurofighter programme and the UK and budgetary limits could change the situation. A big question was whether Spain's politicians believed they could afford STOVL capability in their air force. Spain was briefed by Joint Programme Director Rear Admiral Craig E. Steidle and USAF principal deputy, Office of the Assistant Secretary of the Air Force (Acquisition), George K. Muellner, the previous JPD. Although the 2012 delivery date would be firmed up with the signature of another LoA in the 2007-08 timeframe, the 2012 delivery date could slip. The financial crisis that hit the world affected Spain a bit harder and, combined with delays in the development programme, made Spain an unlikely customer until about 2020. Selection was due by the end of June 2013 but was delayed; there followed a relatively long silence. Rumours started that the process would be repeated which was confirmed in October 2013. Talks were taking place but nothing more was really happening. However, the urgency was ever increasing as the EAV-8Bs acquired for the Spanish Navy from October 1987 were ageing rapidly and had already undergone an upgrade from 2003. The upgrade was performed only on five EAV-8Bs, to the EAV-8B+ standard. The Spanish Air Force was even worse off since their seventy-two F-18s were delivered between 1985 and 1990. The Spanish F-18s were due to be retired by 2025 and a combined buy for the Spanish Navy and Air Force was hoped for by Lockheed. The fact that Spain had signed on to the German/French Future Combat Air System as an observer could change the expected size of the purchase, however.



The Spanish Navy is operating the EAV-8B Harrier here seen at Fairford 2023 with an English F-35B. The fact that Spain operated the EAV-8B made it automatic target country for the JAST and later JSF programme. (*Tony Bending*)

As it was a matter of time, the EAV-8B had to be replaced and the only aircraft that could operate off the *Juan Carlos* carrier, other than the Harrier, would be the F-35B. Spain issued a request for information for fifty F-35s on 4 November with twenty-five of those standard F-35As for the *Ejército del Aire* (EdA, or Spanish Air Force) and twenty-five F-35Bs for the *Armada Española* (Spanish Navy). The *Juan Carlos* has a flight deck length of 201.9 metres (663 feet) and is officially classed as a landing helicopter dock (LHD). The *Juan Carlos* was commissioned on 30 September. As with the Royal Navy's Invincible-class carriers, the *Juan Carlos* (L61) has ski-jump with a 12-degree angle. Target date for service entry was 2027. The F-35B would, as expected, replace the EAV-8B Matadors with Eslla 009 at Rota. As Spain had sixty-four operational F-18s in the *Ejército del Aire* inventory, it was not clear which unit would be replaced. Some F-18s were expected to be replaced by Eurofighter Typhoon in the long term.

Switzerland

Switzerland's partial F-5 Tiger replacement was too early for the F-35 because of delays in the development programme; the Swiss selection in 2012 was from Eurofighter, Dassault Rafale and Super Gripen. Although

Rafale came out on top in the technical evaluation, budget realities meant that the Super Gripen was selected instead, to the very public displeasure and annoyance of Dassault. That the Gripen was chosen for the partial Tiger replacement was not really a problem since the F-35 did not compete in the tender process but was very likely to be invited for any future tender. However, the Swiss selecting the cheapest option did not bode well for the F-35 in future tenders. The timeline for replacement of the F-18 Hornet was not then known but that would be the first opportunity for the F-35. As it happened the Swiss citizens denied Saab of its first European deal for the next generation Gripen in the 2014 referendum. The requirement to replace the Tiger did not disappear or dissolve, in fact Swiss defence minister Guy Parmelin announced 24 February 2016 that the refused deal for 22 Super Gripen made for greater urgency than before as the fleet of F-18s also required replacement. The F-18 had a technical life expectancy till 2025, if these were expected to serve longer then that would require an investment as well.

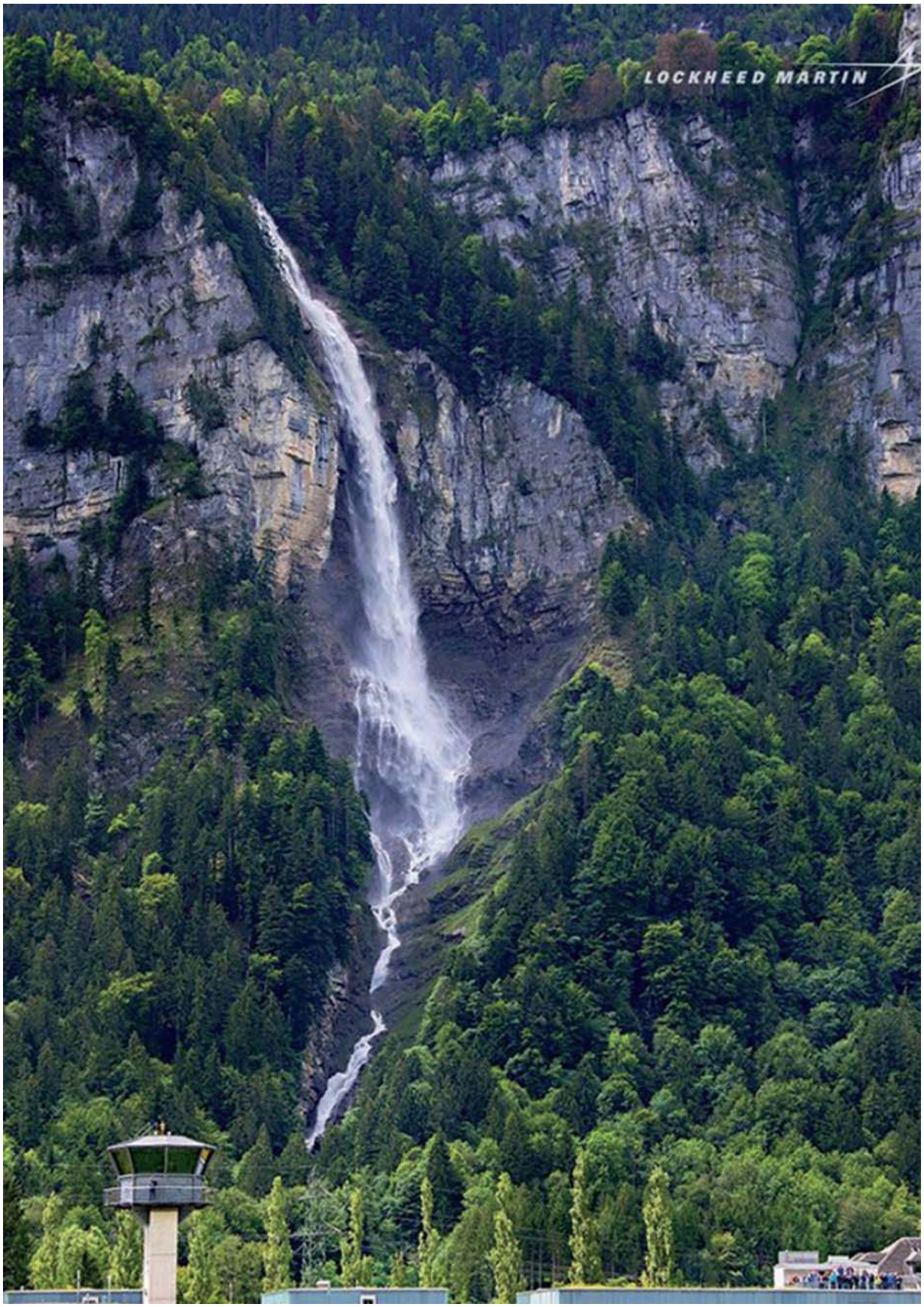


The Swiss Air Force flies the F-18 and the F-5E Tiger. Both require replacement, the F-5E more urgently. Lockheed believed after successful campaigns in Belgium, Denmark, the Netherlands, Norway and Poland, Switzerland would follow.



The last of the four aircraft types that visited Payerne for the evaluation. (*VBS DDPS*)

Following a study, a new evaluation was announced on 8 April 2019. The evaluation would include a flight evaluation in country; previously the Rafale had won that evaluation. Five aircraft were to be evaluated in Switzerland for the *Neues KampfFlugzeug* (NKF) project. The timeframe for the trials was also announced:


LOCKHEED MARTIN



The F-35 in Switzerland, the environment of operation is amazing. (*Lockheed Martin*)

	Type	Date of evaluation	Planned night flight (Reserve date)
1	Eurofighter Typhoon	Weeks 15 and 16	15/04/2019 (16/04/2019)
2	Boeing F-18E/F Super Hornet	Weeks 17 and 18	29/04/2019 (30/04/2019)
3	Dassault Rafale	Weeks 20 and 21	20/05/2019 (21/05/2019)
4	Lockheed Martin F-35A	Weeks 23 and 24	06/06/2019 (11/06/2019)
5	Saab Gripen E	Weeks 25 and 26	26/06/2019 (27/06/2019)

The in-country evaluation would be a first for the F-35. Very few countries required this sort of evaluation before buying the F-35. The requirement was for forty aircraft that would replace both the F-5 Tiger and F-18 Hornet. As soon as the replacement came into service the F-5 would be retired, so that at no time would there be a need to operate three different types of aircraft. The evaluation would have the same or very similar requirements as the previous Tiger replacement programme.

As a requirement of the Swiss constitution (Switzerland is a confederation of cantons), a referendum would also be held so that the general public could approve or disapprove of the deal. The referendum was planned somewhere in 2020 but the selection would not be known so a recurrence of Saab engaging with marketing in country should not happen. Another side of the story was that the people would not know which aircraft was going to be selected and therefore could not vote on selection as had happened in the previous round.

The first contender, the two Eurofighter Typhoon departed from Warton and arrived in Payerne on 9 April 2019 and were planned to depart on the 17th. Boeing sent two Super Hornets to Payerne which arrived on the 25th. Swiss evaluation of the Super Hornet took until 6 May. The French sent two Dassault Rafales which arrived at Payerne on 16 May and were due to depart on the 27th, a total of ten days for their evaluation. Four F-35As from the Rude Rams 34th Fighter Squadron arrived at Payerne, all from LRIP VII (they were 13-5077, 13-5079, 13-5081, 13-5083). A nice touch

was that at least one of the pilots was a female, Captain Kristin 'BEO' Wolfe, the next USAF demonstration pilot.

A request for proposals was issued by the *Armasuisse* in January 2020 and was sent out to the four contenders. Replies to the Rf P were due in August 2020 but this was delayed to November due to the worldwide COVID-19 pandemic. Before making a decision on which contender would gain the order, the Swiss held the referendum on 27 September 2020 to obtain agreement from the population to proceed with the acquisition of a next-generation fighter to replace the F-5E Tiger and F-18C/D. Unlike the previous referendum, in which the Saab JAS 39 Gripen NG had been selected, the F-35 gained approval. Approval was gained with 50.14 per cent of the national vote. The winning margin equated to fewer than 9,000 votes from a total of around 3.2 million with a turn-out of 59.4 per cent.

On 30 September 2020 DSCA announced the possible sale of up to forty F-35As. The request from the government of Switzerland also included engines, munitions, electronic warfare equipment and support and training elements. (Appendix II on page 460 outlines what was available to buyers). The total estimated cost was US$6.58 billion.

