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F-35 Joint Strike Fighter (JSF) Program

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Summary

The largest procurement program in the Department of Defense (DOD), the F-35 Lightning II is a strike fighter aircraft being procured in different versions for the U.S. Air Force, Marine Corps, and Navy. Current DOD plans call for acquiring a total of 2,456 F-35s. Allies are expected to purchase hundreds of additional F-35s, and eight nations are cost-sharing partners in the program with the United States.

The F-35 promises significant advances in military capability. Like many high-technology programs before it, reaching that capability has put the program above its original budget and behind the planned schedule.

The Administration's proposed FY2022 defense budget requested about $9.4 billion in procurement funding for the F-35 program. This would fund the procurement of 48 F-35As for the Air Force, 17 F-35Bs for the Marine Corps, 20 F-35Cs for the Navy and Marines, advance procurement for future aircraft, and continuing modifications. The proposed budget also requested about $2.1 billion for F-35 research and development.

FY2022 defense authorization act: The FY2022 defense authorization bill funded F-35 procurement at $8.7 billion for 85 aircraft (48 F-35As, 17 F-35Bs, and 20 F-35Cs, the numbers requested by the Administration.) The joint explanatory statement accompanying the bill included language

- limiting the number of F-35s that could be procured based on the cost of operating and maintaining them;
- transferring responsibility for the F-35 program from the joint program office under DOD to the military services;
- requiring the Secretary of Defense to investigate, assess, and implement corrective actions for the F-35 breathing system;
- requiring the Air Force and Navy to submit acquisition strategies for advanced F-35 engines; and
- directing the Comptroller General of the United States to conduct an annual review of F-35 sustainment efforts.

FY2022 defense appropriations bill: The version of the FY2022 Department of Defense appropriations bill introduced in the House (H.R. 4432) funded F-35 procurement at $8.5 billion, plus $745 million in advance procurement for 85 aircraft (48 F-35As, 17 F-35Bs, and 20 F-35Cs), the requested numbers of aircraft and $.2 billion below the Administration's request. The advance procurement amount represented a decrease of $73 million from the request. The report accompanying the bill (H.Rept. 117-88) included language providing for modification of two F-35s per variant to a test configuration.

The version reported to the Senate by the Senate Appropriations Committee (S. 3023) also funded 85 aircraft in the quantities requested, for $8.4 billion, plus $818 million in advance procurement, the requested amount.

The explanatory statement accompanying the bill (available at https://www.appropriations.senate.gov/download/defrept_final) included language criticizing the F—35 Continuous Capability Development and Delivery program, denying the requested increases except for C2D2 test and evaluation. Further, the committee directs that with submission of the FY2023 budget request, the C2D2 program be reported as a separate Major Defense Acquisition Program.

Other language in the report

- allows modification of up to six F-35s to a test configuration; and
- encourages the F-35 Program Executive Officer to continue engagements with industry on potential solutions to increase the reliability of power modules.

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Introduction

In General

The F-35 Joint Strike Fighter (JSF), also called the Lightning II, is a strike fighter airplane being procured in different versions for the Air Force, Marine Corps, and Navy. The F-35 program is DOD's largest weapon procurement program in terms of total estimated acquisition cost. Current Department of Defense (DOD) plans call for acquiring a total of 2,456 F-35s[1] for the Air Force, Marine Corps, and Navy at an estimated total acquisition cost, as of December, 2019, of about $397.8 billion in constant (i.e., inflation-adjusted) FY2012 dollars.[2] U.S. allies are expected to purchase hundreds of additional F-35s, and eight foreign nations are cost-sharing partners in the program.

The Administration's proposed FY2022 defense budget requested about $12.0 billion in procurement funding for the F-35 program. This would fund the procurement of 48 F-35As for the Air Force, 17 F-35Bs for the Marine Corps, 20 F-35Cs for the Navy and Marines, advance procurement for future aircraft, and continuing modifications.

The proposed budget also requested about $2.1 billion for F-35 research and development.

Background

The F-35 in Brief

In General

The Joint Strike Fighter was conceived as a relatively affordable fifth-generation aircraft[3] that could be procured in highly common versions for the Air Force and the Navy. Initially, the Marine Corps was developing its own aircraft to replace the AV-8B Harrier, but in 1994, Congress mandated that the Marine effort be merged with the Air Force/Navy program in order to avoid the higher costs of developing, procuring, operating, and supporting three separate tactical aircraft designs to meet the services' similar, but not identical, operational needs.[4]

All three versions of the F-35 will be single-seat aircraft with the ability to go supersonic for short periods and advanced stealth characteristics. The three versions will vary in their combat ranges and payloads (see the **Appendix**). All three are to carry their primary weapons internally to

[1] Thirteen of the aircraft will be acquired for flight testing through research and development funding.

[2] Office of the Secretary of Defense, *F-35 Lightning II Joint Strike Fighter (JSF) Program (F-35)*, December, 2019.

[3] "Fifth-generation" aircraft incorporate the most modern technology, and are considered to be generally more capable than earlier-generation aircraft. Fifth-generation fighters combine new developments such as thrust vectoring, composite materials, stealth technology, advanced radar and sensors, and integrated avionics to greatly improve pilot situational awareness.

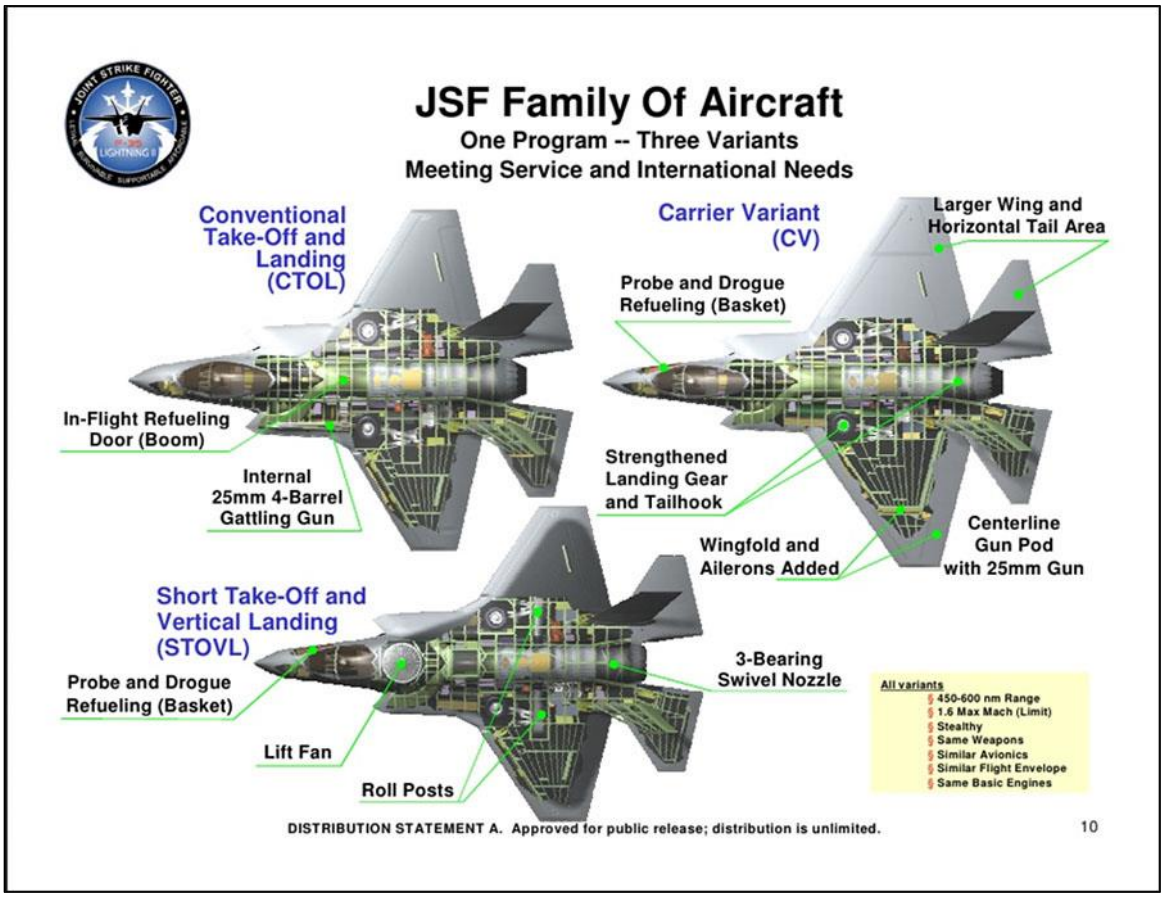
Among fighters currently in service or in regular production, only the Air Force F-22 air superiority fighter and the F-35 are considered fifth-generation aircraft. Russia and China have flown prototype fifth-generation fighters.

Strike fighters are dual-role tactical aircraft that are capable of both air-to-ground (strike) and air-to-air (fighter) combat operations.

[4] The program's operational requirements call for 70% to 90% commonality among all three versions. Many of the three versions' high-cost components—including their engines, avionics, and major airframe structural components—are common. Overall, however, commonality has fallen well short of that goal; see "Devolution of Joint Program Office," below. More details on the merger of the programs can be found in "F-35 Program Origin and History" below.

maintain a stealthy radar signature. Additional weapons can be carried externally on missions requiring less stealth.

Figure 1. F-35 Variants



Source: F-35 Joint Program Office briefing.

Three Service Versions

From a common airframe and powerplant core, the F-35 is being procured in three distinct versions tailored to the varied needs of the military services. Differences among the aircraft include the manner of takeoff and landing, fuel capacity, and carrier suitability, among others.

Air Force CTOL Version (F-35A)

The Air Force plans to procure 1,763 F-35As, a conventional takeoff and landing (CTOL) version of the aircraft. F-35As are to replace Air Force F-16 fighters and A-10 attack aircraft, and possibly F-15 fighters.[5] The F-35A is intended to be a more affordable complement to the Air Force's F-22 Raptor air superiority fighter.[6] The F-35A is not as stealthy[7] nor as capable in air-to-

[5] Stephen Trimble, "Lockheed says F-35s will replace USAF F-15s," *Flight International*, February 4, 2010.

[6] For more on the F-22 program, see CRS Report RL31673, *Air Force F-22 Fighter Program*.

[7] A November 13, 2009, press article states that "The F-22 had a -40dBsm all-aspect reduction requirement [i.e., a requirement to reduce the radar reflectivity of the F-22 when viewed from all angles by 40 decibels per square meter],

air combat as the F-22, but it is designed to be more capable in air-to-ground combat than the F-22, and stealthier than the F-16.

What Is Stealth?

"Stealthy" or "low-observable" aircraft are those designed to be difficult for an enemy to detect. This characteristic most often takes the form of reducing an aircraft's radar signature through careful shaping of the airframe, special coatings, gap sealing, and other measures. Stealth also includes reducing the aircraft's signature in other ways, as adversaries could try to detect engine heat, electromagnetic emissions from the aircraft's radars or communications gear, and other signatures.

Minimizing these signatures is not without penalty. Shaping an aircraft for stealth leads in a different direction from shaping for speed. Shrouding engines and/or using smaller powerplants reduces performance; reducing electromagnetic signatures may introduce compromises in design and tactics. Stealthy coatings, access port designs, and seals may require higher maintenance time and cost than more conventional aircraft.

If the F-15/F-16 combination represented the Air Force's earlier-generation "high-low" mix of air superiority fighters and more-affordable dual-role aircraft, the F-22/F-35A combination might be viewed as the Air Force's intended future high-low mix.[8] The Air Force states that "The F-22A and F-35 each possess unique, complementary, and essential capabilities that together provide the synergistic effects required to maintain that margin of superiority across the spectrum of conflict…. Legacy 4th generation aircraft simply cannot survive to operate and achieve the effects necessary to win in an integrated, anti-access environment."[9]

Marine Corps STOVL Version (F-35B)

The Marine Corps plans to procure 353 F-35Bs, a short takeoff and vertical landing (STOVL) version of the aircraft.[10] F-35Bs are to replace Marine Corps AV-8B Harrier vertical/short takeoff and landing attack aircraft and Marine Corps F/A-18A/B/C/D strike fighters, which are CTOL aircraft. The Marine Corps decided to not procure the newer F/A-18E/F strike fighter[11] and instead wait for the F-35B in part because the F/A-18E/F is a CTOL aircraft, and the Marine Corps prefers aircraft capable of vertical operations. The Department of the Navy states that "The Marine Corps intends to leverage the F-35B's sophisticated sensor suite and very low observable, fifth generation strike fighter capabilities, particularly in the area of data collection, to support the

while the F-35 came in at -30dBsm with some gaps in coverage." (David A. Fulghum and Bradley Perrett, "Experts Doubt Chinese Stealth Fighter Timeline," *Aerospace Daily & Defense Report*, November 13, 2009, pp. 1-2.)

[8] The term high-low mix refers to a force consisting of a combination of high-cost, high-capability aircraft and lower-cost, more-affordable aircraft. Procuring a high-low mix is a strategy for attempting to balance the goal for having a minimum number of very high capability tactical aircraft to take on the most challenging projected missions and the goal of being able to procure tactical aircraft sufficient in total numbers within available resources to perform all projected missions.

[9] Department of the Air Force Presentation to the House Armed Services Committee Subcommittee on Air and Land Forces, United States House of Representatives, Subject: Air Force Programs, Combined Statement of: Lieutenant General Daniel J. Darnell, Air Force Deputy Chief Of Staff For Air, Space and Information Operations, Plans And Requirements (AF/A3/5) [and] Lieutenant General Mark D. Shackelford, Military Deputy, Office of the Assistant Secretary of the Air Force for Acquisition (SAF/AQ) Lieutenant General Raymond E. Johns, Jr., Air Force Deputy Chief of Staff for Strategic Plans And Programs (AF/A8) May 20, 2009, pp. 7-8, 10.

[10] To permit STOVL operations, the F-35B has an engine exhaust nozzle at the rear than can swivel downward, and a mid-fuselage lift fan connected to the engine that blows air downward to help lift the forward part of the plane.

[11] For more on the F/A-18E/F program, see CRS Report RL30624, *Navy F/A-18E/F and EA-18G Aircraft Program*.

Marine Air Ground Task Force well beyond the abilities of today's strike and EW [electronic warfare] assets."[12]

Navy Carrier-Suitable Version (F-35C)

The Navy plans to procure 273 F-35Cs, a carrier-suitable CTOL version of the aircraft, and the Marines will also procure 67 F-35Cs.[13] The F-35C is also known as the "CV" version of the F-35; CV is the naval designation for aircraft carrier. The Navy plans in the future to operate carrier air wings featuring a combination of F/A-18E/Fs (which the Navy has been procuring since FY1997) and F-35Cs. The F/A-18E/F is generally considered a fourth-generation strike fighter.[14] The F-35C is to be the Navy's first aircraft designed for stealth, a contrast with the Air Force, which has operated stealthy bombers and fighters for decades. The F/A-18E/F, which is less expensive to procure than the F-35C, incorporates a few stealth features, but the F-35C is stealthier. The Department of the Navy states that "the commonality designed into the joint F-35 program will minimize acquisition and operating costs of Navy and Marine Corps tactical aircraft, and allow enhanced interoperability with our sister Service, the United States Air Force, and the eight partner nations participating in the development of this aircraft."[15]

Engine

The F-35 is powered by the Pratt & Whitney F135 engine, which was derived from the F-22's F119 engine. The F135 is produced in Pratt & Whitney's facilities in East Hartford and Middletown, CT.[16] Rolls-Royce builds the vertical lift system for the F-35B as a subcontractor to Pratt & Whitney.

Previous Alternative Engine Program

Consistent with congressional direction for the FY1996 defense budget, DOD established a program to develop an alternate engine for the F-35. The alternate engine, the F136, was developed by a team consisting of GE Transportation—Aircraft Engines of Cincinnati, OH, and Rolls-Royce of Bristol, England, and Indianapolis, IN. The F136 was a derivative of the F120 engine originally developed to compete with the F119 engine for the F-22 program.

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[12] Statement of Vice Admiral David Architzel, USN, Principal Military Deputy, Research, Development and Acquisition, LTGEN George J. Trautman III, USMC, Deputy Commandant for Aviation, [and] RADM Allen G. Myers, USN, Director of Warfare Integration, Before the Seapower and Expeditionary Warfare [sic: Forces] Subcommittee of the House Armed Services Committee [hearing] on [the] Department of the Navy's Aviation Procurement Program, May 19, 2009, pp. 1-2.

[13] Features for carrier suitability include, among other things, strengthened landing gear, a strengthened airframe, and an arresting hook so as to permit catapult launches and arrested landings, as well as folding wing tips for more compact storage aboard ship.

[14] Some F/A-18E/F supporters argue that it is a "fourth-plus" or "4.5"generation strike fighter because it incorporates some fifth-generation technology, particularly in its sensors.

[15] Statement of Vice Admiral David Architzel, USN, Principal Military Deputy, Research, Development and Acquisition, LTGEN George J. Trautman III, USMC, Deputy Commandant for Aviation, [and] RADM Allen G. Myers, USN, Director of Warfare Integration, before the Seapower and Expeditionary Warfare [sic: Forces] Subcommittee of the House Armed Services Committee [hearing] on [the] Department of the Navy's Aviation Procurement Program, May 19, 2009, p. 1.

[16] Pratt and Whitney's parent firm is United Technologies. It is expected to be transferred to Raytheon Technologies early in 2021.

DOD included the F-35 alternate engine program in its proposed budgets through FY2006, although Congress in certain years increased funding for the program above the requested amount and/or included bill and report language supporting the program.

The George W. Bush Administration proposed terminating the alternate engine program in FY2007, FY2008, and FY2009. The Obama Administration did likewise in FY2010. Congress rejected these proposals and provided funding, bill language, and report language to continue the program.

The General Electric/Rolls Royce Fighter Engine Team ended its effort to provide an alternate engine on December 2, 2011.

Fuller details of the alternate engine program and issues for Congress arising from it are detailed in CRS Report R41131, *F-35 Alternate Engine Program: Background and Issues for Congress*.

Adaptive Engine Transition Program

In 2007, the Air Force established a program called ADVENT, for Adaptive Versatile Engine Technology. Typical jet engines are optimized for economy (as in airliners and military cargo aircraft) or performance (as in fighters.) By varying the bypass ratio, adaptive technology allows jet engines to switch between modes, to improve fuel efficiency and increase thrust, yielding greater range and persistence. Adaptive engines can also improve thermal management.[17]

The Air Force proposed further developing engines using ADVENT technology in the FY2016 budget submission, as the Adaptive Engine Transition Program (AETP). In the report accompanying its version of the FY2016 National Defense Authorization Act (H.Rept. 114-102), the House encouraged the Air Force to explore acquisition strategies to accelerate the program.

In 2016, GE and Pratt & Whitney received contracts worth approximately $1 billion each to further develop their AETP engines.[18] The Pratt AETP engine is known as the XA101; GE's is the XA100.

Current Program Status

The F-35 is currently in low-rate initial production, with 753 aircraft delivered as of the end of 2021.[19] At least 353 of those were in U.S. service.[20] Four to five aircraft are currently delivered each month. The production rate had been scheduled to increase to 170 per year by 2025, but will level off at 156 per year.[21] In keeping with the acquisition plan that overlapped development and production (known as "concurrency"), the F-35 was also in system development and demonstration (SDD), with testing and software development ongoing, from October 2001 until April 11, 2018. The SDD phase will formally continue until the end of Initial Operational Test

[17] Rebecca Grant, "Adaptive Engines," *Air Force Magazine*, September 1, 2012, https://www.airforcemag.com/article/0912engines/.

[18] Aaron Mehta, "US Air Force Funds Next Advanced Engine Stage," *Defense News*, July 1, 2016, https://www.defensenews.com/training-sim/2016/07/01/us-air-force-funds-next-advanced-engine-stage/.

[19] Steve Trimble, "Lockheed Sets F-35 Delivery Record In 2021," *Aerospace Daily and Defense Report*, January 3, 2022, https://aviationweek.com/defense-space/aircraft-propulsion/lockheed-sets-f-35-delivery-record-2021.

[20] Lockheed Martin, "Program Summary as of March 2020," press release, March 2020, https://a855196877272cb14560-2a4fa819a63ddcc0c289f9457bc3ebab.ssl.cf2.rackcdn.com/18179/program_summary_3.3..png.

[21] Steve Trimble, "Lockheed Sets F-35 Delivery Record In 2021," *Aerospace Daily and Defense Report*, January 3, 2022, https://aviationweek.com/defense-space/aircraft-propulsion/lockheed-sets-f-35-delivery-record-2021.

and Evaluation, when a "Milestone C" full-rate production decision will be made.[22] DOT&E approved entering formal IOT&E on December 3, 2018.[23] The full-rate production decision is expected in FY2021.[24]

Recent Developments

Significant developments since the previous major edition of this report (May 27, 2020) include the following, many of which are discussed in greater detail later in the report:

Lots 15-17 Under Negotiation

The F-35 Joint Program Office and Lockheed Martin began negotiating the prices and quantities for the next three low-rate initial production lots of F-35s in 2019. Lot 15 is expected to include 169 jets; Lot 16, 157; and Lot 17, 159.[25] Although no conclusion to the negotiations has been announced, DOD has issued long-lead contracts for Lots 15 and 16.[26]

Changes in International Orders

As noted, the F-35 is an international program, with commitments from program partners and other countries to share in the development costs and acquire aircraft. The other nations' plans have varied over time. The most recent Selected Acquisition Report, released in December 2019, projected 809 international sales—538 to partners in the program and 271 through foreign military sales, an increase of 45 from the previous projection.[27] More recently

- **Finland's** Ministry of Defense announced that it intended to buy 64 F-35s to replace Finland's current F-18 Hornet fleet. The total procurement, including weapons and maintenance, is valued at ~$10.6B.[28] IOC is expected in 2026-2027.
- **Switzerland** announced in June 2021 that it selected the F-35 as the winner of its fighter competition. The contract is expected to be $5.5B for 36 jets.[29]
- **Thailand's** air chief said the Royal Thai Air Force is considering acquiring eight F-35s.[30]

[22] Under the revised schedule following the 2011 program restructure, Milestone C was anticipated in November 2015.

[23] Director, Operational Test and Evaluation, *FY2019 Annual Report*, December 20, 2019, p. 19.

[24] Director, Operational Test and Evaluation, *FY2019 Annual Report*, December 20, 2019, p. 32.

[25] Vivienne Machi, "Pentagon to Begin F-35 Lots 15-17 Negotiations with Lockheed Martin," *Defense Daily*, February 20, 2019, https://www.defensedaily.com/pentagon-begin-f-35-lots-15-17-negotiations-lockheed-martin/pentagon/.

[26] John Keller, "Lockheed Martin prepares to build another 133 new F-35 combat aircraft and avionics for U.S. military," *Military & Aerospace Electronics*, January 7, 2021, https://www.militaryaerospace.com/sensors/article/14189910/f35-avionics-combat-aircraft. "Local Navy Contract Awards; December 2021," *Southern Maryland Online*, January 6, 2022, https://somd.com/news/headlines/2022/23747.php.

[27] Office of the Secretary of Defense, *F-35 Lightning II Joint Strike Fighter (JSF) Program (F-35)*, December, 2019, p. 88.

[28] Tony Osborne, "F-35 Will Be Finland's Next Fighter," *Aerospace Daily and Defense Report*, December 10, 2021, https://aviationweek.com/defense-space/aircraft-propulsion/f-35-will-be-finlands-next-fighter.

[29] Tony Osborne, "Switzerland Selects F-35," *Aerospace Daily and Defense Report*, June 30, 2021, https://aviationweek.com/defense-space/aircraft-propulsion/switzerland-selects-f-35.

[30] Wassana Nanuam, "Air force eyes F-35 stealth jets," *Bangkok Post*, December 31, 2021, https://www.bangkokpost.com/thailand/general/2240091/air-force-eyes-f-35-stealth-jets.

Devolution of Joint Program Office

Section 142 of P.L. 117-81, the National Defense Authorization Act for Fiscal Year 2022, ordered that the major functions of the F-35 joint program office be transferred to the Air Force and Navy by October 1, 2027. The Under Secretary of Defense for Acquisition and Sustainment, in coordination with the Secretary of the Air Force and the Secretary of the Navy, is required to submit a plan to accomplish this transfer by October 1, 2022. Details and a history are covered in the "Program Management" section below.

Advanced Engines

The FY2022 National Defense Authorization Act (P.L. 117-81) directed the Air Force and Navy to deliver acquisition strategies for advanced engines (see the "Adaptive Engine Transition Program" section above.) Both General Electric and Pratt & Whitney have such engines under development.

Testing Progress

DOD's annual testing report stated,

> In FY20, F-35 testing crossed a major milestone, finishing planned open-air combat and electronic attack trials.... As of the end of September 2020, the remaining required IOT&E events are 64 mission trials in the F-35 Joint Simulation Environment (JSE) and two AIM-120 missile trials that were awaiting corrections to deficiencies in the aircraft's mission systems software....
>
> A substantial amount of testing remains, and it cannot be executed until the Joint Simulation Environment (JSE) is ready. The JSE is a man-in-the-loop, software-in-the-loop mission simulator that will provide the only venue, other than actual combat, to test the F-35 against modern threats in realistic densities and mission scenarios. Development of the JSE is now more than three years behind schedule. [31]

Overall,

> Although the fleet-wide trend in aircraft availability showed modest improvement in 2019 and early 2020, the average fleet-wide monthly availability rate for only the U.S. aircraft, for the 12 months ending in September 2020, is below the target value of 65 percent.
>
> Individual deployed units met or exceeded the 80-percent Mission Capable (MC) and 70-percent Fully Mission Capable (FMC) rate goals intermittently, but were not able to meet these goals on a sustained basis.[32]

F-35 Program Origin and History

The Joint Strike Fighter (JSF) program that became the F-35 began in the early 1990s.[33] Three different airframe designs were proposed by Boeing, Lockheed, and McDonnell Douglas (teamed

[31] Director, Operational Test and Evaluation, *FY2020 Annual Report*, January, 2021, pp. II and 19.

[32] Director, Operational Test and Evaluation, *FY2020 Annual Report*, January, 2021, p. 20.

[33] The JSF program emerged in late 1995 from the Joint Advanced Strike Technology (JAST) program, which began in late 1993 as a result of the Clinton Administration's Bottom-Up Review (BUR) of U.S. defense policy and programs. The BUR envisaged the JAST program as a replacement for two other tactical aircraft programs that were being terminated; the A-12 program, which was intended to provide a stealthy new carrier-based attack plane to replace the Navy's aging A-6 carrier-based attack planes, and the Multi-Role Fighter, which the Air Force had considered as a replacement for its F-16 fighters.

with Northrop Grumman and British Aerospace). On November 16, 1996, the Defense Department announced that Boeing and Lockheed Martin had been chosen to compete in the concept demonstration phase of the program, with Pratt and Whitney providing propulsion hardware and engineering support. Boeing and Lockheed were each awarded contracts to build and test-fly two aircraft to demonstrate their competing concepts for all three planned JSF variants.[34]

The competition between Boeing and Lockheed Martin was closely watched. Given the size of the JSF program and the expectation that the JSF might be the last fighter aircraft program that DOD would initiate for many years, DOD's decision on the JSF program was expected to shape the future of both U.S. tactical aviation and the U.S. tactical aircraft industrial base.

In October 2001, DOD selected the Lockheed design as the winner of the competition, and the JSF program entered the system development and demonstration (SDD) phase, with SDD contracts awarded to Lockheed Martin for the aircraft and Pratt and Whitney for the aircraft's engine. General Electric continued technical efforts related to the development of an alternate engine for competition in the program's production phase.

Table 1. F-35 Variant Milestones

	First flown	Original IOC goal	IOC
F-35A	December 15, 2006	March 2013	August 2, 2016
F-35B	June 11, 2008 First hover: March 17, 2010	March 2012	July 31, 2015
F-35C	June 6, 2010	March 2015	February 28, 2019

Source: Prepared by CRS based on press reports and DOD testimony.

Note: IOC is Initial Operational Capability (discussed below).

As shown in **Table 1**, the first flights of an initial version of the F-35A and the F-35B occurred in the first quarter of FY2007 and the third quarter of FY2008, respectively. The first flight of a

In 1995, in response to congressional direction, a program led by the Defense Advanced Research Projects Agency (DARPA) to develop an advanced short takeoff and vertical landing (ASTOVL) aircraft was incorporated into the JAST program. This opened the way for Marine Corps and UK participation in the JAST program, since the Marine Corps and the UK were interested procuring a new STOVL aircraft to replace their aging Harrier STOVL attack aircraft. The name of the program was then changed to Joint Strike Fighter (JSF) to focus on joint development and production of a next-generation fighter/attack plane.

A Joint Operational Requirements Document for the F-35 was issued in March 2000 and revalidated by DOD's Joint Requirements Oversight Council in October 2001. On October 24, 2001, the Defense Acquisition Board held a Milestone B review for the program. (Milestone B approval would permit the program to enter the SDD phase.) On October 25, 2001, the Secretary of Defense certified to Congress (in accordance with Section 212 of the FY2001 defense authorization act [H.R. 4205/P.L. 106-398 of October 30, 2000]) that the program had successfully completed the CDP exit criteria and demonstrated sufficient technical maturity to enter SDD. On October 26, 2001, the SDD contracts were awarded to Lockheed and Pratt and Whitney. A Preliminary Design Review for the F-35 program was conducted in April 2003, and Critical Design Reviews were held in February 2006 (F-35A and F-35B) and June 2007 (F-35C).

[34] Subsequent to the selection of the Boeing and Lockheed Martin designs, Boeing acquired McDonnell Douglas and merged the two firms' JSF teams.

slightly improved version of the F-35A occurred on November 14, 2009.[35] The F-35C first flew on June 6, 2010.[36]

The F-35B's ability to hover, scheduled for demonstration in November 2009, was shown for the first time on March 17, 2010.[37] The first vertical landing took place the next day.[38]

Summary of Program History

On December 21, 2016, then-President-elect Donald J. Trump received a background briefing on the F-35 program, designed to summarize the program's status and challenges. Although the program has progressed since then, it may be interesting to see how DOD characterizes the history of the program when it is not for a public audience. The pertinent chart presented to President-elect Trump is shown in **Figure 2**. Details of the program history follow.

[35] "First Flight," *Defense Daily*, November 23, 2009, p. 3.