Although this was just an announcement and a decision by the government of Switzerland had not been made, DSCA also announced a similar possible sale for the Boeing F-18E Super Hornet. Interestingly, the total estimated cost of thirty-six F-18Es and four F-18Es, including weaponry and support equipment, was higher at US$7.452 billion.

Another interesting point of the announcement was that, as with all the previous announcements, it included the autonomic logistics information system (ALIS), the point being that the USAF had already decided upon replacing ALIS. The operational data integrated network (ODIN) was to be the replacement and would be introduced by December 2022. Delivery of the Swiss aircraft was not expected before 2024 and therefore could be delivered automatically with ODIN. Lockheed further announced that it offered Switzerland the chance of assembling four of the forty F-35As in Switzerland.

After a short delay the *Armasuisse* announced the results of the *Neuen Kampfflugzeugs* (New Combat Aircraft) evaluation: the F-35 was technically the best option at the lowest operational cost. The Swiss would buy thirty-six F-35s for the Swiss Air Force to replace both the F-5 Tiger and F-18C/D fleet and become the eighth European operator and fifteenth

country to obtain the F-35. The four criteria on which *Armasuisse* evaluated the contenders were:

Effectiveness: 55%
Product support: 25%
Co-operation: 10%
Direct offset: 10%

With 336 points, the F-35 showed the highest overall benefit and was the clear winner with a lead of 95 points or more over the other candidates. This aircraft scored best in three of the four main criteria evaluated.

These criteria and the weight of the criteria were made known beforehand to all contenders. The request for proposals of approximately 600 pages was divided into three parts. The first part dealt with project requirements and the project scope; the second was the question book (there were roughly 2,000 questions asked of each contender and their replies were evaluated by technical subject matter experts, validated and assessed by means of audits, tests and analysis). The third part included the price tables connected to the acquisition not only of the F-35 but also for logistics, armament and training. These price tables were again connected with the results of the two other parts of the request for proposal.

Time frame of the Swiss tender

- 06 July 2018: the first request for proposals sent out to the candidates
- 25 January 2019: handover of the first replies under notarial oversight
- 10 January 2020: final and best offer request to the candidates
- 18 November 2020: handover of the second and final offers under notarial oversight

The results of the second final offers could be negotiated. During visits to the manufacturing countries in January 2021, the armaments chief asked all candidates to confirm to *Armasuisse* within two weeks of the visit that the offer of 18 November 2020 was their last and most advantageous offer (‘Best and Final Offer’). Alternatively, all candidates were given the opportunity to optimise their offers within the same period and, in this case, confirm that this was the last and best offer without compromising the scope of services offered.

The handover of the documents by the candidates to *Armasuisse* and the opening of the offers on 11 February 2021 again took place under notarial supervision. Finally, in May 2021, the candidates were asked to offer an updated payment plan in accordance with the *Armasuisse* requirements, without otherwise adjusting their offers. The corresponding answers from the candidates were received under notarial supervision on 2 June 2021. The decision was originally due by 22 June but was delayed. Nevertheless, rumours broke that the F-35A had come out on top. The official decision was announced on 20 June.

A petition was started in Switzerland against the F-35 acquisition, similar to the petition against the Gripen. Other news reports were about the cost of operation and the figures supplied; it was even reported that the Swiss were asking the Norwegians to supply them with independent data.

Taiwan

Taiwan was in an unfortunate situation as an independent state seen by China as a disobedient province that should return under Chinese mainland rule. Taiwan has an air force equipped with older Lockheed Martin F-16As and F-16Bs and even severely ageing Northrop F-5 Tigers. As export of weapons had in some instances been uncertain due to US/China/Taiwan relations, it developed its own indigenous fighter. The twin-engined AIDC F-CK-1 Ching-kuo had its first flight on 28 May 1989 and so should be considered a fourth-generation fighter. It was originally planned that the AIDC F-CK-1 Ching-kuo would have a production run of 256 aircraft which was reduced to 130 as Taiwan was allowed to purchase 150 F-16 Block 20 A/B and sixty Mirage 2000-5Ei/ Di. That power games between the US and China still influenced the policy on weapons export to Taiwan was proven by the fact that the Obama administration was trying to keep both happy.

Taiwan is a country eager to get its hands on the F-35. It is a small country (13,974 sq miles) and has very few diplomatic ties with other countries. Many other countries do not want to upset China by connecting with it, including the US. China has talked up its intentions recently to reunite with Taiwan, even if that means doing so by force. Taiwan would probably have no problem financing the F-35 as such. However, there is doubt that they could successfully prevent an invasion and it could be too

late for allies to react. If a Chinese invasion was successful, the technology would fall into the hands of the Chinese and so it is unlikely that the US will risk providing Taiwan with the F-35. Under the Trump administration, Taiwan was permitted to acquire the Lockheed Martin F-16V.

Thailand

The Royal Thai Air Force (*Kong Thap Akat Thai*) operated a mix of fighters, including the modified F-5E/F, a couple of squadrons of F-16s and eleven Gripens. In 2013 it was thought that the Royal Thai Air Force was happy to buy more Saab Gripens but this was postponed. An article in the *Bangkok Post* announced the intention to buy the F-35 instead of the Gripen. The commander-in-chief of the Royal Thai Air Force, Air Chief Marshal Napadej Dhupatemiya, was quoted as having interest in buying eight F-35s, believing that, through negotiations, they could get the price down to US$70 million – unlikely since the unit cost had come down to US$82 and was about to stabilise around that figure. According to the commander-in-chief, the Gripen would come at a cost of US$85 million. It was not clear which version he was talking about because there have been media reports that the Gripen E was costing over US$100 million. A batch of eight aircraft seems small but the Royal Thai Air Force had bought their twelve Gripens in two batches of six, since then losing one during an air display, unfortunately killing the pilot on 14 January 2017. Thailand expressed an interest in buying the F-35 and made the necessary budget appropriations to acquire two. The usefulness of two F-35s in an operational context is questionable and it remains to be seen if the USA would grant the request, especially in light of the Thai relationship with the Chinese which might be considered too close for the stealth aircraft to be released to Thailand.

Turkey

The Turkish Air Force (*Türk Hava Kuvvetleri*) was careful in buying only aircraft originating from the United States of America. Fighter aircraft in service were:

Combat aircraft	**Start Service in TuAF**

F-4 Phantom II	1974
F-5 Freedom Fighter	1965
F-16 Fighting Falcon	1987



The painting for Turkey with the bridge over the Bosphorus. Something that at the current rate in 2020 looked more like science fiction. (*Lockheed Martin*)



Türk Hava Kuvvetleri planned on using the F-35 together with their F-16s of which the oldest were reaching 35 service years. (*Gérard Keijsper*)

A NATO member that was long considered one of the poorer members and therefore supported with donations of F-5s from the RNLAF at the time they were retired. Turkey, however, was also a customer for F-16s that would at some time need replacement. Besides the F-16, the McDonnell Douglas F-4 Phantom II and the F-5 Freedom fighter were also soldiering on and could also be replaced by the new JSF. Turkey's air force was impressive in size and was mainly maintained due to its longstanding problems with its close neighbour Greece. All three types of combat aircraft could be considered ripe for replacement by the JSF.



Turkish industry team made a joint effort to gain F-35 business. (*Turkish team*)

On 16 June 1999 Turkey signed a letter of agreement (LoA) regarding joining the CDP for a total of US$6.2 million. Turkey would join under the Foreign Military Sales programme, similar to that formed for Singapore. Turkey was the second country to join as a fourth-level partner and was the eighth to join the JSF programme in total. Impressive air force development and the need to replace the approximately 200 F-4 Phantoms, assured Turkish participation in the SDD phase. Furthermore, Turkey planned to replace early F-16s by the JSF as well. After the F-4s had been replaced the plan was to have only JSFs and F-16s of the Blocks 40 and 50 standards in

the Turkish Air Force. Turkey signed the MoU on 11 July 2002 for level-3 partnership in the SDD phase with an investment of US$175 million. Originally, Turkey had hoped for level-2 partnership which proved too costly. Turkey was the last country to receive their first order in connection with the JSF work and the Turkish government complained about the return on investment by June 2003 as returns were slow in coming in.

Although the work participation improved there was still room for improvement. The Eurofighter Typhoon sales team saw a chance and tried to offer its aircraft to fill another requirement; if the aircraft was deemed a success then it might eat away from the JSF requirement. Lockheed had reason enough to be worried by the effort as two Turkish pilots flew the Eurofighter Typhoon in Italy in early 2005. According to some press reports an off-set package was offered to Turkey to counter the Eurofighter offer. The Turkish Air Force was considering several options, either a force of Eurofighters, a mix of Eurofighters and JSF, or only JSF.



Turkey wants to develop its own fifth-generation fighter with weapons and displayed this with a mock-up at Paris Le Bourget. (*Gérard Keijsper*)

In late October 2006 it was reported that the Turkish Air Force preferred to receive only JSF. It was up to the politicians to make the final decision as the date for the PSDF signature was fast approaching.

Turkey became the second non-English-speaking partner to sign the PSFD. Deputy Secretary of Defense Gordon England and Turkish Minister of National Defence Vecdi Gonul signed the PSFD MoU in January 2007. The estimated procurement amount of aircraft per fiscal year by Turkey was

determined in the PSFD document with delivery approximately two years after contract signature.

Fiscal Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Amount	10	10	10	12	12	10	10	10	10	6	100

Turkey was a country that was having some problems internally, including a coup attempt which was later used to purge the military. There were concerns that it was a risk to release the F-35 to Turkey. On the other hand, Turkey was also stating that they wanted to develop their own air-to-air stealth fighter to complement the F-35. They saw the F-35 more as a strike platform than an air-to-air fighter. Turkey signed up to the F-35 with its first order in LRIP 10, under which it would take delivery of its first two F-35s.

Turkey was also acquiring the S-400 long-range surface-to-air missile (SA-21) Growler from Russia which was cause for concern not only to the USA but also some of its NATO allies. The first F-35s for the Turkish Air Force were due to fly in the second quarter of 2018. Turkey was acting against the Kurds in Syria and Iraq and as such against the interests of the USA in those countries. An American was held in Turkey accused of supporting the Kurdistan Workers' Party. Several bills were introduced to stop delivery of the F-35 and its technologies. In the meantime, preparations for first flight and delivery ceremony were going ahead. The first flight of the Turkish F-35 took place on 10 May 2018 and, although the rhetoric out of Congress was increasing and appeals were sent to defence secretary Matis, the roll-out ceremony of the first Turkish F-35 was going ahead just as planned on 21 June. There were even defiant replies from Turkish officials prior to the roll-out to the suggestion that the F-35 hand-over should be delayed. The roll-out was quite surreal in the sense that Lockheed Martin was celebrating great relations with Turkey, while Congress members were questioning the US-Turkey relationship. The first aircraft was due for delivery to Luke AFB, where the training of pilots from the *Türk Hava Kuvvetleri* would take place. The first two Turkish pilots were already training at Luke AFB at the time of the roll-out. The first aircraft to be transferred to Turkey were due to be delivered in 2019. Congress succeeded in putting a temporary ban on F-35 deliveries to Turkey; the

Pentagon had to deliver an extensive report on three subjects that could affect the operational safety, mainly of the F-35 but not only the F-35.