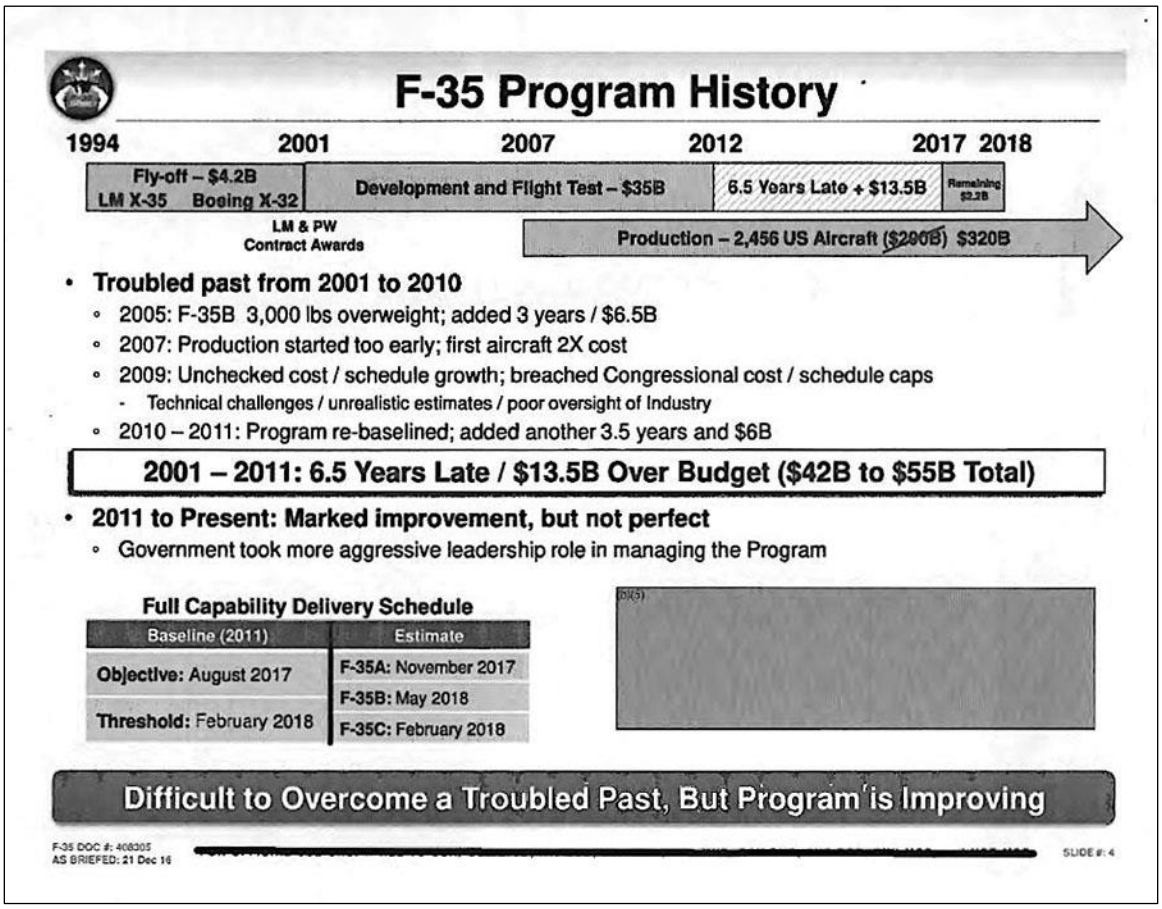
[36] Graham Warwick, "JSF Carrier Variant Meets Handling Goals On First Flight," *Aerospace Daily*, June 7, 2010.

[37] Graham Warwick, "F-35B Hovers for First Time," *Aviation Week/Ares* blog, March 17, 2010.

[38] Graham Warwick, "STOVL F-35B Makes First Vertical Landing," *Aviation Week/Ares* blog, March 18, 2010.

Figure 2. F-35 Program History

(As briefed to President-Elect Trump, 2016)



Source: Joseph Trevithick, "These Are The Briefings President-Elect Trump Got On The F-35, Air Force One, and Nukes," *The War Zone*, April 19, 2019, https://www.thedrive.com/the-war-zone/27541/these-are-the-briefings-president-elect-trump-got-on-the-f-35-air-force-one-and-nukes.

F-35B 3,000 lb. Overweight; Added Three Years/$6.5B

A significant issue in early development, noted in **Figure 2**, was the weight of the F-35B variant. Because the F-35B takes off and lands near-vertically, weight is a particularly critical factor, as aircraft performance with low- to no-airspeed depends directly on the ratio of engine thrust to aircraft weight.

The delay was exacerbated by the consolidation of the former JAST and ASTOVL programs, discussed in footnote 33. Normally, in a development program, the most technically simple variant is developed first, and lessons are applied while working up to more complicated variants. Because the Marine Corps' Harrier fleet was reaching the end of life before the Air Force and Navy fleets the F-35 was designed to replace, in this case, the most complicated variant—the F-35B—had to be developed first. That meant the technical challenges unique to STOVL aircraft delayed all of the variants.

February 2010 Program Restructuring

In November 2009, DOD's Joint Estimating Team issued a report (called JET II) stating that the F-35 program would need an extra 30 months to complete the SDD phase. In response to JET II, the then-impending Nunn-McCurdy breach, and other developments, on February 24, 2010, Pentagon acquisition chief Ashton Carter issued an Acquisition Decision Memorandum (ADM) restructuring the F-35 program. Key elements of the restructuring included the following:

- Extending the SDD phase by 13 months, thus delaying Milestone C (full-rate production) to November 2015 and adding an extra low-rate initial production (LRIP) lot of aircraft to be purchased during the delay. Carter proposed to make up the difference between JET II's projected 30-month delay and his 13-month schedule by adding three extra early-production aircraft to the test program. It is not clear how extra aircraft could be added promptly if production was already behind schedule.
- Funding the program to the "Revised JET II" (13-month delay) level, implicitly accepting the JET II findings as valid.
- Withholding $614 million in award fees from the contractor for poor performance, while adding incentives to produce more aircraft than planned within the new budget.
- Moving procurement funds to R&D. "More than $2.8 billion that was budgeted earlier to buy the military's next-generation fighter would instead be used to continue its development."[39]

"Taken together, these forecasts result in the delivery of 122 fewer aircraft over the Future Years Defense Program (FYDP), relative to the President's FY 2010 budget baseline," Carter said.[40] This reduction led the Navy and Air Force to revise their dates for IOC as noted above.

March 2010 Nunn-McCurdy Breach

On March 20, 2010, DOD formally announced that the JSF program had exceeded the cost increase limits specified in the Nunn-McCurdy cost containment law, as average procurement unit cost, in FY2002 dollars, had grown 57% to 89% over the original program baseline. Simply put, this requires the Secretary of Defense to notify Congress of the breach, present a plan to correct the program, and to certify that the program is essential to national security before it can continue.[41]

> On June 2, 2010, the Under Secretary of Defense for Acquisition, Technology and Logistics issued an Acquisition Decision Memorandum (ADM) certifying the F-35 Program in accordance with section 2433a of title 10, United States Code. As required by section 2433a, of title 10, Milestone B was rescinded. A Defense Acquisition Board (DAB) was held in November 2010.... No decision was rendered at the November 2010 DAB.... Currently, cumulative cost and schedule pressures result in a critical Nunn-McCurdy breach to both the original (2001) and current (2007) baseline for both the Program Acquisition Unit Cost (PAUC) and Average Procurement Unit Cost (APUC). The breach is currently reported at 78.23% for the PAUC and 80.66% for the APUC against the original baseline and 27.34% for the PAUC and 31.23% for the APUC against the current baseline.[42]

[39] Tony Capaccio, "Lockheed F-35 Purchases Delayed in Pentagon's Fiscal 2011 Plan," *Bloomberg News*, January 6, 2010.

[40] *F-35 Lightning II Joint Strike Fighter (JSF) Program Restructure Acquisition Decision Memorandum (ADM)*, Under Secretary of Defense (Acquisition, Technology & Logistics), February 24, 2010.

[41] For a history of the Nunn-McCurdy law and options for its future, see CRS Report R41293, *The Nunn-McCurdy Act: Background, Analysis, and Issues for Congress*, by Heidi M. Peters and Charles V. O'Connor.

[42] Office of the Secretary of Defense, *Selected Acquisition Report (SAR): F-35*, December 31, 2010, p. 4.

February 2012 Procurement Stretch

With the FY2013 budget, F-35 acquisition was slowed, with the acquisition of 179 previously planned aircraft being moved to years beyond the FY2013-2017 FYDP "for a total of $15.1 billion in savings."[43] Note that this stretch, along with the SDD extension already mentioned, contributed to the "6.5 years late" referenced in **Figure 2**.

COVID-19-Related Production Slowdown

On May 19, 2020, Lockheed Martin officials announced a restructuring of the F-35 production plan to account for slowdowns in parts deliveries resulting from the impact of the COVID-19 pandemic on subcontractor production rates. The plan was designed to minimize workforce impacts at the principal F-35 production line in Fort Worth, TX. The restructuring and other COVID-19 effects were expected to reduce the 141 F-35 deliveries planned in 2020 to between 117 and 123. Lockheed had previously changed production methods and cleaning protocols in response to possible COVID-19 cases in its assembly line workforce.[44]

Initial Operational Capability

Congress required a formal declaration of IOCs in Section 155 of the National Defense Authorization Act for Fiscal Year 2013 (P.L. 112-239). The current dates (by fiscal year) are shown in **Table 1**.

The F-35A, F-35B, and F-35C were originally scheduled to achieve IOC in March 2013, March 2012, and March 2015, respectively.[45] The Marine Corps declared F-35B Initial Operational Capability (IOC) on July 31, 2015. The Air Force declared F-35A IOC on August 2, 2016.[46] The Navy declared IOC on February 28, 2019.[47]

It should be noted that IOC means different things to different services:

> F-35A initial operational capability (IOC) shall be declared when the first operational squadron is equipped with 12-24 aircraft, and Airmen are trained, manned, and equipped to conduct basic Close Air Support (CAS), Interdiction, and limited Suppression and Destruction of Enemy Air Defense (SEAD/DEAD) operations in a contested environment. Based on the current F-35 Joint Program Office (JPO) schedule, the F-35A will reach the IOC milestone between August 2016 (Objective) and December 2016 (Threshold)....

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[43] Tony Capaccio, "Pentagon Takes $1.6 Billion From Lockheed F-35 in Biggest Cut," *Bloomberg News*, February 13, 2012.

[44] See, inter alia, Anthony Capaccio, "Lockheed Slowing F-35 Production Amid Covid-Related Parts Delays," *Bloomberg News*, May 19, 2020, https://www.bloomberg.com/news/articles/2020-05-19/lockheed-slowing-f-35-production-amid-covid-related-parts-delays, and Valerie Insinna, "Lockheed slated to miss F-35 delivery target in 2020 as supply chain struggles to keep up," *Defense News*, May 19, 2020, https://www.defensenews.com/breaking-news/2020/05/19/lockheed-to-slow-f-35-production-as-supply-chain-struggles-to-keep-up/.

[45] The Navy had initially accelerated its estimated IOC for the F-35C to September 2014. Andrew Tilghman, "Joint Strike Fighter Timeline Moved Up," *NavyTimes.com*, September 18, 2009. In November 2009, Lockheed announced that the first flight of an F-35C test aircraft would be delayed from the final quarter of 2009 to the first quarter of 2010. (Dan Taylor, "Navy Joint Strike Fighter Carrier Variant Test Aircraft Will Not Fly Until 2010," *Inside the Navy*, November 9, 2009.)

[46] "Air Force Declares F-35A Lightning II 'Combat Ready,'" *Air Force News Service*, August 3, 2016, https://go.usa.gov/xQbTg.

[47] Commander Naval Air Forces Public Affairs, *F-35C Achieves Initial Operational Capability*, Story Number: NNS190228-18, San Diego, CA, February 28, 2019, https://www.navy.mil/submit/display.asp?story_id=108746.

> F-35B IOC shall be declared when the first operational squadron is equipped with 10-16 aircraft, and US Marines are 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. Based on the current F-35 JPO schedule, the F-35B will reach the IOC milestone between July 2015 (Objective) and December 2015 (Threshold)....
>
> Navy F-35C IOC shall be declared when the first operational squadron is equipped with 10 aircraft, and Navy personnel are trained, manned and equipped to conduct assigned missions. Based on the current F-35 JPO schedule, the F-35C will reach the IOC milestone between August 2018 (Objective) and February 2019 (Threshold).[48]

Additionally,

> Each of the three US services will reach initial operating capability (IOC) with different software packages.
>
> The F-35B will go operational for the US Marines in December 2015 with the Block 2B software, while the Air Force plans on achieving IOC on the F-35A in December 2016 with Block 3I, which is essentially the same software on more powerful hardware. The Navy intends to go operational with the F-35C in February 2019, on the Block 3F software.[49]

One complication regarding the Navy's operational capability is that the Navy reportedly will not be able to airlift F-35 engines to carriers at sea until the introduction of the CMV-22 carrier onboard delivery aircraft in 2021.[50]

End of System Development and Demonstration/Entry into IOT&E

The F-35 Joint Program Office declared the 17-year System Development and Demonstration (SDD) effort complete on April 11, 2018. "(T)he developmental flight team has conducted more than 9,200 sorties, accumulated 17,000 flight hours and executed more than 65,000 test points."[51] The end of the flight test effort does not mark the actual end of SDD, though; that will occur at Milestone C, following the completion of initial operational test and evaluation (IOT&E).

The Director of Operational Test and Evaluation (DOT&E) approved entering formal IOT&E on December 3, 2018. DOT&E notes that the F-35 enters IOT&E with 873 unresolved deficiencies, 13 of which are classified as "Category 1 'must-fix' items that affect safety or combat capability."[52] The program's high concurrency means there may be substantial costs to incorporate the lessons of testing: "IOT&E, which provides the most credible means to predict combat performance, likely will not be completed until … over 600 aircraft will already have been built."[53]

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[48] U.S. Navy, United States Marine Corps, United States Air Force, *F-35 Initial Operational Capability*, June 2013.

[49] Aaron Mehta, "After 'Transformative' Year, F-35 Program Focuses on Software, Quantity," *Defense News*, January 14, 2014.

[50] Mark D. Faram, "CMV-22 Osprey will deploy on Vinson with F-35C in 2021," *Navy Times*, April 10, 2018, https://www.navytimes.com/news/your-navy/2018/04/09/cmv-22-osprey-will-deploy-on-vinson-with-f-35c-in-2021/.

[51] Lara Seligman, "F-35 Completes Flight Trials, Now On To Final Test," *Aerospace Daily and Defense Report*, April 12, 2018, http://aviationweek.com/defense/f-35-completes-flight-trials-now-final-test.

[52] Anthony Capaccio, "F-35's Gun That Can't Shoot Straight Adds to Its Roster of Flaws," *Bloomberg News*, January 30, 2020, https://www.instapaper.com/read/1273117282.

[53] Director, Operational Test & Evaluation, *FY 2017 Annual Report*, January 2018, p. 39.

Procurement Quantities

Planned Total Quantities

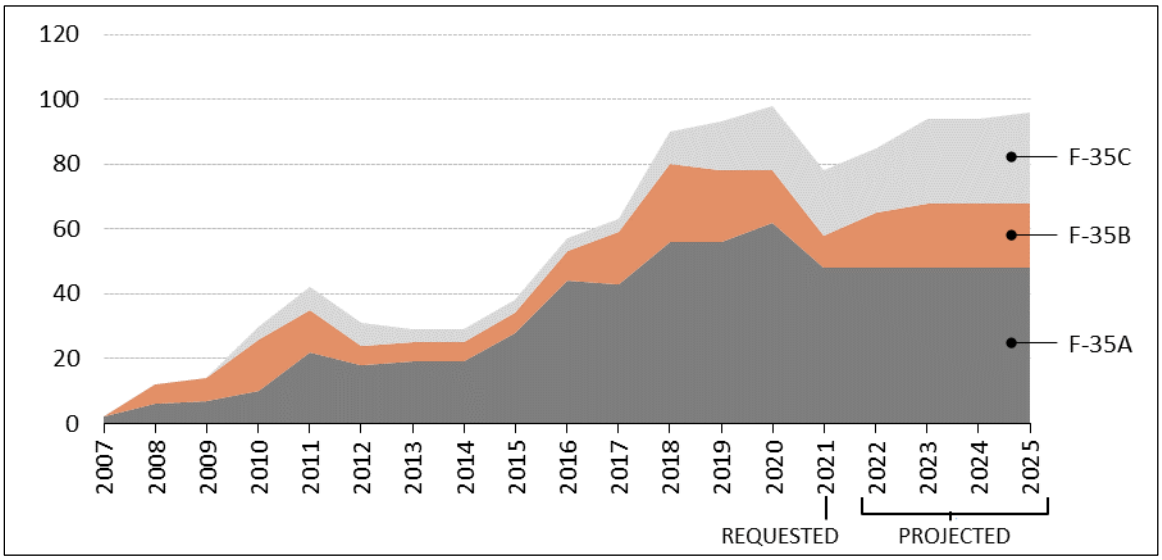
The F-35 program includes a planned total of 2,470 aircraft for the Air Force, Marine Corps, and Navy. This comprises 14 research and development aircraft and 2,456 production aircraft: 1,763 F-35As for the Air Force, 273 F-35Cs for the Navy, and 67 F-35Cs and 353 F-35Bs for the Marine Corps.[54] As noted in "Potential Change in Marine Corps Procurement" above, the Marine Corps recently mooted a change in squadron size that would imply a 54-jet reduction in its planned F-35 fleet, but that has not yet become a validated goal.

Annual Quantities

DOD began procuring F-35s in FY2007. **Figure 3** shows F-35 procurement quantities authorized through FY2020, requested procurement quantities for FY2021, and projected requests through the FYDP. The figures in the table do not include 14 research and development aircraft procured with research and development funding. (Quantities for foreign buyers are discussed in the next section.)

Figure 3. F-35 Procurement Quantities

(Figures shown are for production aircraft; table excludes 14 research and development aircraft)



Source: Prepared by CRS based on DOD data.

[54] "IHS Jane's Defence Insight Report: Air Platforms," June 2013. In 1996, preliminary planning estimated over 3,000 F-35s for DOD and the UK: 2,036 for the Air Force, 642 for the Marines, 300 for the U.S. Navy, and 60 for the Royal Navy. In May 1997, the QDR recommended reducing projected DOD procurement from 2,978 to 2,852: 1,763 for the Air Force, 609 for the Marines, and 480 for the Navy. (Quadrennial Defense Review Cuts Procurement in FY1999, 2000, *Aerospace Daily*, May 20, 1997, p. 280.) In 2003, the Navy reduced its planned procurement of 1,089 F-35Bs and Cs to 680 aircraft as part of the Navy/Marine Corps Tactical Aviation Integration Plan; that requirement was revised in 2016 to 693. See CRS Report RS21488, *Navy-Marine Corps Tactical Air Integration Plan: Background and Issues for Congress*, by Christopher Bolkcom and Ronald O'Rourke (out of print; available to congressional clients from the author upon request). See also DOD, *Selected Acquisition Report: F-35 Lightning II Joint Strike Fighter (JSF) Program (F-35)*, March 19, 2018.

Previous DOD plans contemplated increasing the procurement rate of F-35As for the Air Force to a sustained rate of 80 aircraft per year by FY2015, and completing the planned procurement of 1,763 F-35As by about FY2034. The current Air Force plan levels procurement at 48 per year beginning in 2020; the 1,763 fleet target has not changed.

Past DOD plans also contemplated increasing the procurement rate of F-35Bs and Cs for the Marine Corps and Navy to a combined sustained rate of 50 aircraft per year by about FY2014, and completing the planned procurement of 680 F-35Bs and Cs by about FY2025. The FY2021 budget submission shows a combined F-35B and -C production rate of 30 per year in 2021, toward a fleet goal of 693.

Potential Change in Marine Corps Procurement

On March 23, 2020, the Marine Corps released a "New Force Design Initiative" outlining proposed changes to its force structure. The proposal included reducing the primary aircraft authorization (PAA) of Marine F-35 squadrons from 16 to 10 each. This would affect nine F-35B squadrons (five other active and two reserve F-35B squadrons were already planned to be at 10 PAA). The Corps also has four F-35C squadrons, but those had also previously been planned for 10 PAA.[55] The Marine proposal would appear to require 54 fewer F-35Bs than in the existing program of record, currently 353 F-35Bs and 67 F-35Cs.[56] The Air Force has also been considering force mix changes that could affect the number of F-35s acquired (see the "Issues for Congress" section below).

Proposed Multiyear Procurement

In the December 2017 Selected Acquisition Report, DOD disclosed an intention to acquire F-35s through multiyear contracting.

> From FY 2021 to the end of the program, the USAF production profile assumes one 3-year multi-year procurement (FY 2021-FY 2023) followed by successive 5-year multi-year procurements beginning in FY2024, with the required EOQ investments and associated savings. The Department of Navy (DoN) did not include EOQ funding in the PB 2019 submission for a multiyear in FY 2021-2023 for either the F-35B or F-35C. The DoN plans to reassess that decision in the coming FY 2020 budget cycle. Therefore, the DoN PB 2019 production profile assumes annual procurements from FY 2021-2023, followed by successive 5-year multi-year procurements from FY 2024 to the end of the program with necessary EOQ investments and associated savings.[57]

Subsequent hearings considered the merits of multiyear contracting, but Congress has yet to grant that authority. The FY2020 National Defense Authorization Act (P.L. 116-92) authorized economic order quantity contracting and buy-to-budget acquisition, a variation on multiyear contracting.[58] For a discussion of the differences, see the "F-35 Block Buy" section below.

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[55] U.S. Marine Corps, *2019 Marine Corps Aviation Plan*, Washington, DC, 2019, p. 36, https://www.aviation.marines.mil/portals/11/2019%20avplan.pdf.

[56] U.S. Marine Corps, *Force Design 2030*, March 2020, p. 7, https://go.usa.gov/xvqF9.

[57] Office of the Secretary of Defense, *Selected Acquisition Report (SAR): F-35 Joint Strike Fighter Aircraft (F-35)*, March 19, 2018, p. 11.

[58] See, inter alia, Christen McCurdy, "Congress, Pentagon to hold off on multiyear F-35 contract," *UPI*, November 14, 2019, https://www.upi.com/Defense-News/2019/11/14/Congress-Pentagon-to-hold-off-on-multiyear-F-35-contract/2731573693286/.

Low-Rate Initial Production

F-35s are currently produced under Low-Rate Initial Production (LRIP), with agreements reached for the first 14 lots of aircraft. Each LRIP lot includes both U.S. and international partner aircraft.

Contracted unit prices for F-35s have continued to decline with each production lot. "For example, the price (including airframe, engine and profit) of an LRIP Lot 8 aircraft was approximately 3.6 percent less than an LRIP Lot 7 aircraft, and an LRIP Lot 7 aircraft, was 4.2 percent lower than an LRIP Lot 6 aircraft."[59]

In LRIPs 5, 6, and 7, any cost overruns associated with concurrent development and production would be split equally between the contractor and the government. Prior to LRIP 4, the government bore those costs alone. Beginning with LRIP 8, the contractor is liable for 100% of any cost overrun; if actual cost is lower than the contracted cost, the contractor will receive 80% of the savings, the government 20%.[60]

Table 2. F-35 LRIPs 5-11

(Quantity/Cost in millions of dollars, per aircraft)

LRIP Lot	5[a]	6[b]	7[c, d]	8[e]	9[f]	10[g]	11[h]
F-35A	22/105	23/103	19/98	19/95	42/102	44/95	102/89
F-35B	3/113	7/109	6/104	6/102	13/132	9/123	25/116
F-35C	7/125	6/120	4/116	4/116	2/132	2/122	14/108

Notes: Aircraft costs for LRIPs 5-8 shown do not include engines. All quantities exclude international orders.

a. Christopher Drew, "Lockheed Profit on F-35 Jets Will Rise With New Contract," *The New York Times*, December 17, 2012.

b. Tony Capaccio, "Lockheed Gets Approval Of Next F-35 Production Contract," *Bloomberg News*, July 6, 2012.

c. Amy Butler, "Latest F-35 Deal Targets Unit Cost Below $100 Million," *Aviation Week & Space Technology*, July 30, 2013.

d. Caitlin Lee, "Latest F-35 contracts mark new strategy to reduce costs," *Jane's Defence Weekly*, September 29, 2013.

e. Colin Clark, "New F-35 Prices: A: $95M; B: $102M; C: $116M," *Breaking Defense*, November 21, 2014.

f. Sydney J. Freedberg, Jr., "F-35 'Not Out Of Control': F-35A Prices Drop 5.5%," *Breaking Defense*, December 19, 2016, https://breakingdefense.com/2016/12/33483/.

g. Lockheed Martin, "Agreement Reached on Lowest Priced F-35s in Program History," press release, February 3, 2017, https://www.f35.com/news/detail/agreement-reached-on-lowest-priced-f-35s-in-program-history.

h. Lockheed Martin, *Producing, Operating and Supporting a 5th Generation Fighter*, retrieved March 29, 2020, https://www.f35.com/about/cost.

Although previous LRIP contracts had been arrived at through negotiation between the F-35 Joint Program Office and Lockheed Martin, the LRIP 9 contract was not agreed to by both sides. After prolonged negotiation, the government invoked its right to issue a unilateral contract.[61]

[59] Office of the Secretary of Defense, *Selected Acquisition Report (SAR): F-35 Joint Strike Fighter Aircraft (F-35)*, March 21, 2016, p. 9.

[60] Colin Clark, "New F-35 Prices: A: $95M; B: $102M; C: $116M," *Breaking Defense*, November 21, 2014.

[61] See, inter alia, Colin Clark, "F-35: DoD Forces Lockheed To Accept Its Price For LRIP 9," *Breaking Defense*, November 2, 2016, https://breakingdefense.com/2016/11/jpo-to-lockheed-no-more-talkie-heres-lrip-9-deal/.

F-35 Block Buy

The LRIP 11 award, incorporating as it does options for lots 12-14, has been labeled a block buy.[62] Block buy contracts commit the government to purchasing certain quantities of aircraft over a number of years, which allows the contractor to acquire parts in greater quantity and plan workforce levels in advance, helping to reduce cost. "By purchasing supplies in economic quantities, Lockheed Martin and Pratt & Whitney estimate that 8 percent and 2.3 percent cost savings, respectively, could be achievable."[63] A 2018 RAND Corporation analysis offered some of the possible savings from a (then-mooted) block buy.[64]

What Is Block Buy?[65]

Block buy contracting (BBC) permits DOD to use a single contract for more than one year's worth of procurement of a given kind of item without having to exercise a contract option for each year after the first year. It is similar to multiyear procurement in that DOD needs congressional approval for each use of BBC.

BBC differs from MYP in the following ways:

- There is no permanent statute governing the use of BBC.
- There is no requirement that BBC be approved in both a DOD appropriations act and an act other than a DOD appropriations act.
- Programs being considered for BBC do not need to meet any legal criteria to qualify for BBC because there is no permanent statute governing the use of BBC that establishes such criteria.
- A BBC contract can cover more than five years of planned procurements. The BBC contracts currently being used by the Navy for procuring Littoral Combat Ships, for example, cover a period of seven years (FY2010-FY2016).
- Economic order quantity (EOQ) authority does not come automatically as part of BBC authority because there is no permanent statute governing the use of BBC that includes EOQ authority as an automatic feature. To provide EOQ authority as part of a BBC contract, the provision granting authority for using BBC in a program may need to state explicitly that the authority to use BBC includes the authority to use EOQ.
- BBC contracts are less likely to include cancellation penalties.

"A full block buy, including US jets, could save anywhere from $2 billion to $2.8 billion, according to industry estimates."[66] Congressional approval would be required for a U.S. block buy.[67]

In related developments, Section 141 of the Fiscal Year 2018 National Defense Authorization Act included language authorizing DOD to enter into economic order quantity contracts for advance

[62] Gareth Jennings, "US DoD awards first block-buy for F-35," *Jane's Defence Weekly*, October 30, 2019, https://www.janes.com/article/92238/us-dod-awards-first-block-buy-for-f-35.

[63] U.S. Government Accountability Office, *F-35 JOINT STRIKE FIGHTER: Continued Oversight Needed as Program Plans to Begin Development of New Capabilities*, 16-390, April 2016, p. 23, http://www.gao.gov/assets/680/676584.pdf.

[64] James D. Powers et al., *F-35 Block Buy: An Assessment of Potential Savings*, RAND Project Air Force, RR2063, Santa Monica, CA, 2018, https://www.rand.org/content/dam/rand/pubs/research_reports/RR2000/RR2063/RAND_RR2063.pdf.

[65] Description adapted from CRS Testimony TE10004, *The Status of Coast Guard Cutter Acquisition Programs*, by Ronald O'Rourke.

[66] Valerie Insinna, "Program Head Hints F-35 Contract Could Be Announced at Farnborough," *Defense News*, July 9, 2016.

[67] For a more detailed discussion of block buy, see CRS Report R41909, *Multiyear Procurement (MYP) and Block Buy Contracting in Defense Acquisition: Background and Issues for Congress*, by Ronald O'Rourke.

parts for F-35s to be procured in FY2019 and FY2020, and the FY2020 NDAA (P.L. 116-92) authorized economic order quantity and buy-to-budget for F-35 aircraft.

Lots 12-14 Agreed To

On June 10, 2019, DOD and Lockheed Martin reached initial agreement on F-35 production Lot 12, with options for Lots 13 and 14. The deal would encompass 478 aircraft for $34 billion, including sales to international partners. [68] On October 29, 2019, negotiations were concluded with 149, 160, and 169 aircraft in the respective lots.[69] While the contract announcement provided no breakdown of those numbers by model and year, it did specify that 106 were for the United States (64 F-35As, 26 F-35Bs, and 16 F-35Cs) with 71 F-35As and 18 F-35Bs for foreign countries participating in the consortium and 60 F-35As for Foreign Military Sales customers.[70]

As noted in the "Lots 15-17 Under Negotiation" section above, prices have not been concluded for the last three lots shown in **Table 3**.

Table 3. F-35 LRIPs 12-17

(Quantity/Cost in millions of dollars, per aircraft)

LRIP Lot	12	13	14	15	16	17
F-35A	??/82	??/79	??/78	116/??	101/??	98/??
F-35B	??/108	??/105	??/101	29/??	32/??	37/??
F-35C	??/103	??/98	??/94	24/??	24/??	24/??

Source: LRIP 12-14 costs from Lockheed Martin, "F-35 LRIP 12-14 Fact Sheet," press release, October 29, 2019, https://www.f35.com/content/dam/lockheed-martin/aero/f35/documents/f-35_lot_12-14factsheet_-_29_oct_2019.pdf. Projected LRIP 15-17 quantities from Department of Defense, *LOTs 15-17 Pre Solicitation Notice*, February 13, 2019, https://go.usa.gov/xtj99.

Notes: LRIP 15-17 prices not yet agreed on. In the undefinitized contract action for LRIP 12-14, quantities per model per year are not disclosed.

Program Management

The JSF joint program office is jointly managed and staffed by the Department of the Air Force and the Department of the Navy. Service Acquisition Executive (SAE) responsibility alternates between the two departments. When the Air Force has SAE authority, the F-35 program director is from the Navy, and vice versa. Air Force Lt Gen Eric T. Fick became the F-35 program manager, succeeding Navy Vice Admiral Mathias Winter, on July 11, 2019.[71]

Recognizing that the bulk of F-35 development has been completed, and consonant with broader congressional direction to decentralize acquisition and increase the acquisition authority of the

[68] Lockheed Martin, "Pentagon and Lockheed Martin Reach Handshake Agreement on F-35 Production Contract," press release, June 10, 2019, https://www.f35.com/news/detail/pentagon-and-lockheed-martin-reach-handshake-agreement-on-f-35-product1.

[69] C. Todd Lopez, *DOD Finalizes Purchase Plan for F-35 Aircraft*, Department of Defense, Washington, DC, October 29, 2019, https://www.defense.gov/Explore/News/Article/Article/2002585/dod-finalizes-purchase-plan-for-f-35-aircraft/.

[70] Department of Defense, *Contracts for Nov. 14, 2018*, November 14, 2018, https://go.usa.gov/xtj5e.

[71] U.S. Navy, "F-35 Program Sees Changing of Guard," press release, July 12, 2019, https://www.navy.mil/submit/display.asp?story_id=110201.

military services,[72] Congress ordered that the joint program office's sustainment and acquisition functions be transferred to the Navy and Air Force in the National Defense Authorization Act for Fiscal Year 2022 (P.L. 117-81).

Congress earlier required DOD to examine alternative F-35 management structures.[73] Proponents of transfer argued that the overhead structure of a joint office, even if useful in overseeing development of a joint aircraft, is not needed once production has been established. Further, they argued that the F-35 is functionally three separate aircraft, with much less commonality than envisioned early in the program. "[E]ven the Program Executive Officer of the F-35 Joint Program Office, General Christopher Bogdan, recently admitted the variants are only 20–25 percent common."[74] Supporters cited the requirement by the United States to support international customers and to oversee further software and other upgrades as reasons to keep the office in place.[75]

In a letter to Congress accompanying that report, Under Secretary of Defense for Acquisition and Sustainment Ellen Lord declared an intention to

> begin a deliberate, conditions-based, and risk-informed transition ... from the existing F-35 management structure to an eventual management structure with separate Service-run F-35A and F-35B/C program offices that are integrated with and report through the individual Military Departments.[76]

Software Development

> You can see from its angled lines, the F-35 is a stealth aircraft designed to evade enemy radars. What you can't see is the 24 million lines of software code which turn it into a flying computer. That's what makes this plane such a big deal.[77]

The F-35's integration of sensors and weapons, both internally and with other aircraft, is touted as its most distinctive aspect. As that integration is primarily realized through complex software, it may not be surprising to observe that writing, validating, and debugging that software is among the program's greatest challenges. F-35 operating software is released in blocks, with additional capabilities added from one block to the next.