1. The Turkish acquisition of the Russian S-400 surface-to-air missile defence system and the effect of that acquisition on the relationship between Turkey and the USA.
2. The effect of the S-400 and the safety of other American-made aircraft systems in operation with the Turkish Air Force, such as the F-16, the Black Hawk, Apache and Chinook. The steps required to mitigate those risks were to be presented as well.
3. Turkey was a partner in the Joint Strike Fighter and, therefore, a supplier. Sho uld Turkey be banned from buying the F-35, an examination of the consequences for the US and other partners would be necessary.
4. Industrial participation included:
    - Turkish Aerospace
        - Air Inlet ducts
        - Central fuselage
        - Pylon and adapter
        - Central-fuselage metallic components
        - Central-fuselage composite components
    - Aselsan
        - CNI Avionics Interface Controller (CAIC) module
    - Kale aero
        - Airframe parts
        - Assemblies door-up locks
        - Landing gear-up lock assemblies
    - Kale Pratt & Whitney
        - Engine components
    - Havelsan
        - Integrated Pilot and Maintenance Training Centre support
    - Ayesas
        - Panoramic Cockpit Display
        - Missile remote interface unit card
    - ALP aviation
        - Landing-gear components
        - F135 rear hub
        - F135 titanium Integrally Bladed Rotors (IBR)

  - F135 NI Integrally Bladed Rotors (IBR)
  - Fuel-pump components
  - Brake-system components
  - Structural components
- TEI is the main contractor to set up the following facilities:
  - F135 engine maintenance and repair facility
  - F135 engine final-assembly line
  - F135 T-11 test cell

In the meantime, it was announced that the third and the fourth F-35s destined for Turkey were ready for delivery in March 2019. Production of the F-35 went ahead as planned and the two new aircraft for the Turkish Air Force were flying in early 2019 with first deliveries to Turkey planned for late 2019. As Turkey was deemed to be uncompromising in its stance to acquire the Russian S-400 air-defence system and even threatened that, if the F-35s were not to be delivered, they would withhold strategic parts and thus make production of the F-35 impossible. It was clear that withholding the parts would disrupt production but the assertion that those parts could only be made in Turkey was well away from reality. On 28 March 2019 Senators James Lankford (R-OK), Jeanne Shaheen (D-NH), Thom Tillis (R-NC) and Chris Van Hollen (D-MD) introduced a bill to prohibit the transfer of F-35 JSF aircraft to Turkey until the US government certified that Turkey would not accept delivery of Russia's S-400 air-defence system. A bill was included as an amendment in the FY2019 National Defense Authorisation Act (NDAA) directing the Secretary of Defense to submit a plan to Congress to remove Turkey from participation in the F-35 programme.

News broke on 2 April that parts delivery to Turkey had stopped because of the acquisition of the Russian S-400 air-defence system. As the set date for delivery of the S-400, July 2019, was approaching and Turkey was making no attempts to actually overcome the problems but throwing oil on the fire by saying that the delivery of the S-400 system could be earlier than the original date, the US gave Turkey a deadline which would expire by the end of the first week of June 2019, by which time it should have cancelled the S-400 deal or would face being thrown out of the F-35 programme; other undefined sanctions would follow. To ensure that the S-400 deal would not simply be delayed, Turkey would have to buy Raytheon's Patriot

system instead. At this time four Turkish F-35s were flying out of Luke AFB and the next two were close to rolling off the production line for delivery to Turkey in November.

Once it became clear that there was to be no reconciliation on the acquisition of the S-400 IADS, the training of Turkish crews was stopped. It took time to replace all Turkish sub-contractors for the F-35. According to the GAO the last parts deliveries from Turkey should have been completed by March 2022.

On 27 October 2021 a US delegation visited Turkey for consultation in Ankara about the situation around the Turkish acquisition of F-35s. The talks were described as positive but came as quite a surprise. The delegations had agreed to meet again in a couple of months. Ever since the moment that Turkey had been removed from the Joint Strike Fighter programme there were talks about F-16 upgrades. These talks seemed to be stalling. Furthermore, since the Ukrainian invasion Sweden and Finland wanted to join NATO. It was mainly Turkey and Hungary blocking them. The Biden administration ruled out that in return for Turkey allowing Sweden and Finland into NATO Turkey would receive F-35s. The second meeting on the F-35 topic between Turkish and US delegations was announced by the US Department of Defense and took place in Washington DC on 18 January 2023. Five days later the Turkish president issued quite a sharp statement against Sweden joining NATO, indicating the Swedish would be boycotted by Turkey.

United Arab Emirates

The United Arab Emirates (UAE) was a state that was playing a big part in civil and military aviation. Just think of the aerospace exhibition held every two years in Dubai. Emirates Airlines and the UAE Armed Forces had been at the forefront as well, having paid development money for the most modern version of the F-16E/F Block 60. Their longstanding interest in Eurofighter Typhoon and the Dassault Rafale however did not lead to a deal. The UAE had asked the US if the F-35 would be available, a request that was initially declined to appease Israeli fears during the Obama administration. This changed when the Trump administration said that the fifth-generation fighter would be available to the United Arab Emirates Armed Forces and the USAF used Al Dahfra base in the United Arab

Emirates for their first F-35 deployments to the Middle East in 2019. It was an opportunity for the UAE to have a close look at the F-35A. In a white paper published by the United Arab Emirates US embassy, it was stated that the US had used Al Dahfra Air Base for deployments for F-16 Falcons, F-15 Strike Eagles, KC-10 Extenders, U-2 Dragon Ladies, RQ-4 Global Hawks and E-3 Sentry (AWACS) for their war on terror.

Israel would be very likely to protest to such a sale to an Arab country and reminded the US administration about one of America's laws that it must provide a qualitative military edge to keep Israel's military advantage real. An unexpected turn of events came when news broke that the United Arab Emirates signed the Abraham Accords Peace Agreement on 15 September 2020. The parliaments of both countries ratified the agreement the following month. It meant that the UAE became the third Arab state after Jordan and Egypt to sign a peace deal with Israel. In the eyes of the US administration, this opened the door for the sale of the F-35 to the United Arab Emirates. What Israel and the United Arab Emirates have in common are very bad relations with Iran, both of them considering Iran a dangerous threat to their sovereignty. In the afore-mentioned white paper this was confirmed by the following statement: 'The most formidable threat is Iran's proliferation of offensive ballistic missiles, precision-guided munitions and armed drones.'

In October 2020 former US defence secretary Mark Esper and Israeli defence minister Benjamin Gantz met to discuss the US's 'long-standing and continuing commitment to maintaining Israel's Qualitative Military Edge (QME)'. With Israel's full acceptance of re-assurances that the US will 'maintain Israel's security superiority in the Middle East for decades to come,' on 23 October the Israeli prime minister and defence minister issued a joint statement noting that Israel would not oppose the sale of the F-35 to the UAE. On 29 October, Prime Minister Netanyahu called the decision to sell F-35s to the UAE 'an important achievement for the State of Israel'.

A huge coup for the United Arab Emirates (UAE) was announced on 11 November with the announcement that DSCA had provided three proposed sales for arms to the United Arab Emirates. One was for General Atomic Aeronautical Systems, a maximum of eighteen MQ-9 remotely-piloted aircraft which is weapon-ready with an estimated value of US$2.97 billion, one for the F-35 with an estimated value of US$10.4 billion and one for armament for both platforms with an approximate value of US$10.0 billion.

Some senators did not agree with Senator Bob Menendez stating:

The State Department and Department of Defense also refused to respond to Congressional inquiries as to how the Administration would deal with specific national security risks inherent in the proposed sale, which is comprised of the world's most advanced stealth fighter jet, over 14,000 more deadly bombs and munitions, and the second-largest ever sale of US drones to a single country.

We are introducing these bipartisan resolutions out of a shared understanding that Congress must strongly assert its statutory authority over our nation's foreign arms sales. As I tried to warn the Trump administration, circumventing deliberative processes for considering a massive infusion of weapons to a country in a volatile region with multiple ongoing conflicts is downright irresponsible. There are a number of outstanding concerns as to how these sales would impact the national security interests of both the United States and of Israel. As a result, Congress is once again stepping in to serve as a check to avoid putting profit over US national security and that of our allies, and to hopefully prevent a new arms race in the Middle East.

I support the normalisation of relations between Israel and the United Arab Emirates (UAE), but nothing in that agreement requires us to flood the region with more weapons and facilitate a dangerous arms race,' said Chris Murphy senator from Connecticut from the Senate foreign Relations committee. 'The Emiratis are an important security partner, but their recent behaviour indicates that these weapons may be used in violation of US and international law. The UAE has violated past arms sales agreements, resulting in US arms ending up in the arms of dangerous militia groups, and they have failed to comply with international law in Libya and Yemen. A sale this large and this consequential should not happen in the waning days of a lame duck presidency, and Congress must take steps to stop this dangerous transfer of weapons.

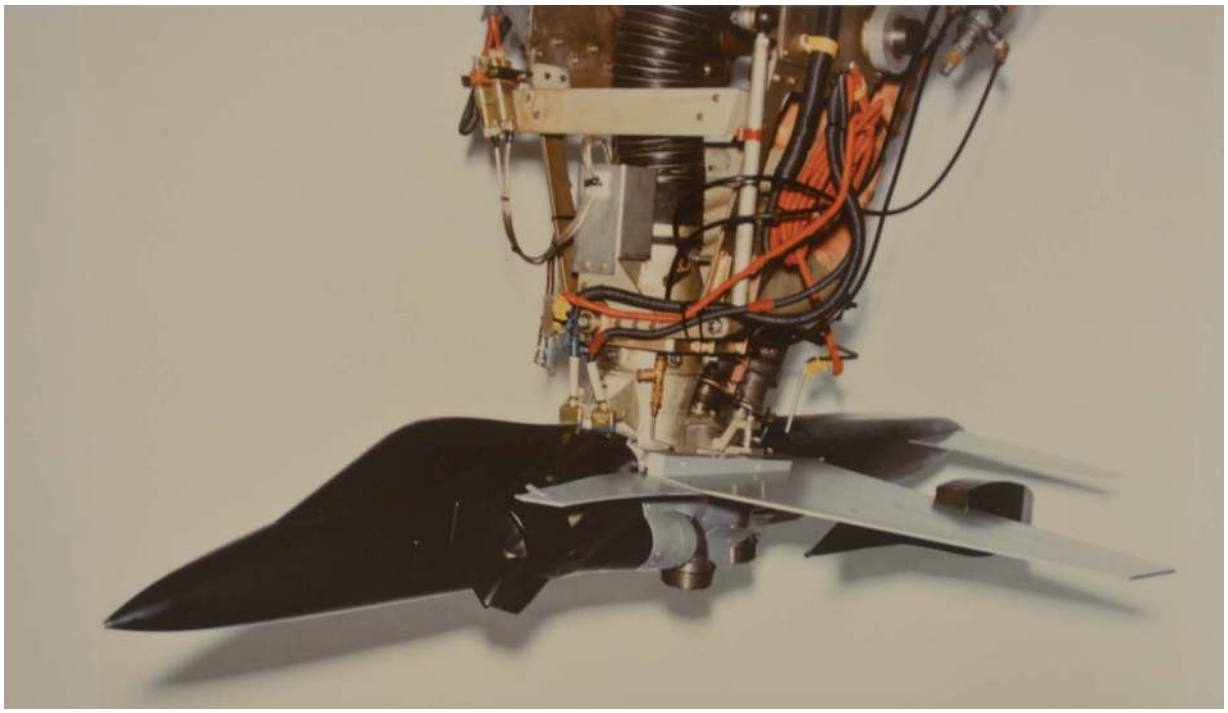
After a review the Department of State confirmed in April 2021 that the sales would proceed. The speed of the deal was not looked upon kindly by the United Arab Emirates who took the world by surprise by signing a deal for eighty Dassault Rafales on 3 December to replace their Dassault Mirage 2000-9s. Although it was stated at the time that this deal was complementary to the F-35 deal, according to Major General Ibrahim

Nasser Al Alawi, commander of the UAE Air Force and Air Defence, the UAE shortly afterwards suspended discussions on the F-35. It was unclear if this was a negotiating tactic but it would delay the deal. The main problem was UAE ties with China through the Huawei 5G technology available in their country. Previously, the UK had encountered similar problems as they had Huawei only as sub-supplier which they themselves had deemed safe, but the USA was able to convince them otherwise.