> I'm concerned about the software, the operational software.... And I'm concerned about the ALIS [Autonomic Logistics Information System], that is another software system,

[72] CRS Report R45068, *Acquisition Reform in the FY2016-FY2018 National Defense Authorization Acts (NDAAs)*, by Heidi M. Peters.

[73] Section 146 of the FY2017 National Defense Authorization Act (P.L. 114-328).

[74] S.Rept. 114-255, p. 280.

[75] See, inter alia, Oriana Pawlyk, "As Services Take Greater Role on F-35, Joint Program Office to Remain," *Military.com*, April 11, 2018, https://www.military.com/dodbuzz/2018/04/11/services-take-greater-role-f-35-joint-program-office-remain.html; Valerie Insinna, "F-35 program head supportive of future transition to service-led offices," *Defense News*, April 12, 2018, https://www.defensenews.com/digital-show-dailies/navy-league/2018/04/11/f-35-program-head-supportive-of-future-transition-to-service-led-offices/; and Marc Selinger, "DoD Eyes Shifting F-35 Management To Military Services," *Defense Daily*, April 4, 2018.

[76] Letter from Ellen M. Lord, Under Secretary (Acquisition and Sustainment), to Rep. Mac Thornberry, Chairman, House Committee on Armed Services, March 27, 2018.

[77] David Martin, "Is the F-35 worth it?," *60 Minutes*, February 16, 2014.

> basically that will provide the logistics support to the systems. – Frank Kendall, Under Secretary of Defense for Acquisition, Technology & Logistics.[78]

Currently, the ultimate planned software release is Block 4, which will be the first block to contain full combat capability and a complete weapons suite, including conventional weapons like the Small Diameter Bomb II and nuclear capability. However, Block 4 will not be available to all F-35s; it will require aircraft upgraded with Technical Refresh-3 (TR-3) hardware.[79] New F-35s are expected to begin delivering with TR-3 in lot 15, scheduled for CY2023.[80]

Table 4. F-35 Software Block Schedule

Block	Attributes	Released
2B	Required for Marine IOC	March, 2015
3i (initial)	Required for USAF IOC; basic aircraft operation and navigation, some combat capability.	August, 2016
3F (final) (now called 30PXX)	Required for Navy IOC; expanded combat capability with basic weapons.	September, 2017
4	Adds nuclear weapons capability (among other things)	Under development

Source: Compiled by CRS from various sources.

Kendall's concern was echoed by then-F-35 program manager Air Force Lieutenant General Christopher Bogdan. In testimony to the House Armed Services Subcommittee on Tactical Air and Land Forces, he noted that it is the

> "complexity of the software that worries us the most.... Software development is always really, really tricky... We are going to try and do things in the final block of this capability that are really hard to do." Among them is forming software that can share the same threat picture among multiple ships across the battlefield, allowing for more coordinated attacks.[81]

C2D2 Program

Beginning in 2018, upgrades to the F-35's software and other capabilities were combined in an effort now known as Continuous Capability Development and Delivery (C2D2). C2D2's principal task is developing the Block 4 software, but it includes other elements like TR-3 and dual (nuclear) capability, discussed below. According to the Director of Operational Test and Evaluation,

> The current Continuous Capability Development and Delivery (C2D2) process has not been able to keep pace with adding new increments of capability as planned. Software

[78] Aaron Mehta, "After 'Transformative' Year, F-35 Program Focuses on Software, Quantity," *Defense News*, January 14, 2014. Kendall is now Secretary of the Air Force.

[79] Valerie Insinna, "F-35 upgrade plan awaiting approval from top Pentagon acquisition exec," *Defense News*, October 2, 2018, https://www.defensenews.com/air/2018/10/02/f-35-upgrade-plan-awaiting-approval-from-top-pentagon-acquisition-exec/.

[80] Director, Operational Test and Evaluation, *FY2019 Annual Report*, December 20, 2019, p. 21.

[81] Amy Butler, "Bogdan Warns Of Possible Six-Month F-35 Slip After Development Ends," *AviationWeek.com*, February 26, 2014.

> changes, intended to introduce new capabilities or fix deficiencies, often introduced stability problems and adversely affected other functionality. [82]

According to the Government Accountability Office, that development is now behind schedule and over budget:

> Since May 2019, we found the program office has increased its estimate by about 14 percent, to $12.1 billion, primarily due to schedule delays. The program now expects to extend the delivery of Block 4 capabilities by 2 additional years, through 2026… Additionally, most of the capabilities the F-35 program planned to deliver in 2019 were delayed.[83]

C2D2 Program Oversight

A shown in **Table 5**, the FY2021 budget submission projects the cost of C2D2 as $7.0 billion to FY2025. International partners may contribute to this development effort; according to then-F-35 program executive officer Vice Admiral Mathias Winter in 2018, consortium partners were prepared to contribute $3.7 billion toward Block 4 software development through 2024.[84] Some in Congress argue that a program of that size should part with traditional procurement practice for an upgrade and be run as a separate Major Defense Acquisition Program, with its own budget line and the concomitant reporting requirements; language to this effect was included in the Senate's version of the FY2017 National Defense Authorization Act. This is discussed further in "Issues for Congress," below.

Table 5. C2D2 Budgets, FY2021-FY2025

(In millions of dollars)

	FY21	FY22	FY23	FY24	FY25	Total
F-35A	785.336	549.279	450.915	521.012	586.709	2893.251
F-35B	379.549	323.597	294.404	283.981	244.932	1526.463
F-35C	330.386	261.923	246.494	265.615	248.487	1352.905
International	359.626	285.969	211.292	208.053	177.542	1242.482
All						7015.101

Source: FY2021 DOD RDT&E budget submission books for Air Force and Navy. The FY2022 budget books did not include outyear projections.

Notes: Only line items specifically designated as C2D2.

The $7.0 billion specifically designated for C2D2 may not be the total funding for the program, as Vice Admiral Winter had earlier indicated that just the cost for the Block 4 upgrade was to be more than $10 billion through FY2024.[85]

[82] Director, Operational Test and Evaluation, *FY2019 Annual Report*, December 20, 2019, p. 19.

[83] U.S. Government Accountability Office, *F-35 JOINT STRIKE FIGHTER: Actions Needed to Address Manufacturing and Modernization Risks*, GAO-20-339, May, 2020, p. 31, https://www.gao.gov/products/GAO-20-339.

[84] Pat Host, "Pentagon faces major cost increase on F-35 Block 4 modernisation," *IHS Jane's Defence Weekly*, March 8, 2018, http://www.janes.com/article/78443/pentagon-faces-major-cost-increase-on-f-35-block-4-modernisation.

[85] Pat Host, "Pentagon faces major cost increase on F-35 Block 4 modernisation," *IHS Jane's Defence Weekly*, March 8, 2018, http://www.janes.com/article/78443/pentagon-faces-major-cost-increase-on-f-35-block-4-modernisation.

Autonomic Logistics Information System

The issues cited above focused on software development for the F-35's onboard mission systems. A supporting system, the Autonomic Logistics Information System (ALIS), also requires extensive software development and testing. "ALIS is at the core of operations, maintenance and supply-chain management for the F-35, providing a constant stream of data from the plane to supporting staff."[86] The pace of ALIS development has been cited by service officials as hindering F-35 deployment.

DOD's Director of Operational Test & Evaluation stated that

> Although the program released several new versions of ALIS in 2019 that improved ALIS usability, these improvements did not eliminate the major problems in ALIS design and implementation. These deficiencies caused delays in troubleshooting and returning broken aircraft to mission capable status.[87]

GAO reported that

> ALIS may not be deployable: ALIS requires server connectivity and the necessary infrastructure to provide power to the system. The Marine Corps, which often deploys to austere locations, declared in July 2015 its ability to operate and deploy the F-35 without conducting deployability tests of ALIS. A newer version of ALIS was put into operation in the summer of 2015, but DOD has not yet completed comprehensive deployability tests.
>
> ALIS does not have redundant infrastructure: ALIS's current design results in all F-35 data produced across the U.S. fleet to be routed to a Central Point of Entry and then to ALIS's main operating unit with no backup system or redundancy. If either of these fail, it could take the entire F-35 fleet offline.[88]

To date, the F-35's operators have been coping with ALIS's shortcomings. "Most capabilities function as intended only with a high level of manual effort by ALIS administrators and maintenance personnel. Manual work-arounds are often needed to complete tasks designed to be automated."[89]

> Air Force Lt. Gen. Chris Bogdan told reporters that the plane could fly without the $16.7 billion ... ALIS for at least 30 days. The software, which runs on ground computers, not the plane itself, manages the aircraft's supply chain, aircraft configuration, fault diagnostics, mission planning, and debriefing – none of which are critical to combat flight.[90]

[86] Aaron Mehta, "After 'Transformative' Year, F-35 Program Focuses on Software, Quantity," *Defense News*, January 14, 2014.

[87] Director, Operational Test and Evaluation, *FY2019 Annual Report*, December 20, 2019, p. 20.

[88] U.S. Government Accountability Office, *F-35 Sustainment: DOD Needs a Plan to Address Risks Related to Its Central Logistics System*, 16-439, April 14, 2016.

[89] Director, Operational Test and Evaluation, *FY2017 Annual Report*, January 2018, p. 53.

[90] Patrick Tucker, "F-35 Will Fly Despite Auditor's Fleet-Grounding Warning," *Defense One*, April 17, 2016.

ALIS Replacement

Some of the problems with ALIS reportedly stem from its 1990s-based architecture.[91] DOD is replacing ALIS with a new technology system called ODIN, for Operational Data Integrated Network.[92]

ODIN is designed to be more user-friendly and less prone to error. Program officials decided to replace ALIS rather than upgrading it further in order to take advantage of modern programming architectures.

> We have old hardware, we have old operating systems… if we were ever going to get to a modern software architecture, modernizing ALIS wasn't going to get us there. [Replacement is] so that we can leverage all the things that have happened in software development over the last couple of decades.
>
> The code in this airplane is old… it's frankly going to take a couple of years for this to all iron itself out.[93]

ODIN will work with F-35s that have the Technical Refresh-3 hardware package, beginning with acquisition Lot 15 in 2023. That package includes a new integrated core processor, panoramic cockpit display, and an enhanced memory unit. The company intends to incorporate TR3 in F-35s starting in Lot 15, with those jets rolling off the production lot in 2023.[94] Earlier F-35s will, at least initially, continue with ALIS version 3.5, which is being refreshed "roughly every 120 days or so." "ALIS 3.5 is going to be the core … capability for our sustainers until we get ODIN up and online."[95]

Dual Capability

Some F-35As will be dual capable aircraft (DCA), meaning that they will have the ability to deliver nuclear ordnance. Dual capability is expected to be included in the Block 4 software release, with initial capability for the B61-12 weapon.[96] The F-35A DCA is scheduled to achieve nuclear certification in January, 2023.[97]

Funding for DCA development has been carried alternately in Air Force PE 0207142F, under F-35 Squadrons, and C2D2, PE 0604840F. Requested funding in FY2022, in PE 0207142F, is $44.816 million; the FY2022 NDAA approved this sum.

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[91] Lara Seligman, "F-35 Sustainment Challenges Mount As Global Fleet Grows," *Aviation Week and Space Technology*, April 5, 2018, http://aviationweek.com/defense/f-35-sustainment-challenges-mount-global-fleet-grows.

[92] See, inter alia, John A. Tirpak, "F-35 Program Dumps ALIS for ODIN," *Air Force*, January 21, 2020, https://www.airforcemag.com/f-35-program-dumps-alis-for-odin/.

[93] Brigadier General David Abba, Director of the F-35 Integration Office, Headquarters U.S. Air Force, "Briefing to the Mitchell Institute," Arlington, VA, March 9, 2020, https://www.youtube.com/watch?v=DPvKWp7tSqY.

[94] Valerie Insinna, "Lockheed hypes F-35's upgrade plan as interest in 'sixth-gen' fighters grows," *Defense News*, June 21, 2019, https://www.defensenews.com/digital-show-dailies/paris-air-show/2019/06/21/lockheed-hypes-f-35s-upgrade-plan-as-interest-in-sixth-gen-fighters-grows/.

[95] Brigadier General David Abba, op.cit.

[96] Testimony of Lt Gen Christopher C. Bogdan, F-35 Program Executive Officer, before the U.S. Congress, House Committee on Armed Services, Subcommittee on Tactical Air and Land Forces, *Military Services Fifth–Generation Tactical Aircraft Challenges and F–35 Joint Strike Fighter Program Update*, 115th Cong., 1st sess., February 16, 2017, H.A.S.C. No. 115–6 (Washington: GPO, 2017), p. 17. For more on the B61, see CRS Report RL33640, *U.S. Strategic Nuclear Forces: Background, Developments, and Issues*, by Amy F. Woolf.

[97] Office of the Secretary of Defense, *Selected Acquisition Report (SAR): F-35 Joint Strike Fighter Aircraft (F-35)*, March 17, 2019, p. 14.

Cost and Funding[98]

Total Program Acquisition Cost[99]

As of December 2019, the most recent Selected Acquisition Report, the total estimated acquisition cost (the sum of development, procurement, and military construction [MilCon] costs) of the F-35 program in constant (i.e., inflation-adjusted) FY2012 dollars was about $321.4 billion, including about $71.9 billion in research and development, about $245.0 billion in procurement, and about $4.5 billion in MilCon.[100]

In then-year dollars (meaning dollars from various years that are not adjusted for inflation), the figures are about $397.8 billion, including about $70.1 billion in research and development, about $322.5 billion in procurement, and about $5.2 billion in military construction. That represents approximately $30 billion less than projected the previous year.

Prior-Year Funding

Through FY2018, the F-35 program had received a total of roughly $150.6 billion of funding in then-year dollars, including about $58.4 billion in research and development, about $89.2 billion in procurement, and approximately $3.0 billion in military construction.

Unit Costs

As of December 2019, the F-35 program had a program acquisition unit cost (or PAUC, meaning total acquisition cost divided by the 2,470 research and development and procurement aircraft) of about $108.1 million and an average procurement unit cost (or APUC, meaning total procurement cost divided by the 2,456 production aircraft) of $83.1 million, in constant FY2012 dollars.

However, this reflects the cost of the aircraft without its engine, as the engine program was broken out as a separate reporting line in 2011.

As of December 2019, the F-35 engine program had a program acquisition unit cost of about $22.1 million and an average procurement unit cost of $16.7 million in constant FY2012 dollars. Just as the reported airframe costs represent a program average and do not discriminate among the variants, those engine costs do not discriminate between the single engines used in the F-35A and C and the more expensive engine/lift fan combination for the F-35B.

However, beginning in December 2016, DOD's Selected Acquisition Reports broke out unit recurring flyaway costs of the three engines as well as the separate airframes, as follows:

[98] The F-35 program receives (or in the past received) funding from the Air Force, Navy, and Defense-Wide research, development, test, and evaluation (RDT&E) accounts (the Defense-Wide RDT&E funding occurred in FY1996-FY1998); Non-Treasury Funds (i.e., financial contributions from the eight other countries participating in the F-35 program)—a source of additional research and development funding; the Air Force and Navy aircraft procurement accounts (the Navy and Marine Corps are organized under the Department of the Navy, and Marine Corps aircraft development and procurement costs are funded through the Navy's RDT&E and aircraft procurement accounts); and the Air Force MilCon account and the Navy and Marine Corps MilCon account.

[99] Figures in this section come from Office of the Secretary of Defense, *F-35 Lightning II Joint Strike Fighter (JSF) Program (F-35)*, December, 2019. This is the most recent Selected Acquisition Report issued for the program.

[100] The procurement cost figure of about $245.0 billion does not include the cost of several hundred additional F-35s that are to be procured other countries that are participating in the F-35 program. The figure does, however, assume certain production-cost benefits for DOD aircraft that result from producing F-35s for other countries.

Table 6. F-35 Projected Unit Recurring Flyaway Cost

(Assumes 802 international sales)

$M (2012)	F-35A	F-35B	F-35C
Airframe	57.4	72.1	72.3
Engine	10.7	26.3	10.8
Total	68.1	98.4	83.1

Source: Office of the Secretary of Defense, *F-35 Lightning II Joint Strike Fighter (JSF) Program (F-35)*, December, 2019. This is the most recent Selected Acquisition Report issued for the program.

Note: Versions of this chart prior to FY2018 assumed 2443 U.S. sales and 612-673 international sales rather than 2456/802.

Critics note that the costs reported in the Selected Acquisition Reports contain a number of assumptions about future inflation rates, production learning curves, and other factors, and argue that these figures do not accurately represent the true cost of developing and acquiring the F-35.[101]

Other Cost Issues

Acquisition Cost and Long-Term Affordability

Over time, as the program has matured and unit costs have decreased in succeeding procurement lots, attention on F-35 costs has shifted. The acquisition cost of the program is still large, and as DOD considers the prospect of flat budgets for the future, other programs increasingly compete with the F-35 for budget share. The Government Accountability Office, for example, has increasingly questioned DOD's ability to afford the current F-35 program given other demands on budgets. This is a contrast to earlier reports, which focused more on the program's ability to meet its cost targets.

More recently, though, attention has moved to long-term affordability and sustainment costs, as discussed below.

Unit Cost Projections

The F-35 program had long established a goal of making the F-35 cost-competitive with previous-generation aircraft. (It should be noted that the articles cited below reference the cost of the F-35A, the simplest model.)

> F-35 fighter jets will sell for as little as $80 million in five years, according to the Pentagon official running the program.
>
> "The cost of an F-35A in 2019 will be somewhere between $80 and $85 million, with an engine, with profit, with inflation," U.S. Air Force Lieutenant General Christopher Bogdan, the Pentagon's manager of the program, told reporters in Canberra today.[102]

[101] A detailed critique of the SAR figures with suggestions for alternatives appeared in *Time* magazine's "Battleland" blog. Authored by Winslow Wheeler of the Center for Defense Information, the most relevant entries are http://nation.time.com/2013/06/04/alphabet-soup-paucs-apucs-urfs-cost-variances-and-other-pricing-dodges/ and http://nation.time.com/2013/06/05/the-deadly-empirical-data/.

[102] Jason Scott, "F-35s to Sell for as Low as $80 Million in 2019, Pentagon Says," *Bloomberg.com*, March 11, 2014.

That article dated from 2014. More recently, efforts were increased to reach the same target:

> [Lockheed Martin] will invest up to $170 million over the next two years to extend its existing "Blueprint for Affordability" measure ... to drive down the unit cost of an F-35A to $85 million by 2019.[103]

As noted in **Table 6**, the average unit flyaway cost of an F-35A is officially projected at $80.6 million in constant 2012 dollars. However, according to the recent agreement on F-35 production lot 11, an F-35A "is set to decrease from a Lot 11 price of $89.2 million to $82.4 million in Lot 12; $79.2 million in Lot 13; and $77.9 million in Lot 14."[104]

Engine Costs

In 2013, engine maker Pratt & Whitney embarked on a program to reduce the F-35 engine's cost.[105] Following release of data showing the "cost of acquiring the planned 2,443 airframes and associated systems rose 1%, while engine costs climbed 6.7%,"[106] the program manager reportedly singled out Pratt for criticism "after having improved relations with the F-35's prime contractor, Lockheed Martin Corp., securing lower prices for each batch of new airframes and closing deals far quicker than in the past."[107]

Subsequently, Pratt & Whitney has signed contracts for engines through LRIP 11 that show a steady percentage decrease in cost. The LRIP 11 announcement did not included a dollar figure for the engines, instead citing percentage decreases in cost. "[Pratt & Whitney] is claiming competitive privilege in its sole-source deal for F-35 engines in not releasing its actual numbers."[108]

Pratt says that "in general, the unit recurring flyaway (URF) price for the 110 LRIP Lot 11 conventional takeoff and landing and carrier variant propulsion systems will be reduced 0.34 percent from the previously negotiated LRIP Lot 10 URF. The URF price for the 25 LRIP Lot 11 short takeoff and vertical landing propulsion systems (including lift systems) will be reduced 3.39 percent from the previously negotiated LRIP Lot 10 URF."[109]

The issue of engine cost transparency is addressed in "Issues for Congress," below.

Anticipated Upgrade Costs

The degree of concurrency in the F-35 program, in which aircraft are being produced while the design is still being revised through testing, has made upgrades to early-production aircraft inevitable. "For all F-35 variants, structural and durability testing led to significant discoveries

[103] Valerie Insinna, "Lockheed Extends F-35 Cost-Cutting Initiative To Save Billions," *Defense News*, July 11, 2016.

[104] Valerie Insinna, "In newly inked deal, F-35 price falls to $78 million a copy," *Defense News*, October 29, 2019, https://www.defensenews.com/air/2019/10/29/in-newly-inked-deal-f-35-prices-fall-to-78-million-a-copy/.

[105] Andrea Shalal, "Pratt must push harder to cut F-35 engine cost -Pentagon," *Reuters.com*, April 7, 2014.

[106] Doug Cameron, "Pentagon official criticizes Pratt & Whitney," *Marketwatch.com*, April 17, 2014.

[107] Ibid.

[108] Ibid.

[109] Pratt & Whitney, "Pratt & Whitney and F-35 Program Office Announce Contract Award for 135 F135 Engines," press release, May 31, 2018, https://utc.com/en/news/PW/2018/05/31/pratt-whitney-and-f-35-program-office-announce-contract-award-for-135-f135-engi.

requiring repairs and modifications to production designs, some as late as Lot 12 aircraft, and retrofits to fielded aircraft."[110]

The cost of those upgrades may vary, depending on what revisions are made during the testing process. However, the cost of such upgrades is not included in the negotiated price of each production lot.

The first F-35As, for example, were loaded with a basic software release (Block 1B) that provides basic aircraft control, but does not have the degree of sensor fusion or weapons integration expected in later blocks. "The initial estimate for modifying early-production F-35As from a basic configuration to a capable warfighting level is $6 million per jet, plus other associated expenses not included in that figure."[111] That would make the current cost of upgrading the earliest F-35As to Block 3F about $100 million. In order to increase capability, the Air Force intends to upgrade the aircraft step-by-step as new software releases become available rather than waiting and jumping to the final release of Block 3F.

The cost of the major upgrade to Block 4 is discussed in "Issues for Congress," below.

Operating and Support Costs

Since 2015, operations and sustainment costs for the F-35 fleet's lifecycle have been estimated at more than $1 trillion,[112] "which DOD officials have deemed unaffordable. The program's long term sustainment estimates reflect assumptions about key cost drivers that the program does not control, including fuel costs, labor costs, and inflation rates."[113] "The eye-popping estimate has raised hackles at the Defense Department and on Capitol Hill since it was disclosed in 2011. It covers the cost of fuel, spare parts, logistics support and repairs."[114] It may be worth noting that "the F-35 was ... the first big Pentagon weapons program to be evaluated using a 50-year lifetime cost estimate—about 20 years longer than most programs—which made the program seem artificially more expensive."[115]

The December 2018 F-35 Selected Acquisition Report spoke (in language unusual for that document) to the need to reduce those costs:

> At current estimates, the projected F-35 sustainment outlays based upon given planned fleet growth will strain future service O&S budgets. (NB: The previous version had used the words "are too costly.") The prime contractor must embrace much-needed supply chain management affordability initiatives, optimize priorities across the supply chain for spare and new production parts, and enable the exchange of necessary data rights to implement the required stand-up of planned government organic software capabilities.[116]

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[110] Director, Operational Test and Evaluation, *FY2019 Annual Report*, December 20, 2019, p. 23.

[111] Gabe Starosta, "Block Upgrades For Earliest F-35s To Cost $6M Per Aircraft," *InsideDefense.com*, March 26, 2014.

[112] Office of the Secretary of Defense, *Selected Acquisition Report (SAR): F-35*, editions for December, 2011 through December, 2019.

[113] U.S. Government Accountability Office, *F-35 JOINT STRIKE FIGHTER: Problems Completing Software Testing May Hinder Delivery of Expected Warfighting Capabilities*, GAO-14-322, March 2014, p. 12.

[114] Sandra I. Erwin, "Next Battle for F-35: Bring Down Operations Costs," *National Defense (nationaldefensemagazine.org)*, April 6, 2014.

[115] Marine Corps Assistant Commandant for Aviation Lt. Gen. Terry Robling, cited in Andrea Shalal-Esa, "Lifetime cost to run F-35 fighter: about $1 trillion," *Reuters.com*, February 26, 2012.

[116] Office of the Secretary of Defense, *Selected Acquisition Report (SAR): F-35 Joint Strike Fighter Aircraft (F-35)*, April 17, 2019, p. 10. See also Anthony Capaccio, "Lockheed Gets Edict to Cut F-35's $1.1 Trillion Support Bill," *Bloomberg News*, April 5, 2018, https://www.bloomberg.com/news/articles/2018-04-05/pentagon-says-lockheed-must-

A media report indicated that the Air Force was considering reducing its buy of F-35As due to its support costs. "The shortfall would force the service to subtract 590 of the fighter jets from the 1,763 it plans to order ... the Air Force faces an annual bill of about $3.8 billion a year that must be cut back over the coming decade."[117] "'If you can afford to buy something but you have to keep it in the parking lot because you can't afford to own and operate it, then it doesn't do you much good,' says [former] F-35 JPO Program Executive Officer Vice Adm. Mat Winter."[118] The Air Force has subsequently begun acquiring the F-15EX fighter, in part arguing that its operating costs are significantly lower than the F-35's.[119]

Operations and sustainment costs as of the December 2019 Selected Acquisition Report were reported at $630.5 billion in 2012 dollars (or $1.2 trillion in then-year dollars). It should be noted that this estimate, provided by DOD's Cost Assessment and Program Evaluation office, was not updated from the December 2018 figure, and following language in the FY2020 National Defense Authorization Act, DOD no longer publishes Selected Acquisition Reports.

"The operation and sustainment cost is a bigger issue," (then-Air Force acquisition chief William) LaPlante said. "It's the one that will say whether or not we can afford (the F-35) in the longer run."[120]

Operations costs have been being addressed on several fronts, including changes in training, basing, support, and other approaches.

> To attack this problem, the F-35 program office in October 2013 set up a "cost war room" in Arlington, Va.... A team of government and contractor representatives assigned to the cost war room are investigating 48 different ways to reduce expenses. They are also studying options for future repair and maintenance of F-35 aircraft in the United States and abroad.[121]

> The U.S. Air Force is looking to slash the number of locations where it will base F-35 Joint Strike Fighter squadrons to bring down the jet's estimated trillion-dollar sustainment costs.... "When you reduce the number of bases from 40 to the low 30s, you end up reducing your footprint, making more efficient the long-term sustainment," David Van Buren, the service's acquisition executive, said in a March 2 exit interview at the Pentagon.[122]

More recently, "Lockheed, Northrop and BAE are also starting a 'sustainment cost reduction initiative' aimed at cutting operations and maintenance expenses by 10 percent during fiscal 2018 through fiscal 2022. The vendors will invest $250 million and hope to reap at least $1 billion in savings over five years."[123]

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keep-1-1-trillion-f-35-costs-down.

[117] Anthony Capaccio, "Air Force Risks Losing Third of F-35s on Upkeep Costs," *Bloomberg News*, March 28, 2018, https://www.bloomberg.com/news/articles/2018-03-28/air-force-risks-losing-third-of-f-35s-if-upkeep-costs-aren-t-cut.

[118] Lara Seligman, "F-35 Sustainment Challenges Mount As Global Fleet Grows," *Aviation Week and Space Technology*, April 5, 2018, http://aviationweek.com/defense/f-35-sustainment-challenges-mount-global-fleet-grows.

[119] See also CRS In Focus IF11521, *Air Force F-15EX Fighter Program*.

[120] Andrea Shalal, "U.S. focuses on cheaper, more reliable F-35 jet: Air Force official," *Reuters.com*, April 1, 2014.

[121] Sandra I. Erwin, "Next Battle for F-35: Bring Down Operations Costs," *National Defense (nationaldefensemagazine.org)*, April 6, 2014.

[122] Marcus Weisgerber, "USAF Eyes Deep Cuts To F-35 Bases," *Defense News*, March 3, 2012.

[123] Valerie Insinna, "Lockheed Extends F-35 Cost-Cutting Initiative To Save Billions," *Defense News*, July 11, 2016.

Manufacturing Locations

The F-35 is manufactured in several locations. Lockheed Martin builds the aircraft's forward section in Fort Worth, TX. Northrop Grumman builds the midsection in Palmdale, CA, and the tail is built by BAE Systems in the United Kingdom.[124] Final assembly of these components takes place in Fort Worth. Final assembly and checkout facilities have also been established in Cameri, Italy, and Nagoya, Japan.

The Pratt & Whitney F135 engine for the F-35 is produced in East Hartford and Middletown, CT. Rolls-Royce builds the F-35B lift system in Indianapolis, IN.

Basing

On December 21, 2017, the Air Force announced Naval Air Station Joint Reserve Base Fort Worth, TX, as the preferred alternative for the first F-35A reserve component base. Davis-Monthan Air Force Base, AZ; Homestead Air Reserve Base, FL; and Whiteman AFB, MO, were also candidate bases. At the same time, Truax Field, WI, and Dannelly Field, AL, were announced as the next Air National Guard F-35A bases, with aircraft slated to arrive in 2023. Gowen Field ANGB, ID; Selfridge ANGB, MI; and Jacksonville Air Guard Station, FL, were also considered. Burlington Air National Guard Base, VT, had previously been selected.[125]

Active component F-35As had already been announced as going to Hill AFB, UT, and RAF Lakenheath, England. Eielson AFB, AK, had earlier been announced as the preferred base for the first overseas F-35 squadron.[126] Luke AFB, AZ, and Eglin AFB, FL, are the main F-35 training bases. F-35As also operate from Edwards AFB, CA, and Nellis AFB, NV.

In the United States, Marine F-35s are based at Marine Corps Air Stations Yuma, AZ, and Beaufort, SC. Navy F-35s fly from Naval Air Stations Lemoore, CA, and Patuxent River, MD.

International Participation

In General

The F-35 program is DOD's largest international cooperative program. DOD has actively pursued allied participation as a way to defray some of the cost of developing and producing the aircraft, and to "prime the pump" for export sales of the aircraft.[127] Allies in turn view participation in the F-35 program as an affordable way to acquire a fifth-generation strike fighter, technical knowledge in areas such as stealth, and industrial opportunities for domestic firms.

Eight allied countries—the United Kingdom, Canada, Denmark, The Netherlands, Norway, Italy, Turkey, and Australia—initially participated in the F-35 program under a Memorandum of Understanding (MOU) for the SDD and Production, Sustainment, and Follow-On Development (PSFD) phases of the program. These eight countries have contributed varying amounts of

[124] CRS site visit to Palmdale, CA, March 10, 2016.

[125] U.S. Air Force, "AF selects locations for next two Air National Guard F-35 bases," press release, December 21, 2017, https://go.usa.gov/xQTRw.

[126] Secretary of the Air Force Public Affairs, "Eielson AFB selected as preferred alternative for first overseas-based F-35As," press release, August 4, 2014, http://go.usa.gov/xxhNw.

[127] Congress insisted from the outset that the JAST program include ongoing efforts by DARPA to develop more advanced STOVL aircraft, opening the way for UK participation in the program.

research and development funding to the program, receiving in return various levels of participation in the program. International partners are also assisting with Initial Operational Test and Evaluation (IOT&E), a subset of SDD.[128] The partner countries are expected to purchase hundreds of F-35s, with the United Kingdom's 138 being the largest anticipated foreign fleet.[129]

Turkey's participation in the F-35 program was subsequently curtailed after a disagreement with the United States over its acquisition and intended fielding of a Russian air defense system.[130] The circumstances of that change are summarized below and described in CRS Report R44000, *Turkey: Background and U.S. Relations In Brief*, and CRS Report R41368, *Turkey: Background and U.S. Relations*, both by Jim Zanotti and Clayton Thomas.