United Kingdom

It is difficult to describe the UK as an export country since it was involved so early in the programme but, on the other hand, it has only an 8 per cent part in the development costs and about 15 per cent of the production. The JSF is still ultimately seen as a Lockheed-Martin product even though BAE Systems has been criticised for joining with US industry instead of European (mainly by the French but also, to a lesser extent, the Germans). It was, however, clear that the United Kingdom could not find a partner willing to develop a supersonic STOVL-capable fighter in Europe which had its hands full with Eurofighter Typhoon, Dassault Rafale and Saab Gripen. Declining defence budgets and political will to fund another major fighter project was not present.

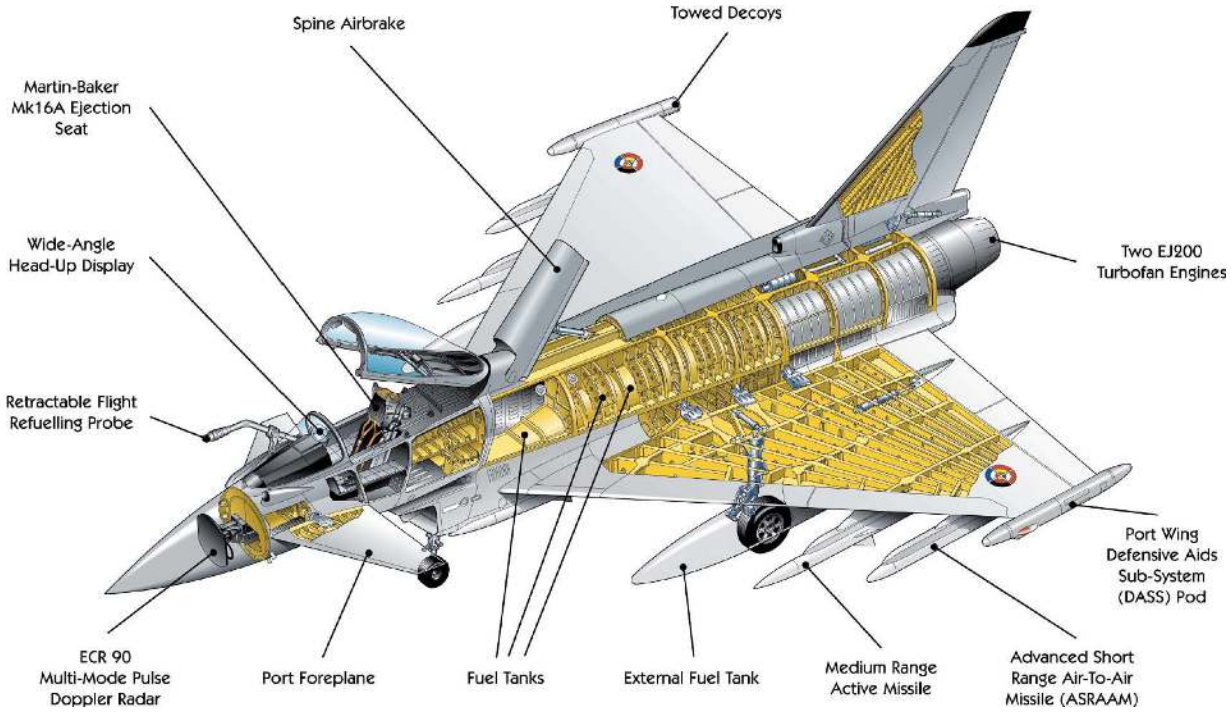
The United Kingdom was a main instigator and operator of STOVL-capability with the Harrier a source of national pride. British industry was acutely aware of its advantage and, eager to maintain it, was lobbying the RAF and US to fund technology studies for an eventual replacement. These replacement studies took place almost continuously from the moment the Harrier entered service, starting with P.1154 which was on the drawing board at the same time as the Harrier in the early 1960s. Harrier was seen as a stepping-stone interim capability, to the supersonic capability that was to follow soon.



One of the projects that made it into the BAe windtunnel for the ASTOVL programme. (*Brooklands Museum*)



This was one of the designs evaluated for the Future Offensive Air System (FOAS) but eventually the JSF fulfilled the role. (*BAE Systems*)



The United Kingdom invested heavily in the Concept Demonstration Phase when the four nation Eurofighter project was going through some development problems and cost increase. (*BAE Systems*)


BK-1





BK-1 was the first foreign F-35 full-stop. Here the progression till roll-out. (*Lockheed Martin*)



From roll-out to the final finishes hall. It is only a short ride. (*Lockheed Martin*)



Lockheed Martin Test Pilot Bill Gigliotti giving the BK-1 its first outing in the Fort Worth area. (*Lockheed Martin*)

Initially, the RAF was not enamoured with the Harrier which was more or less forced in by the politicians. In the beginning the usefulness of the Harrier was questioned: it was only subsonic and would be a sitting duck against supersonic opposition; it would require protection by other fighter aircraft. This was proved wrong in exercises and then combat during the Falklands when the Royal Navy used its Sea Harriers in the air defence role and shot down twenty-three enemy aircraft while losing none in air-to-air combat. The Harrier had won two battles at the same time. As the first prototype Harrier not counting the P.1127 and Kestrels had flown in 1966, the technology was getting aged in 1982 at the time of the Falklands and it was time to speed up research for a replacement.

The USMC were busy upgrading their Harriers but the Harrier would never be capable of the dream capability of combining its STOVL capability with the supersonic capability the services wanted. Although it was not said aloud, the RAF was not enamoured by the STOVL idea since there was always the so-called STOVL penalty for the same reason that the

US Navy preferred catapult-launch and arrested-landing capability. The supersonic Harrier replacement had been pursued with co-operative projects with the US throughout the 1980s. British Aerospace considered it unlikely that the realisation of the Harrier replacement would come about without international co-operation and thought that the US offered the most realistic option by 1984. In 1984 the British MoD initiated work on drafting a new requirement for a Sea Harrier replacement: NST-6464. British Aerospace received a half-year duration feasibility contract for two studies in January 1985. One was to be a lower-cost and low-risk (Harrier-like) option with a look at a replacement with an in-service date of 1997; it was also to look at upgrading and thereby extending the Sea Harrier's life beyond 1997. This study was to be led by British Aerospace Weybridge. The second study was to be performed by British Aerospace Warton for an aircraft that fulfilled the proposed requirements from NST-6464 and was to put forward a timeline and cost estimate. From the timeline an approximate in-service dateline would be derived. Strangely, the British Aerospace department where the Harrier was designed, Kingston, was left out of the task.



The first take-off by BK-1. (*Lockheed Martin*)



First Flight. (*Lockheed Martin*)

Not only was it a problem to find partners in Europe, but the RAF was the customer for Eurofighter, which had been in development since 1982. Eurofighter, at the time called the European Fighter Aircraft (EFA), was in financial difficulties and when savings had to be offered in return for its increased cost, the RAF offered its long-term costings for the funding of a future Harrier replacement. The future Harrier budget was carried 75 per cent by the RAF and 25 per cent by the Royal Navy. This was a clear threat to the future of fixed-wing aviation in the Royal Navy. However, Invincible-class carriers revived fixed-wing aviation in the Royal Navy and proved its worth in the air defence role during the Falklands.

The DARPA study was to take from May to November 1988 with DARPA keen on British Aerospace joining the programme. Although British Aerospace kept as an option a British-only demonstrator, as with the EAP for the Eurofighter, it was not really likely until there were commitments from other countries just like the European Fighter Aircraft. Britain going it alone was not realistic since the last two combat aircraft to enter operational service were the Sepecat Jaguar and Panavia Tornado. The best option was to get co-operation from other countries, but with the Sepecat Jaguar the French wanted 60 per cent of the responsibility. Co-

operation with Germany and Italy was viewed more positively. France also participated in the European Fighter Aircraft until Dassault pulled out.



Safely returned, smoke coming of the wheels. (*Lockheed Martin*)



Lockheed Martin test pilot Bill Gigliotti celebrating the milestone for the British. (*Lockheed Martin*)

The United Kingdom was a partner as far back as 9 August and the memorandum of understanding signed with the partnership in the common affordable lightweight fighter (CALF) to study options and technology to replace the Harrier in service dating from. Studies had been performed earlier and even a Harrier III was an option but, since the design of the Harrier was almost forty years old, its growth was limited. In 1990 British Aerospace displayed a model of what should have been the Harrier III. The replacement programme began in earnest in 1996, when a requirement was set and was called the future carrier-borne aircraft (FCBA) to replace the Sea Harrier FRS.2, which was to begin retiring in 2006. The new requirement was set in staff target (Sea/Air) 6464.

The UK was the only country to become a full partner and contribute US$200 million for the concept demonstration phase (CDP), budgeted at US$2 billion. On behalf of the UK MoD and US DoD respectively D.

Malcolm McIntosh, Chief of Defence Procurement and Dr Paul Kaminsky Under-Secretary of Defence for Acquisition and Technology, signed an MoU regarding this co-operation on 20 December 1995. The UK was heavily criticised by the French who thought that Europe should keep together and buy European. The French, already nervous as a result of the success of the F-16, were afraid of a déjà vu situation and therefore compared the JSF programme with the Trojan horse for the European aerospace industry, somehow forgetting that Dassault was a partner in the Boeing X-32. One team was pushing their CATIA CAD/CAM programme to be used on the JSF programme as such with both manufacturers.



The British Eurofighter Typhoons were there for integration testing with the F-35. The UK wanted to make sure they could be integrated together seamlessly. (*USAF*)



The British pilots were trained at Eglin AFB and were integrated with the VMFAT-501 ‘Warlords’. (*Crown Copyright 2014*)

In 1998 the Strategic Defence Review changed matters for the programme as it was planned that both the Fleet Air Arm’s Sea Harriers and the Royal Air Force (RAF) Harriers would be placed under one command, called ‘Joint Force 2000’. Joint Force 2000 was to operate from Land and Sea bases, the cost-cutting measure ensuring commonality between aircraft used on ships and land bases. The task of Joint Force 2000 was to provide precision strikes at land, sea and air targets, air escort for joint assets and protection against aggression.

Joint Force 2000 came into existence on 1 April 2000 under the title Joint Force Harrier with the Sea Harrier FA.2s and Harrier GR.7/7As in its inventory, aircraft that were nearing the time that they needed replacement. The fact that it was now a Joint RN/RAF unit made the FCBA title for the Sea Harrier replacement redundant and a new name for the common replacement was chosen from May 2001 that better reflected the single need for replacing two aircraft. The Future Joint Combat Aircraft (FJCA) project was born. The plan was to replace both the Sea Harrier FA.2 and the Harrier GR.77A although, shortly afterwards, it was decided that, while the Sea

Harrier FA.2 would be retired in 2006, Harrier GR.7 would be upgraded to Harrier GR.9 and operate from sea bases and ashore, improving their capability and lifetime until the FJCA would be available to replace the Harrier GR.9.

It was unclear which aircraft would be chosen and BAE Systems had set its biggest bet on the JSF although it was uncertain that that programme would survive all the budgets cuts contemplated. Even the newly-elected Republican President George W. Bush was heard saying that three new aircraft projects could not be afforded and it was to be seen which projects would be cut. At that time the JSF was the least advanced aircraft under development and therefore seen as the programme at highest risk. This made the UK choose a second option, a navalised version of the Eurofighter Typhoon.



The F-35B has an enormous amount of doors that have to open correctly to be able to function properly. (*Crown Copyright 2016*)



During the first UK visit this formation of an UK and US F-35B together with a colourful Panavia Tornado. (*Crown Copyright 2016*)

The Typhoon option had a bigger weapon load, higher speed and, more importantly, longer range. The commonality issue was also pushed since the RAF had already ordered 232 Eurofighter Typhoons. Another partner in the Eurofighter project was also briefed on the naval version, as they would encounter the same problem when they went to replace their Harriers. Initial studies for the navalised version were begun in 1996 and had some good results. In 1997 a more in-depth study began that lasted twenty-seven months into possibilities and requirements connected with navalising the Eurofighter Typhoon. Two versions of a navy Typhoon were under consideration one, was Short Take Off But Arrested Recovery (STOBAR) and the other a conventional catapult-launched version like the F/A-18E/F and Rafale. The STOBAR version would require thrust vectoring on the EJ200 engine which was already under study by the Spanish EJ200 partner (ITP or *Industria de Turbo Propulsores*).

Another aircraft in contention was the French Rafale, which had been adapted from the outset for French naval service requirements. The Rafale was, however, French and British home industry would have little or no influence or jobs in the programme. Another option, the Boeing F/A-18E/F,

was about to enter US Navy service. However, all three aircraft lacked stealth and the vertical-landing capability. Previous co-operation with Boeing (previously McDonnell Douglas) on the Harrier and the Goshawk made a better opening for influence for BAE Systems but was still not an ideal option. The best option for UK industry remained the JSF.



A formation of early F-35Bs over England. (*Crown Copyright 2018*)



STOVL operations was for the UK the reason from the outset to cooperate with the USA. It was therefore incomprehensible that for a short time the carrier version was considered. (*Crown copyright 2018*)

Funding insecurity gave the British a better negotiating position and signing was delayed slightly to try to get more out of the deal for the British industry but finally, on 17 January 2001, the UK signed a memorandum of understanding with the US to become a level-1 partner in the engineering, manufacturing and demonstration (EMD) phase. It was not made clear which version was the favoured, i.e. STOVL or CV, and at the time it was said only that the JSF was the preferred option. Level-1 partnership allowed the UK to be part of the evaluation of both designs. Evaluation commenced shortly afterwards on 8 February 2001.

The decision was eventually made to go for the STOVL version on 30 September 2002. The UK was, however, also looking at replacing the aircraft carrier HMS *Ark Royal*. The decision to opt for the STOVL version was thought to have an effect on the size of the carrier needed. The MoD was, however, looking at the bigger picture since they did not want to rule out using the E-2 Hawkeye; if there would be a replacement for the JSF that would not be STOVL-capable the aircraft carrier would not need to be scrapped. The MoD denied that the reason had anything to do with the

uncertainty that the STOVL JSF version was not going to be built. Another reason for choosing the STOVL version was its flexibility: a STOVL version can operate in weather conditions where the CV version could not be launched from ships, which can be a major operational advantage. The JSF chosen for the British FJCA became known in the press as the JCA, losing its future designation.

Problems around technology transfer were present from the early start. The problems would all be solved one by one, according to officials from the Joint Programme Office. Frictions between the two countries, however, were not diminishing. It seemed they were increasing. Early in the SDD countries like Norway and Turkey gained most attention because of their dissatisfaction but, in 2005, that changed to the UK. Just before the Paris Air Show it transpired that integration of the ASRAAM missile was to be delayed, which was a problem for the UK as it would delay full weapon capability and the missile's export chances. The worries were of such a standard that Prime Minister Blair discussed the problems with President George Bush. Technology transfer was a major problem and by the end of 2005 the decision to cancel the alternative engine without consulting the UK was considered a slap in face, something not to be done to someone providing a tenth of the funding for the entire programme. The technology transfer problem was, however, considered more serious since it was not certain that maintenance could be done completely by the customer in the UK. According to some armed forces officials this was unacceptable and would mean that another option would have to be found. With no alternative readily available it could mean a loss of capability for the UK armed forces. The memorandum of understanding planned for signing later in 2006 (the production, sustainment and follow on development (PSFD) was in doubt. It was hoped that all partner nations would sign that document and commit to a certain number but that would be impossible for the UK if it would not receive total autonomy on the technical side. The French made an offer that the UK could always buy Rafale as that was a fourth-generation fighter qualified for shipborne operations. In fact, as the UK and France were co-operating on the aircraft carrier it would make their requirements more similar in that respect.



The F-35B being launched during operational testing on the *Queen Elizabeth*. The operational testing was given the name Westlant 19. (*Crown Copyright 2019*)

Prior to a visit to the US regarding the JSF in March 2006, the new UK defence minister for procurement Lord Drayson stated:

Whilst I appreciate the concerns of some in the US about the issue of Technology Transfer, the British public expect their Government to equip our Armed Forces with the very best and I am determined to best represent the interests of our national security and our British Service personnel.

The next key milestone in the programme, the signing of the Production, Containment and Follow-On Development MoU will commit the United Kingdom to the whole life of the JSF programme. We must therefore be sure to understand the nature and balance of the obligations between our nations consistent with the principles of the agreements on JSF we have signed to date. Operational sovereignty, the ability to integrate, upgrade, operate and sustain the aircraft as we see fit and without recourse to others is of paramount importance.



Some patriotic feelings were shown during this aerial refuelling. (*Crown Copyright 2016*)

Let me state our bottom line. These issues are important to us because they enable us to make the judgement that the aircraft are ‘fit to fight’ and we can send our airmen and women into action in that knowledge. This decision has to be one for the UK, indeed the British Government’s responsibility to our Armed Forces, and their families, means that this judgement can only be made by the UK. If we do not have the information and technology needed to make that decision, then I shall not be able to sign the MoU. I recognise the consequences that would have on the UK’s continuing participation in the programme.

During his visit he was to meet with several influential senators to speak about this, the planned F136 engine cancellation and the interconnected treatment the UK received. His comments regarding the F136 engine were clear cut:

The F136 inserts an important competitive element to the JSF programme by providing an alternative choice for the aircraft engine both at initial acquisition and, importantly, through life, with all the monetary savings that

this will offer us both. There is also the potential growth capability that the F-136 offers as a new-generation engine. We believe the F136 engine will lead to lower through-life costs and deliver the best outcome for both our war fighters and our taxpayers.

For these reasons and given the importance of the project to Rolls Royce, we expect, as a level-1 partner, to be properly consulted on decisions of this magnitude. As the Minister responsible for the UK defence industrial base, I still wish to see funding for F-136 included in the Department of Defence programme. This is something that I will be following up with the Administration this week.



F-35B during Westlant. (*Crown copyright 2019*)

Considering that Tony Blair had already lobbied on the decision, it was not clear what the results would be and if the F136 engine could be saved. UK withdrawal from the JSF programme at this stage would mean a loss of face for the US and loss of money for the UK and would definitely hurt the special relationship the two countries professed to have. The lobbying seemed to have a positive effect on things as the Senate reinstated funding on the engine.

On 8 December 2006 the UK House of Commons issued a warning that the MoD should be careful not to sign the PSFD until assurances were given regarding sovereignty issues around operational use of the F-35A Lightning II but on the other hand be careful not to hurt the special relationship between the US and UK. The MoD answered that it would not commit until all the assurances that it deemed necessary were received. Only four days later that seemed to have been achieved and Lord Drayson signed the PSFD MoU with US deputy secretary of defence, Gordon England.

The estimated procurement amount of aircraft per fiscal year by the United Kingdom was determined in the PSFD document with delivery approximately two years after contract signature; the UK was expected to sign in fiscal year 2009 for deliveries to start in 2011.

Fiscal Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Amount	2	3	8	3	2	9	9	12	12	12

Fiscal Year	2019	2020	2021	2022	2023	2024	Total
Amount	12	12	12	12	12	6	138

Defence Secretary John Hutton announced on 18 March 2009 that the United Kingdom would purchase three Lockheed Martin F-35B Lightning II operational test aircraft, thereby becoming the first country to commit to the operational test-and-evaluation phase of the JSF programme. He was in Washington to put his signature on a memorandum of understanding. This was a much-needed boost for the under-fire JSF programme. A few weeks later the first long-lead items for the first STOVL F-35 for the UK were contractually announced together with an increase for US Navy versions.

The change of government during May 2010 had the result of a new review on defence spending being carried out. The new government had

inherited an unenviable situation with the economy more or less in a shambles. A need to reduce expenditure was paramount and there was no doubt that the Ministry of Defence was facing cuts. The review was released in October 2010 and sent shockwaves through the defence world. The cuts were major and the JSF was not being spared. Although exact numbers were not being mentioned, the most important change for the F-35 Lighting II was that the raison d'être, the STOVL version, was being abandoned. Instead, the UK would acquire the carrier version: not only would the acquisition cost be lower but also the operational and sustainment costs. This would have an effect on the aircraft carrier as the catapult and arrestor-bar recovery had to be installed. A conversion development phase was to be implemented to assess the costs and risks involved with adapting the carrier to cats-and-traps configuration. Two main conversion options were available: HMS *Queen Elizabeth* in-refit, or HMS *Prince of Wales* in-build. If the refit option was chosen, HMS *Queen Elizabeth* would require modification following building. However, if the in-build option for HMS *Prince of Wales* was chosen, the modifications could be accommodated as the build progressed. The conversion development phase was to last eighteen months.

There would be twelve F-35Cs based on the carrier. The exact number of F-35Cs to be acquired was not specified, so for the time being Lockheed Martin counted on the amount of record, 138 aircraft. That the UK had already ordered three STOVL aircraft for operational testing was an expensive write off. The UK tried to exchange at least one of its test aircraft with the USA, so that it would have a service representative test aircraft. This effort was successful as on 30 November 2011 the US Senate approved a swap deal for BK-3. According to the deal the UK would pay for bringing BK-3 up to US Marine Corps standards and, of course, for bringing the carrier version up to Royal Navy specification. RAF Squadron Leader Jim Schofield had his first flight on 1 February 2012.