Effects of Turkish Expulsion

Turkey's removal affected the F-35 program in two principal areas. The first was a potential reduction in the projected number of F-35s to be produced, although as other customers have appeared and the U.S. Congress ordered Turkey's F-35s be reallocated to the U.S. Air Force, the net effect has yet to be determined.

The other effects were the requirement to find replacements for the main engine overhaul facility for European F-35s, which was to have been hosted in Turkey and will now go to Norway and the Netherlands, and for Turkish suppliers participating in the program, providing parts estimated at between $5 billion-$6 billion in value over 20 years.[131]

"According to U.S. officials, most of the supply chain handled by Turkish companies was due to move elsewhere by March 2020, with a few contracts in Turkey continuing until later in the year. The cost of shifting the supply chain, beyond some production delays, was estimated in July 2019 to be between $500 million and $600 million."[132]

The Government Accountability Office found that, "[a]s of December 2019, the program has identified new suppliers for all of these parts, but it still needs to bring roughly 15 parts currently produced in Turkey up to the current production rate…. According to an official with the Under Secretary of Defense for Acquisition and Sustainment, by accepting parts from Turkish suppliers through lot 14, the program will have additional time to ensure new suppliers can meet demands for parts."[133]

Two additional countries—Israel and Singapore—are security cooperation participants outside the F-35 cooperative development partnership.[134] Israel has agreed to purchase 33 F-35s, and may want as many as 50.[135] Japan chose the F-35 as its next fighter in October 2011, and formally

[128] Currently, the UK, Italy, and the Netherlands have agreed to participate in the IOT&E program. UK, the senior F-35 partner, will have the strongest participation in the IOT&E phase. Italy and the Netherlands are contributing a far smaller amount and will take part only in the coalition concept of operations (CONOPS) validation testing. (Telephone conversation with OSD/AT&L, October 3, 2007.) Other partner nations are still weighing their option to participate in the IOT&E program. The benefits to participation are expedited acquisition of aircraft, pilot training for the test cycle, and access to testing results.

[129] Gareth Jennings, "UK to approve bulk F-35B buy in 2017," *IHS Jane's 360*, February 6, 2014.

[130] For more discussion, see CRS Report R41761, *Turkey-U.S. Defense Cooperation: Prospects and Challenges*, by Jim Zanotti, and CRS Report R41368, *Turkey: Background and U.S. Relations*, by Jim Zanotti and Clayton Thomas.

[131] "Procurement, Turkey," *Jane's Sentinel Security Assessment - Eastern Mediterranean*, December 16, 2010.

[132] CRS Report R44000, *Turkey: Background and U.S. Relations In Brief*, by Jim Zanotti and Clayton Thomas.

[133] U.S. Government Accountability Office, *F-35 JOINT STRIKE FIGHTER: Actions Needed to Address Manufacturing and Modernization Risks*, GAO-20-339, May 2020, pp. 30-31, https://www.gao.gov/products/GAO-20-339.

[134] DOD offers Foreign Military Sales (FMS)-level of participation in the F-35 program for countries unable to commit to partnership in the program's SDD phase. Israel and Singapore are believed to have contributed $50 million each, and are "Security Cooperative Participants." (Selected Acquisition Report, Office of the Secretary of Defense for Acquisition. December 31, 2005.)

[135] Bob Cox, "Israeli government ok's F-35 buy," *Fort Worth Star-Telegram*, September 16, 2010. Yaakov Lappin, "Israel, US Sign F-35 Agreement," *Jerusalem Post*, October 8, 2010, and Lara Seligman, "Israeli Air Chief Asks For

committed to 147 F-35Bs in August 2019.[136] South Korea committed to the F-35 in 2014.[137] As noted earlier, Finland has decided to buy 64 and Switzerland 36. Sales to additional countries are possible. Some officials have speculated that foreign sales of F-35s might eventually surpass 2,000 or even 3,000 aircraft.[138]

Sales to Israel, Japan, and South Korea are conducted through the standard Foreign Military Sales process, including congressional notification. F-35 sales to nations in the consortium, conducted under 22 U.S.C. 2767, are not reviewed by Congress.[139]

The UK is the most significant international partner in terms of financial commitment, and the only Level 1 partner.[140] On December 20, 1995, the U.S. and UK governments signed an MOU on British participation in the JSF program as a collaborative partner in the definition of requirements and aircraft design. This MOU committed the British government to contribute $200 million toward the cost of the 1997-2001 Concept Demonstration Phase.[141] On January 17, 2001, the U.S. and UK governments signed an MOU finalizing the UK's participation in the SDD phase, with the UK committing to spending $2 billion, equating to about 8% of the estimated cost

17 More F-35s," *Aerospace Daily & Defense Report*, June 23, 2016.

[136] Paul Kallender-Umezu, "Japan F-X Competition Win Victory for JSF Program," *Defense News*, December 20, 2011. Ankit Panda, "Japan Officially Selects F-35B for Its STOVL Fighter," *The Diplomat*, August 18, 2019, https://thediplomat.com/2019/08/japan-officially-selects-f-35b-for-its-stovl-fighter/.

[137] Choe Sang-hun, "South Korea Formally Announces Intent to Buy 40 Lockheed Fighter Jets," *The New York Times*, September 24, 2014.

[138] Andrea Shalal-Esa, "Pentagon sees 6,000 possible F-35 sales," *Reuters.com*, June 17, 2009. See also Marina Malenic, "F-35 Sales Could Double As Countries Look To Replace Aging Fleets, General Says," *Defense Daily*, June 18, 2009: 6, and Marcus Weisgerber, "JSF Program Anticipates Nearly 700 F-35 Buys [For International Customers] Between FY-09 and FY-23, *Inside the Air Force*, July 31, 2009.

[139] Correspondence to CRS from F-35 Joint Program Office, January 31, 2018. For more details on the Foreign Military Sales process, see CRS In Focus IF11437, *Transfer of Defense Articles: Foreign Military Sales (FMS)*, by Nathan J. Lucas and Michael J. Vassalotti.

[140] International participation in the F-35 program is divided into three levels, according to the amount of money a country contributes to the program—the higher the amount, the greater the nation's voice with respect to aircraft requirements, design, and access to technologies gained during development. Level 1 Partner status requires approximately 10% contribution to aircraft development and allows for fully integrated office staff and a national deputy at director level.

Level II partners consist of Italy and the Netherlands, contributing $1 billion and $800 million, respectively. On June 24, 2002, Italy became the senior Level II partner ("F-35 Joint Strike Fighter (JSF) Lightning II: International Partners," http://www.globalsecurity.org/military/systems/aircraft/f-35-int.htm). Italy wants to have its own F-35 final assembly line, which would be in addition to the existing F-35 maintenance and upgrade facility. The Netherlands signed on to the F-35 program on June 17, 2002, after it had conducted a 30-month analysis of potential alternatives.

Australia, Denmark, Norway, Canada, and Turkey joined the F-35 program as Level III partners, with contributions ranging from $125 million to $175 million. ("Australia, Belgium Enter Joint Strike Fighter Program as EMD Partners," *Inside the Air Force*, April 21, 2000.)

Unlike the SDD phase, PSFD phase does not make any distinction as to levels of participation. Also unlike the bilateral SDD MOUs, there is a single PSFD MOU for all partner nations. In signing the PSFD MOU, partner nations state their intentions to purchase the F-35, including quantity and variant, and a determination is made as to their delivery schedule. PSFD costs will be divided on a "fair-share" based on the programmed purchase amount of the respective nation. So-called "offset" arrangements, considered the norm in defense contracts with foreign nations, usually require additional incentives to compensate the purchasing nation for the agreement's impact to its local workforce. F-35 officials decided to take a different approach, in line with the program's goal to control costs, to avoid offset arrangements and promote competition as much as possible. Consequently, all partner nations have agreed to compete for work on a "best-value" basis and have signed the PSFD MOU.

[141] "U.S., U.K. Sign JAST Agreement," *Aerospace Daily*, December 21, 1995, p. 451.

of SDD. A number of UK firms, such as BAE and Rolls-Royce, participate in the F-35 program.[142]

International Sales Quantities

The cost of F-35s for U.S. customers depends in part on the total quantity of F-35s produced. As the program has proceeded, some new customers have emerged, such as South Korea and Japan, mentioned above. Other countries have considered increasing their buys, while some have deferred previous plans to buy F-35s. It is perhaps noteworthy that the latest Selected Acquisition Reports increased the number of assumed international sales for cost purposes from 612 to 802.[143] Recent updates to other countries' purchase plans are detailed in "Changes in International Orders," above.

Table 7. F-35 International Orders

Country	Quantity	Model(s)
Australia [144]	100	A
Belgium [145]	34	A
Denmark	27	A
Finland	64	A
Israel	50	A
Italy	90	60A / 30B
Japan [146]	147	105 A / up to 42 B
Netherlands [147]	46	A
Norway [148]	52	A

[142] BAE is a major partner to Lockheed Martin and is providing the aft fuselage, empennage, and electronic warfare suite for the aircraft. Rolls-Royce is partnered with GE on the F136 engine and is a subcontractor to Pratt and Whitney for producing components for the F-35B's STOVL lift system. In October 2009, Rolls Royce broke ground on a new plant in Virginia to make parts for the F136 engine. (Rolls Royce press release, "Rolls-Royce expands US capability; begins construction on new manufacturing facility in Virginia," October 19, 2009, available at http://www.rolls-royce.com/investors/news/2009/091019_manufacturing_virginia.jsp.) Rolls Royce's 2001 contract with Pratt and Whitney for design and development of the STOVL lift components is valued at $1 billion over 10 years. ("Rolls-Royce Finishes First JSF Propulsion System Flight Hardware," Rolls-Royce Media Room, available at http://www.rolls-royce.com/media/showPR.jsp?PR_ID=40243.) All F-35Bs, regardless of what engine they use, are to employ Rolls Royce components in their STOVL lift systems.

[143] Office of the Secretary of Defense, *Selected Acquisition Report (SAR): F-35 Joint Strike Fighter Aircraft (F-35)*, editions of 2016-2019.

[144] "Two more Australian F-35s arrive at Luke AFB," *Australian Defence Magazine*, May 31, 2019, https://www.australiandefence.com.au/defence/air/two-more-australian-f-35s-arrive-at-luke-afb.

[145] John A. Tirpak, "New F-35 Block Buy is Close, Lockheed Says," *Air Force*, October 23, 2019, https://www.airforcemag.com/new-f-35-block-buy-is-close-lockheed-says/.

[146] White House Press Office, *Remarks by President Trump and Prime Minister Abe of Japan in Joint Press Conference*, Tokyo, May 27, 2019, https://www.whitehouse.gov/briefings-statements/remarks-president-trump-prime-minister-abe-japan-joint-press-conference-3/.

[147] Sebastian Sprenger, "The Netherlands to buy nine more F-35s for $1.1 billion," *Defense News*, October 8, 2019, https://www.defensenews.com/global/europe/2019/10/08/the-netherlands-to-buy-nine-more-f-35s-for-11-billion/.

[148] Government of Norway, *Major Milestone: Norway declares IOC for F-35A*, November 6, 2019, https://www.regjeringen.no/en/aktuelt/major-milestone-norway-declares-ioc-for-f-35a/id2676740/, and Christopher

Country	Quantity	Model(s)
Poland [149]	32	A
South Korea [150]	60	A
Singapore [151]	4 with options for 8 more	B
Switzerland	36	A
United Kingdom	138	B
Total	888	

Source: Lockheed Martin, at https://www.f35.com/f35/global-enterprise.html, modified by noted press reports.

The F-35 has won every major competition in which it was entered, most recently in Finland and Switzerland. The only such competition remaining at the moment is in Canada, but Spain may consider F-35Bs to maintain carrier operations as it begins to retire its F-18 Hornets late this decade.

As noted, a significant question remains over whether Canada will continue as an F-35 partner. In 2015, the Trudeau government repudiated the previously announced purchase of 65 (which had originally been 80), while remaining a formal partner in the program.[152] A new competition for 88 jets is underway, with the F-35 and Saab Gripen remaining after the F-18's elimination.[153] Lockheed Martin has stated that if Canada withdraws as a customer, Canadian work share will suffer.[154]

Work Shares and Technology Transfer

DOD and foreign partners in the JSF program have occasionally disagreed over the issues of work shares and proprietary technology. For example, the United States rejected a South Korean request for transfer of four F-35 technologies that could assist in the development of a Korean indigenous fighter program (although 21 other technologies were approved).[155]

Dennis, "US officials welcome Norway's new F-35 capabilities in an increasingly competitive Northern Europe," *Stars and Stripes*, November 27, 2019, https://www.stripes.com/news/europe/us-officials-welcome-norway-s-new-f-35-capabilities-in-an-increasingly-competitive-northern-europe-1.608872.

[149] Bartosz Glowacki, "Poland signs F-35 contract worth $4.6bn," *FlightGlobal*, January 31, 2020, https://www.flightglobal.com/defence/poland-signs-f-35-contract-worth-46bn/136476.article, and U.S. Mission Poland, *Poland's Purchase of F-35 Fighters*, Warsaw, January 31, 2020, https://pl.usembassy.gov/purchase_f35/. Defense Security Cooperation Agency, *Poland – F-35 Joint Strike Fighter Aircraft*, Washington, DC, September 11, 2019, https://www.instapaper.com/read/1285363759.

[150] Jeff Jeong, "South Korea to buy 20 more F-35 jets," *Defense News*, October 10, 2019, https://www.defensenews.com/global/asia-pacific/2019/10/10/south-korea-to-buy-20-more-f-35-jets/.

[151] John Geddie and Aradhana Aravindan, "U.S. State Dept. approves sale of 12 F-35 jets to Singapore," *Reuters*, January 10, 2020, https://www.reuters.com/article/us-singapore-defence-lockheed/u-s-state-dept-approves-sale-of-12-f-35-jets-to-singapore-idUSKBN1Z90G9.

[152] Lee Berthiaume, "Liberals fork over another $30 million to keep Canada at F-35 table," *Canadian Press*, May 25, 2017, http://www.cbc.ca/news/politics/f-35-fighter-jet-joint-strike-canada-fee-1.4131285.

[153] David Ljunggren, "Canada tells Boeing its bid for C$19 bln fighter jet contract falls short - source," *Reuters*, November 25, 2021, https://www.reuters.com/business/aerospace-defense/canada-rules-boeing-out-c19-bln-fighter-jet-contract-canadian-press-2021-11-25/.

[154] Aaron Mehta, "No System in Place To Strip Canadian F-35 Participation," *Defense News*, July 11, 2016.

[155] Jung Sung-ki, "Tech Transfer Hobbles South Korea's Fighter Program," *Defense News*, September 27, 2015, and Jon Grevatt, "US approves F-35 offset technology transfer to South Korea," *IHS Jane's Defence Industry*, December

The governments of Italy and the United Kingdom have lobbied for F-35 assembly facilities to be established in their countries. In July 2010, Lockheed and the Italian firm Alenia Aeronautica reached an agreement to establish an F-35 final assembly and checkout facility at Cameri Air Base, Italy, to deliver aircraft for Italy and the Netherlands. The facility opened in July 2013.[156] A similar facility has opened in Nagoya, Japan, with the first aircraft delivered in 2017.[157] Norway and the Netherlands will host engine overhaul and logistics facilities Turkey had been scheduled to until its exclusion from the program.

Proposed FY2022 Budget

Table 8 shows the Administration's FY2022 request for Air Force and Navy research and development and procurement funding for the F-35 program, along with FY2020 and FY2021 funding levels. **Table 9** shows the procurement request in greater detail.