The conversion development phase for the aircraft carrier showed that the cost of conversion was ballooning. Just after the switch deal had been made between the US and the UK for the third UK STOVL aircraft news broke that the STOVL version was back under consideration. The change of heart was within the government, as acknowledged by Prime Minister Cameron who was not afraid to go back on the earlier decision if it was

proven to be the least costly option. Indeed it was. During May 2012 the decision was announced that the UK would revert to the STOVL variant.

All negotiation to transfer the BK-3 were declared naught. The United Kingdom saw its first two aircraft, BK-1 and BK-2, being flown and the first one even being handed over during a ceremony on 19 July 2012. Shortly afterwards the first British jet, with fuselage marking ZM135, was transferred to Eglin AFB where it would be based for the planned initial pilot training. As soon as the preparations for the initial operational test and evaluation commenced in earnest the aircraft would be transferred to Edwards AFB. IOT&E was, however, delayed and training of British pilots was delayed as well due to operational utility evaluation at Eglin. The first two British pilots to go through the official training programme there started their training in January 2013. The third British F-35 was flown for the first time on 1 April and was integrated with VMFAT-501 as a training asset. BK-04 was again a test aircraft destined to become part of 17(R) Test and Evaluation Squadron.

It took till 2018 for fifteen aircraft to have been delivered to the UK, all of which resided in the US with most being used to train pilots for the famous Dambusters Squadron that was due to return to the UK for the RAF's Centenary celebrations. The arrival of the first four F-35s was due in June 2018. Although not on the official programme it was expected that, somehow, they would participate at RAF Fairford and the Farnborough Air Show.

Glossary

AAA	Anti-Aircraft Artillery
AAIB	Aircraft Accident Investigation Board
ACAS	Air-to-air Collision Avoidance System
ACC	Air Combat Command
ACS	Attitude Control System
ADVENT	Adaptive Versatile Engine Technology
AES	Automatic Ejection System
AESA	Active Electronically Scanned Array
AETD	Adaptive Engine Technology Demonstration
AFB	Air Force Base
AFFTC	Air Force Flight Test Centre
AFRL	Air Force Research Laboratory
AGCAS	Automatic Ground Collision Avoidance System
AGE	Aerospace Ground Equipment
AHS	Ammunition Handling System
AI	Air Interdiction
AIB	Accident Investigation Board
AIMS	Aviation Inflatable Maintenance Shelter
ALC	Air Logistics Centre
ALIS	Autonomic Logistics Information System
ALOA	Autonomic Logistic Operating Unit
AMRAAM	Advanced Medium Range Air-to-Air Missile
ANG	Air National Guard
AoA	Angle of Attack
AR	Armed Reconnaissance
ASMT	Aircraft Systems Maintenance Trainer
ASRAAM	Advanced Short Range Air-to-Air Missile
ASTOVL	Advanced Short Take Off and Vertical Landing
ATC	Academic Training Centre

ATC	Advanced Technology Centre
ATF	Advanced Tactical Fighter
AV	Air Vehicle
AVD/H	Air Vehicle Data/Health
AVEL	AMRAAM Vertical Ejection Launcher
AVI	Air Vehicle Integration
AVM	Air Vehicle Manager
BDA	Battle Damage Assessment
BLu	Belgische Luchtmacht or Belgian Air Force.
BRAC	Base Re-alignment and Closure
BRU	Bomb Rack Unit
BVR	Beyond Visual Range
CALF	Common Affordable Lightweight Fighter
CAS	Close Air Support
CAS	Control Actuation System
CBR	Chemical, Biological, Radiological
C4I/CNI	Command, Control, Communication, Computers and Intelligence/Communication Navigation and Identification
CDA	Concept Demonstration Aircraft
CDP	Concept Demonstration Phase
CDR	Critical Design Review
CFD	Computational Fluid Dynamics
CFF	Call For Fire
COTS	Commercial off The Shelf
CPB	Centraal Plan Bureau
CPC	Corrosion Prevention and Control
CPE	Central Point of Entry
CQ	Carrier Qualification
CSMU	Crash Survivable Memory Unit
CST	Central Standard Time
CTF	Combined Test Force
CTOL	Conventional Take-off and Landing
CV	Carrier Version
DAB	Defence Acquisition Board
DACT	Dissimilar Air Combat Training
DARPA	Defence Advanced Research Project Agency
DART	Data Acquisition, Recording, and Telemetry

DAS	Distributed Aperture System
DASC	Direct Air Support Centre
DCA	Defensive Counter Air
DCA	Dual-Capable Aircraft
DCMA	Defence Contract Management Agency
DCS	Direct Commercial Sales
DEWS	Digital Electronic Warfare Systems
DfE	Design for Environment
DGA	Directorate General of Armaments
DMRT	Deployable Mission Rehearsal Trainer
DoD	Department of Defense
DOT&E	Director of Operational Test & Evaluation
DSCA	Defense Security Co-operation Agency
DVI	Direct Voice Input
EA	Electronic Attack
ECCM	Electronic Counter-counter-measures
ECM	Electronic Counter-measures
ECS	Environmental Control System
EEE (E3)	Electromagnetic Environmental Effects
EFA	European Fighter Aircraft
EFADS	Environmentally Friendly Aircraft Decontamination System
EHA	Electro-Hydrostatics Actuators
EIS	Environmental Impact Study
EMD	Engineering, Manufacturing and Demonstration
EMS	Exceedance Management System
EO	Electro-Optical
EOTS	Electro-Optical Targeting System
ESFM	Ejection-Seat Firing Module
ESG	Engine Starter Generator
ESH	Environmental Safety and Health
ESMT	Ejection System Maintenance Trainer
ETS	Embedded Training System
EW	Electronic Warfare
EWS	Electronic Warfare Squadron
FACO	Final Assembly & Check Out
FCA	Future Combat Aircraft

FCBA	Future Carrier Borne Aircraft
FCS	Flight Control System
FDC	Fire Direction Centre
FDE	Force Development Evaluation
FETT	First Engine to Test
FJCA	Future Joint Combat Aircraft (later JCA Joint Combat Aircraft)
FLIR	Forward Looking Infra-Red
FMS	Foreign Military Sales
FMS	Full Mission Simulator
FMT	Flight Mission Trainer
FMV	Full Motion Video
FOD	Foreign Object Damage
FOUO	For Office Use Only
FOV	Field Of View
FRC	Fleet Readiness Centre
FS	Fighter Squadron
FS	Fuselage Station
FSD	Full Scale Development
FTC	Flight Test Centre
FTS	Flight Test Squadron
FTU	Flight Test Upgrade
FY	Fiscal Year (in the US a FY runs from 1 Oct. until 30 Sept.
GAO	General Accounting Office
GAU	Gun Automatic Unit
GBU	Guided Bomb Unit
GCAS	Ground Collision Avoidance System
GCLF	Gas Coupled Lift Fan
GDATP	General Dynamics Armament and Technical Products
GDP	Gross Domestic Product
GEnv	Ground Environment
GPS	Global Positioning System
GSCU	Gun System Control Unit
GTA	Ground Training Aid
GTV	Guided Test Vehicle
HARM	High speed Anti-Radiation Missile

HDD	Head Down Display
HE	High Explosive
HEI	High Explosive Incendiary
HGI	Hot Gas Ingestion
HIMARS	High Mobility Artillery Rocket System
HMD	Helmet Mounted Display
HPC	High Pressure Compressor
HRC	Health Reporting code
HUD	Head Up Display
IAF	Israeli Air Force
IBR	Integrally Bladed Rotor
ICAWS	Integrated Caution Advisory Warning System
ICW	Integrated Courseware
ICP	Integrated Core Processor
IFMV	Interim Full Motion Video
IHAVS	Integrated Helmet Audio Visual System
IHE	Intelligent Help Environment
IIR	Imaging Infra-Red
I/ITSEC	Interservice/Industry Training, Simulation and Education Conference
ILS	Instrument Landing System
IMS	Integrated Master Schedule
INS	Inertial Navigation System
IOC	Initial Operational Capability
IOT&E	Initial Operational Test & Evaluation
IPP	Integrated Power Package
ISIE	Intevac Silicon Imaging Engine
ISR	Intelligence Surveillance and Reconnaissance
ITC	Integrated Training Centre
ITF	Integrated Test Force
ITP	Industria de Turbo Propulsores
JASDF	Japan Air Self-Defense Force
JAST	Joint Advanced Strike Technology
JDAM	Joint Direct Attack Munition
JEPAC	Joint Electronic Protection for Air Combat
JFH	Joint Force Harrier
JOTT	Joint Operational Test Team

JPD	Joint Programme Director
JPEO-CBD	Joint Programme Executive Office for Chemical and Biological Defence
JPM	Joint Programme Manager
JPO	Joint Programme Office
JSF	Joint Strike Fighter
JSM	Joint Strike Missile
JSOW	Joint Stand Off Weapon
JTAC	Joint Terminal Attack Controller
JTD	Joint Technical Data
KLu	Koninkelijke Luchtmacht
KPP	Key Performance Parameters
LASER	Light Amplification by Stimulated Emission of Radiation
LAU	Launcher AAM Unit
LCA	Light Combat Aircraft
LFT	Live Fire Test
LFT&E	Live Fire Test & Evaluation
LGB	Laser Guided Bomb
LO	Low Observables
LOA	Letter of Offer and Acceptance
LOAL	Lock On After Launch
LOHAS	Low Observable Health Assessment System
LPI	Low Probability of Intercept
LPLC	Lift Plus Lift Cruise
LRIP	Low Rate Initial Production
LRU	Line Replaceable Unit
LSPM	Large Scale Powered Model
LVC	Live, Virtual, Constructive
LWF	Lightweight Fighter
MAWTS	Marine Aviation Weapons and Tactics Squadron
MCAS	Marine Corps Air Station
MCD	Microwave Corrosion Detector
MGS	Missionised Gun System
MNDE	Microwave Non Destructive Evaluation
MOB	Main Operating Bases
MoD	Ministry of Defence
MoU	Memorandum of Understanding

MQM	Mission Qualified Maintainer
MRAAM	Medium Range Air-to-Air Missile
MRT	Mission Rehearsal Trainer
MRTT	Multi-Role Tanker Transport
MTBF	Mean Time Between Failure
MVI	Maintenance Vehicle Interface
NAS	Naval Air Station
NAWC	Naval air Warfare Centre
NAWC-AD	Naval Air Warfare Centre-Aircraft Division
NAWC-TSD	Naval Air Warfare Centre-Training Systems Division
NAWC-WD	Naval Air Warfare Centre-Weapons Division
NDMA	Norwegian Defence Management Agency
NDP	National Disclosure Policy
NIFCA-CA	Naval Integrated Fire Control - Counter Air
NIPO	Navy Integrated Programme Office
NLG	Nose Landing Gear
NST	Naval Staff Target
OARF	Outdoor Aerodynamic Research Facility
OBIGGS	On Board Inert Gas Generation System
OBOGS	On Board Oxygen Generating System
OCU	Operational Conversion Unit
ODC	Ozone Depleting Containments
OEF	Operation ENDURING FREEDOM
OFP	Operational Flight Programme
OGE	Outside Ground Effects
OML	Outer Mold Line
OMS	Off-Board Mission Support
OMSE	Off-board Mission Support Environment
OMS-WS	Off-board Mission Support Work Station
ONR	Office of Naval Research
ORD	Operational Requirement Document
OSD	Office of the Secretary of Defence
OT&E	Operational Test & Evaluation
OUE	Operational Utility Evaluation
PBL	Performance Based Logistics
PCD	Panoramic Cockpit Display
PDR	Preliminary Design Review

PGU	Projectile Gun Unit
PMD	Portable Maintenance Device
POGO	Project On Government Oversight
PPE	Personal Protective Equipment
PSFD	Production, Sustainment and Follow On Development
PTA	Pilot Training Aid
PTC	Pilot Training Centre
PTMS	Power & Thermal Management System
PVI	Pilot Vehicle Interface
PWSC	Preferred Weapon System Concept
QEC	Queen Elizabeth Class
QRA	Quick Reaction Alert
QRC	Quick Reaction Cycle
RAF	Royal Air Force
RCN	Roll Control Nozzle
RCS	Radar Cross Section
Rf I	Request for Information
RfGP	Request for Government Proposals
Rf P	Request for Proposals
RLG	Ring Laser Gyro
RN	Royal Navy
RNAF	Royal Netherlands Air Force
ROKAF	Republic of Korean Air Force
RSAF	Republic of Singapore Air Force
ROM	Rough Order of Magnitude
RTMC	Real Time Motion Capture
RVL	Rolling Vertical Landing
RWR	Radar Warning Receiver
(SAPHEI-T	Semi-Armor Piercing High Explosive Incendiary-Tracer
SAR	Synthetic Aperture Radar
SBIR	Small Business Innovation Research
SCM	Supply Chain Management
SDB	Small Diameter Bomb
SDD	System Development & Demonstration
SDLF	Shaft Driven Lift Fan
SEAD	Suppression of Enemy Air Defences
SFC	Specific Fuel Consumption

SFTD	Software Fault Tolerance Demonstration
SHM	Structural Health Monitoring
SINCGARS	SINgle Channel Ground and Airborne Radio System
SGR	Sortie Generation Rates
SLOC	Source Lines Of Code
SMFD	Secondary Multi-Function Display
SMPS	Scaleable Multi Processing System
SMS	Ship Motion Sensor
SMS	Stores Management System
SoF	Safety of Flight
SPEAR	Selected Precision Effects At Range
SPM	Shots Per Minute
SRAAM	Short Range Air-to-Air Missiles
S&RE	Suspension & Release Equipment
STO	Short Take Off
STOBAR	Short Take Off But Arrested Recovery
STOVL	Short Take Off and Vertical Landing
SWAT	STOVL Weight Attack Team
TEMP	Test and Evaluation Master Plan
TMS	Training Management System
TPS	Test Pilot School
TRL	Technology Readiness Level
TRS	Transparency Removal System
TVL	Thrust Vector Lever
UCARL	United Kingdom, Canada, Australia Re-programming Laboratory
USAF	United States Air Force
USMC	US Marine Corps
USRM	Under Seat Rocket Motor
VAVBN	Variable Area Vane Box Nozzle
VFDR	Variable Flow Ducted Rocket
VHP	Vaporised Hydrogen Peroxide
VLBB	Vertical Landing Bring Back
VMC	Vehicle Management Computer
VTO	Vertical Take Off
WLT	Weapons Loading Trainer
WTI	Weapons and Tactics Instructor

WTTP	Weapons and Tactics Training Programme
3BSM	Three Bearing Swivel Module
3BSN	Three Bearing Swivel Nozzle

Appendix I

Customer Aircraft Overview

Service/program of record	LRIP	Ordered/ delivered		bases	Serial numbers	Units
Defense Contract Management Agency				Fort Worth Cameri Nagoya		
The United States Air Force and Air National Guard Total requirement 1763	I, II, III, IV, V, VI, VII, VIII, IX, X, XI, XII, XIII XIV XV Total	2/2 6/6 7/7 10/10 22/22 18/18 19/19 19/19 26/26 44/44 48/48 61/61 38/38 56/56 49/32 425/408	AF-6 – AF-7 AF-8 – AF-13 AF-14 – AF-20 AF-21 – AF-30 AF-31 – AF-52 AF-53 – AF-70 AF-71 – AF-89 AF-90 – AF-108 AF-109 – AF-134 AF-135 – AF-178 AF-179 – AF-226 AF-227 – AF-272 AF-273 – AF-287 AF-288 – AF-325 AF-326 – AF-381 AF-382 – AF-430	Edwards AFB Eglin Nellis Luke Hill Burlington Eielson AFB RAF Lakenheath Truax field Tyndall Danelly field	07-0744 – 07-0745 08-0746 – 08-0751 09-5001 – 09-5007 10-5009 – 10-5018 11-5020 – 11-5041 12-5042 – 12-5059 13-5065 – 13-5083 14-5089 – 14-5107 15-5118 – 15-5143 15-5160 – 15-5203 17-5237 – 17-5284, 18-5336 – 18-5381 18-5445 – 18-5459 19-5460 – 19-5497 20-5566 – 20-5621 22-5682 – 22-5730	461st Flight Test Squadron 58th Fighter Squadron 422 Test and Evaluation Squadron 31 Test and Evaluation Squadron 16th Weapon Squadron 6th Weapon Squadron 61st Fighter Squadron 62nd Fighter Squadron 63rd Fighter Squadron 944 Fighter Wing 308 Fighter Squadron 34th Fighter Squadron 4th Fighter Squadron 421st Fighter Squadron 356th Fighter Squadron 355th Fighter Squadron 134th Fighter Squadron (ANG) 60th Fighter Squadron 495th Fighter Squadron 493rd Fighter Squadron 65th Aggressor Squadron 310th Fighter Squadron 312th Fighter Squadron 176th Fighter Squadron (ANG) 378th Fighter Squadron 95th Fighter Squadron 100th Fighter Squadron (ANG)
United States Marine Corps Total requirement 353	II, III, IV, V, VI, VII, VIII, IX, X, XI, XII, XIII XIV XV Total	6/6 7/7 16/16 3/3 6/6 6/6 6/6 6/6 9/9 22/22 24/24 20/20 16/16 18/18 165/165	BF-6 – BF-11 BF-12 – BF-18 BF-19 – BF-34 BF-35 – BF-37 BF-38 – BF-43 BF-44 – BF-49 BF-50 – BF-55 BF-56 – BF-61 BF-62 – BF-70 BF-71 – BF-92 BF-93 – BF-114 BF-115 – BF-116 BF-117 – BF-136 BF-137 – BF-152 BF-153 – BF-170	NAS Patuxent River Eglin AFB Edwards AFB Yuma Beaufort Iwakuni Miramar Cherry Point USS Wasp USS Essex USS Makin island USS America USS Tripoli USS Boxer	168057 – 168062 168308 – 168314 168717 – 168732 168838 – 168840 169023 – 169028 169164 – 169169 169292 – 169297 169411 – 169416 169587 – 169595 169607 – 169628 196678 – 169697 169786 – 169787 169794 – 169813 169912 – 169927 170048 - 170065	VX-23 VMFAT-501 VMX-22 VMX-1 VMFA-121 VMFA-211 VMFA-122 Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) VMFAT-502 VMFA-242 VMFA-225 VMFA-542 VMFA-533 (2024)

United States Navy and USMC Total requirement 273 + 67	IV V, VI, VII, VIII, IX, X, XI, XII, XIII XIV XV Total	4/4 7/7 7/7 4/4 4/4 2/2 2/2 10/10 4/4 4/4 6/6 3/3 28/28 85/85	CF-6 – CF-9 CF-10 – CF-16 CF-17 – CF-23 CF-24 – CF-27 CF-28 – CF-31 CF-32 – CF-33 CF-34 – CF-35 CF-36 – CF-45 CF-46 – CF-49 CF-50 – CF-53 CF-54 – CF-59 CF-60 – CF-62 CF-63 – CF-90	NAS Patuxent River Eglin AFB NAS Lemoore NAS Fallon	168733 – 168736 168841 – 168847 169029 – 169035 169160 – 169163 169302 – 169305 169424 – 169425 169600 – 169601 169631 – 169640 169702 – 169705 169788 – 169791 169798 – 169803 169939 – 169941 170083 – 170110	VX-23 VF-101 VX-9 VF-125 VF-147 Naval Aviation Warfighting Development Center (NAWDC) or Topgun VMFA-314 VFA-97 VMFA-311 VFA-86 VMFA-251 (2025)
Royal Air Force and Royal Navy Total requirement 138	III, IV, VII, VIII, IX, X, XI, XII, XIII XIV XV Total	2/2 1/1 1/1 4/4 6/6 3/3 1/1 3/3 6/6 8/8 35/35	BK-1 – BK-2 BK-3 BK-4 BK-5 – BK-8 BK-9 – BK-14 BK-15 – BK-17 BK-18 BK-19 – BK-21 BK-22 – BK-27 BK-28 – BK-35 BK-36 – BK-xx	Eglin AFB Edwards AFB MCAS Beaufort RAF Marham HMS Queen Elizabeth HMS Prince of Wales	168315 – 168316 168737 169170 169298 – 169301 169417 – 169422 169596 – 169598 169629 169698 – 169700 169928 – 169933 170074 – 170081 170xxx	VMFAT-501 17 Squadron 207 Squadron 617 Squadron 809 Squadron
Koninklijke Luchtmacht Royal Netherlands Air Force Total requirement 52	III, IV, XI, XII, XIII XIV XV XVI XVII Total	1/1 1/1 8/8 8/8 8/8 8/8 3/3 9/2 6/0 52/39	AN-1 AN-2 AN-3 – AN-10 AN-11 – AN-18 AN-19 – AN-26 AN-27 – AN-34 AN-35 – AN-37 AN-38 – AN-46 AN-47 – AN-52	Eglin AFB Edwards AFB Luke AFB Leeuwarden Volkel	09-5008 FW 10-5019 FW 17-5302 – 17-5309 18-5405 – 18-5412 19-5522 – 19-5529 20-5656 – 20-5663 22-5743 – 22-5745	58 Fighter Squadron 323 Test and Evaluation Squadron 308 Fighter Squadron Defensie Materiaal Organisatie (Defence Material Organisation) 322 Squadron 313 Squadron 312 Squadron
Royal Australian Air Force Total requirement 100	VI, X, XI, XII, XIII XIV XV Total	2/2 8/8 8/8 15/15 15/15 15/15 9/0 72/63	AU-1 – AU-2 AU-3 – AU-10 AU-11 – AU-18 AU-19 – AU-33 AU-34 – AU-48 AU-49 – AU-63 AU-64 – AU-72	Luke AFB Williamstown Tindal	12-5060 – 12-5061 15-5211 – 15-5218 17-5294 – 17-5301 18-5390 – 18-5404 19-5507 – 19-5521 20-5630 – 20-5644 22-5730 – 22-5738	61st Fighter Squadron 2 Operational Conversion Unit (OCU) 3 Squadron 77 Squadron 75 Squadron
Aeronautica Militare Italian Air Force Total requirement 60	VI, VII, VIII, IX, X, XI, XII, XIII XIV XV Total	3/3 3/3 2/2 1/1 1/1 2/2 2/2 3/3 5/5 6/6 28/28	AL-1 – AL-3 AL-4 – AL-6 AL-7 – AL-8 AL-9 AL-10 AL-11 – AL-12 AL-13 – AL-14 AL-15 – AL-17 AL-18 – AL-22 AL-23 – AL-28	Luke AFB Amendola Ghedi	12-5062 – 12-5064 13-5084 – 13-5086 14-5108 – 14-5109 15-5144 15-5204 17-5286 – 17-5287 18-5382 – 18-5383 19-5498 – 19-5500 20-5651 – 20-5655 22-57xx – 22-57xx	62nd Fighter Squadron 32 Stormo 13° Gruppo 6 Stormo 102° Gruppo

Luftforsvaret Royal Norwegian Air Force Total requirement 52	VII, VIII, IX, X, XI, XII, XIII XIV XV XVI Total	2/2 2/2 6/6 6/6 6/6 6/6 6/6 6/6 6/2 6/0 52/42	AM-1 – AM-2 AM-3 – AM-4 AM-5 – AM-10 AM-11 – AM-16 AM-17 – AM-22 AM-23 – AM-28 AM-29 – AM-34 AM-35 – AM-40 AM-41 – AM-46 AM-47 – AM-52	Luke AFB Ørland Evenes	13-5087 – 13-5088 14-5110 – 14-5111 15-5145 – 15-5150 15-5205 – 15-5210 17-5288 – 17-5293 18-5384 – 18-5389 19-5501 – 19-5506 20-5664 – 20-5669 22-5746 – 22-5751 xx-xxxx – xx--xxxx	62nd Fighter Squadron Norwegian Defence Management Agency 332 Skvadron 331 Skvadron
Kheil HaAvir Israeli Air Force Total requirement 50	VIII, IX, X, XI, XII, XIII XIV XV XVI Total	2/2 7/7 6/6 6/6 6/6 6/6 6/6 6/0 5/0 50/39	AS-1 – AS-2 AS-3 – AS-9 AS-10 – AS-15 AS-16 – AS-21 AS-22 – AS-27 AS-28 – AS-33 AS-34 – AS-39 AS-40 – AS-45 AS-46 – AS-50	Nevatim AFB Tel-Nof AFB	14-5112 – 14-5113 15-5151 – 15-5157 15-5227 – 15-5232 17-5324 – 17-5329 18-5433 – 18-5438 19-5554 – 19-5559 20-5670 – 20-5675 22-57xx – 22-57xx xx-xxxx – xx--xxxx	140 Fighter Squadron 116 Fighter Squadron Flight Test Center 117 Fighter Squadron
Kōkū Jieitai Japanese Air Self- Defence Force Total requirement 105 + 42	VIII, IX, X, XI, XII, XIII XIV XV Total	4/4 2/2 6/6 6/6 6/6 6/6 6/6 6/6 42/42	AX-1 – AX-4 AX-5 – AX-6 AX-7 – AX-12 AX-13 – AX-18 AX-19 – AX-24 AX-25 – AX-30 AX-31 – AX-36 AX-37 – AX-42	Luke AFB Misawa AB	14-5114 – 14-5117 15-5158 – 15-5159 15-5233 – 15-5236 17-5330 – 17-5335 18-5439 – 18-5444 19-5560 – 19-5565 20-5676 – 20-5681 22-57xx – 22-57xx	944th Operations Group Detachment 2 Ninjas 302 Hikotai 301 Hikotai
Marina Militare Italian Navy Total requirement 30	IX, X, XI, XII, XIII XIV XV Total	1/1 1/1 1/1 1/1 1/1 1/1 2/2 8/8	BL-1 BL-2 BL-3 BL-4 BL-5 BL-6 BL-7 – BL-8	MCAS Beaufort Amendola	169423 169599 169630 169701 169934 170082 1700xx – 1700xx	VMFAT-501 32 Stormo 13° Gruppo
Türk Hava Kuvvetleri Turkish Air Force Total requirement 100 cancelled	X, XI, XII, XIII XIV Total	2/2 4/4 8/8 8/8 8/8 30/30	AT-1 – AT-2 AT-3 – AT-6 AT-7 – AT-14 AT-15 – AT-22 AT-23 – AT-30	Luke AFB	15-5219 – 15-5220 17-5310 – 17-5313 18-5413 – 18-5420 19-5534 – 19-5541 20-5622 – 20-5629	63rd Fighter Squadron These were all bought up for the USAF
Daehanminguk Gong-gun Republic of Korea Air Force Total requirement 60	X, XI, XII, XIII Total	6/6 10/10 12/12 12/12 40/40	AW-1 – AW-6 AW-7 – AW-16 AW-17 – AW-28 AW-29 – AW-40	Luke AFB Cheongju	15-5221 – 15-5226 17-5314 – 17-5323 18-5421 – 18-5432 19-5542 – 19-5553	944th Operations Group Detachment 2 Ninjas 151 Squadron 152 Squadron
Flyvevåbnet or Royal Danish Air Force Total requirement 27	XIII XIV XV Total	4/4 6/6 4/0 4/0 18/10	AP-1 – AP-4 AP-5 – AP-10 AP-11 – AP-14 AP-15 – AP-18	Luke AFB Skrydstrup	19-5530 – 19-5533 20-5645 – 20-5650 22-5739 – 22-5742 22-57xx – 22-57xx	308 Fighter Squadron 727 Eskadrilla

Belgische Lucht Component or Belgian Air Component Total requirement 34	XV Total	4/0 4/0	AY-1 – AY-4	Luke AFB (2023) Belgium 2025	22-57xx – 22-57xx	312 Fighter Squadron
Siły Powietrzne or Polish Air Force Total requirement 32	XVI Total	32/0	AZ-01 -	Ebbing Air National Guard Base, Arkansas (2024) Lask (2026)	Not allocated	
Republic of Singapore Air Force Total requirement 12	Total	12/0		F-35B (2026) Ebbing Air National Guard Base, Arkansas	Not allocated	
Schweizer Luftwaffe or Swiss Air Force Total requirement 36	Total	36/0		F-35A (2026)	Not allocated	
Ilmavoimat or Finnish Air Force Total requirement 64	Total	64/0		F-35A (2026)	Not allocated	
Luftwaffe German Air Force Total requirement 35	Total	35/0		F-35A (2026) Buchel	Not allocated	
Royal Canadian Air Force Total requirement 88	Total	88/0	2026 (4) 2027 (6) 2028 (6) 2029 (18) 20230 (18) 2031 (18) 2032 (16)	F-35A (2026)	Not allocated	
vzdušné síly armády české republiky Czech Air Force Total requirement 24	Total	24/0	2029 (6) 2031 (6) 2032 (4) 2033 (4) 2034 (4)	F-35A (2029) Čáslav	Not allocated	
Total 3497		1407/1034				

Appendix II

	F-35A CTOL	F-35B STOVL	F-35C CV
Length	15.58 m / 51.1ft	15.58 m / 51.1ft	15.64 m / 51.4ft
Wingspan	10.67 m / 35 ft	10.67 m / 35 ft	13.11 m / 43 ft
Wing area	42.73 $m^2$460 ft^2	42.73 $m^2$460 ft^2	57.6 $m^2$620 ft^2
Combat radius	>1,092 km / 590 n. mi.	>833 km / 450 n. mi.	>1,111 km / 600 n. mi.
Empty weight	13,300 kg(29,300 lb)	14,700 kg(32,300 lb)	15,800 kg(34,800 lb)
Internal fuel	8,280 kg (18,250 lb)	6,125 kg (13,500 lb)	8,860 kg (19,750 lb)
Max take off weight	31,800 kg (70,000 lb class)	27,300 kg (60,000 lb class)	31,800 kg(70,000 lb class)
Thrust/weight ratio • full fuel: • 50% fuel:	 0.87 1.07	 0.90 1.04	 0.75 0.91
Internal fuel range	2,220 km (1,200 n. mi)	1,670 km (900 n. mi)	2,520 km (1,400 n. mi)
Combat radius on internal fuel	1,082 km (584 n. mi)	869 km (469 n. mi)	1,141 km (615 n. mi)

Appendix III

Purchase packages included, in addition to the aircraft:

Munitions
Sidewinder AIM-9X Block II+ (Plus) tactical missiles
Sidewinder AIM-9X Block II captive air training missiles (CATMs)
Sidewinder AIM-9X Block II special air training missiles (NATMS)
Sidewinder AIM-9X Block II tactical guidance units
Sidewinder AIM-9X Block II CATM guidance units
KMU-572 JDAM guidance kits for GBU-54
Bomb Mk82 500lb GP
Bomb Mk82, inert
GBU-53/B small diameter bomb II (SDB II) all-up round (AUR)
GBU-53/B SDB II guided test vehicle (GTV)
Detector laser DSU-38A/B
Detector laser DSU-38A(D-2)/B
FMU-139D/B Fuse
KMU-572(D-2)/B trainer (JDAM)
40-inch wing release lanyard
GBU-53/B SDB II weapon-load crew trainers (WLCT)
Cartridge, 25mm PGU-23/U
Weapons containers
Aircraft and munitions support and test equipment;

Other
Additional (spare) Pratt and Whitney F-135 engines
command, control, communications, computer and intelligence/communications
navigational, and identification (C4I/CNI)
autonomic logistics global support system (ALGS)
autonomic logistics information system (ALIS)

full-mission trainer; weapons employment capability, and other subsystems, features and capabilities
F-35 unique infra-red flares
re-programming centre access
F-35 performance-based logistics
software development/integration
aircraft ferry and tanker support
flight-test instrumentation
aircraft ferry and tanker support
support equipment
tools and test equipment
communications equipment
spares and repair parts
personnel training and training equipment
publications and technical documents

Appendix IV

F-35 OPERATED WEAPONS	Australia	Belgium	Canada	Czech R.	Denmark	Finland	Germany	Israel	Italy	Japan	S. Korea	Netherlands	Norway	Poland	Singapore	Switzerland	UK	USA
AIR TO AIR																		
AIM-9X Sidewinder	X	X	X	X		X	X	X	X		X	X	X		X	X		X
AIM-132 ASRAAM																	X	
Phyton 5								X										
IRIS-T																		
AIM-120 AMRAAM	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X	X
Meteor									X								X	
Derby								X										
AIR TO GROUND																		
GBU-31 – 2000lb	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X
GBU-32 – 1000lb								X	X									X
GBU-12 Paveway II		X			X	X		X	X		X	X	X	X	X		X	X
Paveway IV																	X	
AGM-154 JSOW																		X
GBU-48EPII		X			X	X			X			X	X	X			X	X
GBU-49		X			X	X			X			X	X	X			X	X
GBU-38 JDAM 500lb		X			X	X	X		X		X	X	X	X			X	X
GBU-54 LJDAM 500lb						X	X		X						X	X		X
GBU-39 SDB I	X	X				X		X	X		X	X	X				X	X
GBU-53/B SDB II Stormbreaker	X			X		X	X						X			X		X
AGM-154C-1 JSOW C-1						X												X
AGM-158B-2 JASSM-ER						X	X							X				X
B61-12		X					X					X						X
Joint Strike Missile						X				X			X					X
SPEAR																	X	
AARGM-ER	X					X						X						X
SPICE 2000lb								X										
SPICE 1000lb								X										
HYPERSONIC																		X