Table 8. FY2022 F-35 Funding Request

(Figures in millions of then-year dollars)

	FY2020		FY2021		FY2022 (request)	
	Funding	Quantity	Funding	Quantity	Funding	Quantity
RDT&E funding						
Dept. of Navy	726.3	—	720.9	—	998.5	
Air Force	727.1	—	815.9	—	1,054.8	
Subtotal	1,453.4	—	1,536.8	—	2,053.3	
Procurement funding						
Dept. of Navy	4,419.6	34	4,576.8	36	4,831.3	37
Air Force	5,903.6	62	6,217.6	60	4,520.2	48
Subtotal	10,323.1	96	10,794.4	96	9,351.6	85
Mods	410.5		554.4		619.5	
TOTAL	12,187.1	96	12,885.6	98	12,024.3	85

Source: *Program Acquisition Costs by Weapons System*, Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer, May 2021.

Note: Figures shown do not include funding for MilCon funding or research and development funding provided by other countries.

Table 9. FY2022 F-35 Procurement Request

(All dollars in millions)

	F-35A	F-35B	F-35C
Quantity	48	17	20
Procurement cost	4,714.8	2,517.5	2,388.8
Less previous advance procurement	547.2	260.8	280.2
Subtotal	4,167.6	2,256.7	2,108.6

21, 2016.

[156] Craig Hoyle, "An Italian view on the F-35," *Flightglobal.com/DEW Line blog*, August 7, 2013.

[157] Amy Butler, "First F-35 Assembled In Italy To Roll Out Early Next Year," *Aerospace Daily and Defense Report*, December 10, 2014, and David Cenciotti, "The First Japanese-Built F-35A Unveiled At Nagoya Production Facility In Japan," *The Aviationist*, June 5, 2017, https://theaviationist.com/2017/06/05/the-first-japanese-built-f-35a-unveiled-at-nagoya-production-facility-in-japan/.

	F-35A	F-35B	F-35C
Advance procurement for future aircraft	352.6	216.8	249.1
Spares	267.7	79.2	113.8
Total FY21 request	**4,520.2**	**2,473.5**	**2,357.8**
Average procurement cost per aircraft	98.2	148.1	119.4

Source: February 2021 DOD justification books.

Issues for Congress

Overall Need for F-35

The F-35's cutting-edge capabilities are accompanied by significant costs. Some analysts have suggested that upgrading existing aircraft might offer sufficient capability at a lower cost, and that such an approach makes more sense in a budget-constrained environment. Others have produced or endorsed studies proposing a mix of F-35s and upgraded older platforms; yet others have called for terminating the F-35 program entirely. Congress has considered the requirement for F-35s on many occasions and has held hearings, revised funding, and added oversight language to defense bills. As the arguments for and against the F-35 change, the program matures, and/or the budgetary situation changes, Congress may wish to consider the value of possible alternatives, keeping in mind the program progress thus far, funds expended, evolving world air environment, and the value of potential capabilities unique to the F-35.

Planned Total Procurement Quantities

A potential issue for Congress concerns the total number of F-35s to be procured. As mentioned above, planned production totals for the various versions of the F-35 were left unchanged by a number of reviews. Since then, considerable new information has appeared regarding cost growth and budget constraints that may challenge the ability to maintain the expected procurement quantities. "'I think we are to the point in our budgetary situation where, if there is unanticipated cost growth, we will have to accommodate it by reducing the buy,' said Undersecretary of Defense Robert Hale, then Pentagon comptroller."[158]

Some observers, noting potential limits on future U.S. defense budgets, potential changes in adversary capabilities, and competing defense-spending priorities, have suggested reducing planned total procurement quantities for the F-35. A September 2009 report on future Air Force strategy, force structure, and procurement by the Center for Strategic and Budgetary Assessments, for example, states that

> [A]t some point over the next two decades, short-range, non-stealthy strike aircraft will likely have lost any meaningful deterrent and operational value as anti-access/area denial systems proliferate. They will also face major limitations in both irregular warfare and operations against nuclear-armed regional adversaries due to the increasing threat to forward air bases and the proliferation of modern air defenses. At the same time, such systems will remain over-designed – and far too expensive to operate – for low-end threats....

[158] Marina Malenic, "DoD Comptroller: Further F-35 Cost Growth Jeopardizes Buy Quantity," *Defense Daily*, March 4, 2010.

> Reducing the Air Force plan to buy 1,763 F-35As through 2034 by just over half, to 858 F-35As, and increasing the [annual F-35A] procurement rate to end [F-35A procurement] in 2020 would be a prudent alternative. This would provide 540 combat-coded F-35As on the ramp, or thirty squadrons of F-35s[,] by 2021[, which would be] in time to allow the Air Force budget to absorb other program ramp ups[,] like NGB [the next-generation bomber, B-21].[159]

Block 4/C2D2 as a Separate Program

Development of the F-35 Block 4 software, part of an effort now called Continuous Capability Development and Delivery (C2D2), is expected to cost as much as $10.8 billion over the next six years.[160] "The F-35 Joint Program Office (JPO) plans to transition into the next phase of development – Continuous Capability Development and Delivery (C2D2) – beginning in CY18, to address deficiencies identified in Block 3F development and to incrementally provide planned Block 4 capabilities."[161]

"The JPO's latest plan for F-35 follow-on modernization ... C2D2, relies heavily on agile software development—smaller, incremental updates to the F-35's software and hardware instead of one big drop, with the goal of speeding follow-on upgrades while still fixing remaining deficiencies in the Block 3F software load."[162]

Some in Congress argue that a program of that size should part with traditional procurement practice for an upgrade and be run as a separate Major Defense Acquisition Program (MDAP), with its own budget line and the concomitant requirements. At a March 23, 2016, hearing of a House Armed Services subcommittee

> Government Accountability Office (GAO) Director of Acquisition and Sourcing Management Michael Sullivan argued that the Block 4 estimated cost justifies its management as a separate program, but F-35 Program Executive Officer (PEO) Air Force Lt. Gen. Christopher Bogdan countered that breaking it off would create an administrative burden and add to the program's price tag and schedule.[163]

The House-passed version of the FY2020 National Defense Authorization Act (H.R. 2500) contained a provision (§132) that would require the Secretary of Defense to designate the C2D2 program as a major subprogram of the F-35 program. An enacted into law, the act (P.L. 116-92) does not designate Block 4 and/or C2D2 as a major subprogram, but requires the Secretary of Defense to submit an annual integrated master schedule and past performance assessment for each planned phase of Block 4 and C2D2 upgrades.

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[159] Thomas P. Ehrhard, *An Air Force Strategy for the Long Haul*, Washington, Center for Strategic and Budgetary Assessments, 2009, pp. xii and xiv. The report was released on September 17, 2009, according to CSBA's website, and is available at http://www.csbaonline.org/4Publications/PubLibrary/R.20090917.An_Air_Force_Strat/R.20090917.An_Air_Force_Strat.pdf. Subsequent to writing this report, the author became a special assistant to the Air Force Chief of Staff.

[160] Pat Host, "Pentagon faces major cost increase on F-35 Block 4 modernisation," *IHS Jane's Defence Weekly*, March 8, 2018, http://janes.ihs.com/Janes/Display/1830607.

[161] Director, Operational Test and Evaluation, *FY 2017 Annual Report*, Washington, DC, January 2018, p. 31, http://www.dote.osd.mil/pub/reports/FY2017/.

[162] Lara Seligman, "What F-35 Can Learn From F-22 Upgrade Hiccups," *Aviation Week and Space Technology*, March 28, 2018, http://aviationweek.com/defense/what-f-35-can-learn-f-22-upgrade-hiccups.

[163] Valerie Insinna, "Bogdan: Separate Program For F-35 Block 4 Mods Would Increase Cost, Schedule Difficulties," *Defense Daily*, March 24, 2016.

An emerging issue is the continued oversight of Block 4. As GAO noted in May 2020, delays in the program mean that the Block 4 effort is now likely to last longer than its congressional reporting requirement.[164] The National Defense Authorization Act of 2017 (P.L. 114-328) included language requiring annual reports on the progress of Block 4 through 2023. As the program is now projected to continue through 2026, Congress may wish to consider extending that requirement or other oversight measures.

Competition

Lieutenant General Bogdan's comments regarding the difficulty of cost control in a sole-source environment (see "Engine Costs," above) reflect a broader issue affecting defense programs as industry consolidates and fewer sources of supply are available for advanced systems. Congress may wish to consider the merits of maintaining competition when overseeing system procurements (for example, the use of competition to maintain cost pressure was a principal argument in favor of the F-35 alternate engine program).[165] On the F-35 program, that competition could include contracting for lifecycle support as a way to address sustainment costs.

Appropriate Fighter Mix

A significant issue, beginning with the FY2020 DOD budget submission, is the optimal mix of fighter aircraft in the Air Force fleet. Previous plans had focused on the F-35 as the mainstay of the future fighter fleet, in keeping with an Air Force initiative to move to an all-fifth-generation-and-beyond force. In FY2020, however, the Air Force requested an initial 8 of a projected buy of 144 F-15EX fighters. The F-15EX is an improved version of the F-15 Eagle and Strike Eagle fighter series, which the United States last acquired in 2001.[166]

Subsequently, the Air Force justified the request on two grounds: that the operating costs of the F-35 were significantly higher than fourth-generation aircraft like the F-15EX, and that the service needed to acquire 72 new fighters per year to maintain its fleets as older aircraft retire.[167]

The Air Force has maintained that F-35 and F-15EX do not compete directly for funding. Observers note that, regardless, the F-15EX proposal came at a time when the Air Force reduced its planned F-35 buy from 60 to 48 jets per year. Further, some argue that the additional capabilities inherent in the F-35 provide a better value at similar cost.[168] F-15 advocates note the

[164] U.S. Government Accountability Office, *F-35 JOINT STRIKE FIGHTER: Actions Needed to Address Manufacturing and Modernization Risks*, GAO-20-339, May, 2020, pp. 31-32, https://www.gao.gov/products/GAO-20-339.

[165] For more on this issue, see CRS Report R41131, *F-35 Alternate Engine Program: Background and Issues for Congress*.

[166] For more on this issue, see CRS Insight IN11078, *Proposed Air Force Acquisition of New F-15EXs*.

[167] Valerie Insinna, "The US Air Force doesn't want F-15X. But it needs more fighter jets," *Defense News*, February 28, 2019, https://www.defensenews.com/digital-show-dailies/air-warfare-symposium/2019/02/28/the-air-force-doesnt-want-f-15x-but-it-needs-more-fighter-jets/. Oriana Pawlyk, "Air Force Wants Both F-35 and F-15EX. But if Forced to Choose, It's No Contest: SecAF," *Military.com*, May 20, 2019, https://www.military.com/daily-news/2019/05/20/air-force-wants-both-f-35-and-f-15ex-if-forced-choose-its-no-contest-secaf.html.

[168] See, for example, John Venable, *The F-35A Is the World's Most Dominant, Cost-Effective Fighter: The Air Force Needs to Accelerate Its Acquisition Now*, The Heritage Foundation, Washington, DC, March 2, 2020, https://www.heritage.org/defense/report/the-f-35a-the-worlds-most-dominant-cost-effective-fighter-the-air-force-needs-0.

age of current U.S. F-15s, and that new F-15EXs offer better value than extending the lives of existing ones.[169]

More recently, the Air Force has been considering replacing some F-16s, which had been expected to be replaced by F-35s, with unmanned systems instead.

> [Air Combat Command commander Gen. Mike] Holmes suggested that low-cost and attritable unmanned aircraft systems (UAS) might be considered… as a replacement for F-16 Block 25/30 jets… within 5-8 years. In congressional testimony on March 12, Holmes added that ACC's goal is to achieve a fighter fleet ratio of 60% fifth-generation jets, such as F-35As and F-22s, to 40% fourth-generation aircraft, including F-15s, F-16s and A-10s.[170]

That ratio had previously been expressed as 50-50.[171]

Engine Cost Transparency

In the specific case of the F-35, Pratt & Whitney and the Joint Program Office have declined to reveal the cost per engine in each LRIP contract, replacing dollar costs with percentage savings and aggregate contract values that include items other than the engines themselves. Congress may wish to consider whether this approach is sufficient to provide useful oversight, and weigh that value against a contractor's right to protect competition-sensitive data. A possible analogue can be found in the debate over whether public disclosure of the contract value for the B-21 bomber might reveal more data than prudent, or whether that revelation is a reasonable cost to allow proper program oversight.

Acquiring Advanced Engines

Congress directed in the FY2022 National Defense Authorization Act (P.L. 117-81) that the military services publish strategies to procure advanced adaptive powerplants for the F-35 (see the "Adaptive Engine Transition Program" section above). However, as the engines will not be common across the F-35 fleet, costs for each service's version may pose challenges to the service budgets. Commonality and concomitant savings were a significant selling point of the F-35 program. Congress may wish to consider the tradeoff between enhanced performance and higher cost.[172]

Affordability

An additional potential issue for Congress for the F-35 program concerns the affordability of the F-35, particularly in the context of projected shortfalls in both Air Force fighters and Navy and Marine Corps strike fighters.

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[169] Brian Everstine, "NORTHCOM Stresses Importance of F-15EX Buy for Homeland Defense," *Air Force Magazine*, March 12, 2020, https://www.airforcemag.com/northcom-stresses-importance-of-f-15ex-buy-for-homeland-defense/.

[170] Steve Trimble, "As USAF Fleet Plans Evolve, Can the F-35A Program Survive Intact?," *Aviation Week*, March 19, 2020, https://aviationweek.com/defense-space/usaf-fleet-plans-evolve-can-f-35a-program-survive-intact.

[171] Valerie Insinna, "The US Air Force doesn't want F-15X. But it needs more fighter jets," *Defense News*, February 28, 2019, https://www.defensenews.com/digital-show-dailies/air-warfare-symposium/2019/02/28/the-air-force-doesnt-want-f-15x-but-it-needs-more-fighter-jets/.

[172] See, inter alia, John A. Tirpak, "Adding New AETP Engine to F-35 Means Air Force Alone Would Pay for It," *Air Force Magazine*, September 1, 2021, https://www.airforcemag.com/adding-new-aetp-engine-f-35-air-force-alone-would-pay-for-it/.

Although the F-35 was conceived as a relatively affordable strike fighter, some observers are concerned that in a situation of constrained DOD resources, F-35s might not be affordable in the annual quantities planned by DOD, at least not without reducing funding for other DOD programs. As the annual production rate of the F-35 increases, the program will require more than $10 billion per year in acquisition funding at the same time that DOD will face other budgetary challenges. The issue of F-35 affordability is part of a larger and long-standing issue concerning the overall affordability of DOD's tactical aircraft modernization effort, which also includes procurement of F/A-18E/Fs, increasingly capable unmanned aerial vehicles, and, as mentioned, F-15EXs.[173]

Implications for Industrial Base

Another potential issue for Congress regarding the F-35 program concerns its potential impact on the U.S. tactical aircraft industrial base. The award of the F-35 SDD contract to a single company (Lockheed Martin) raised concerns in Congress and elsewhere that excluding Boeing from this program would reduce that company's ability to continue designing and manufacturing fighter aircraft.[174]

Similar concerns regarding engine-making firms have been raised since 2006, when DOD first proposed (as part of the FY2007 budget submission) terminating the F136 alternate engine program. Some observers are concerned that if the F136 were cancelled, General Electric would not have enough business designing and manufacturing fighter jet engines to continue competing in the future with Pratt & Whitney (the manufacturer of the F135 engine). Others argued that General Electric's considerable business in both commercial and military engines was sufficient to sustain General Electric's ability to produce this class of engine in the future.

Exports of the F-35 could also have a strong impact on the U.S. tactical aircraft industrial base through export. Most observers believe that the F-35 could potentially dominate the combat aircraft export market, much as the F-16 has. Like the F-16, the F-35 appears to be attractive because of its relatively low cost, flexible design, and promise of high performance. Competing fighters and strike fighters, including France's Rafale, Sweden's JAS Gripen, and the Eurofighter Typhoon, are positioned to challenge the F-35 in the fighter export market.

Some observers are concerned that by allowing foreign companies to participate in the F-35 program, DOD may be inadvertently opening up U.S. markets to foreign competitors who enjoy direct government subsidies. A May 2004 GAO report found that the F-35 program could "significantly impact" the U.S. and global industrial base.[175] GAO found that two laws designed to protect segments of the U.S. defense industry—the Buy American Act and the Preference for Domestic Specialty Metals clause—would have no impact on decisions regarding which foreign companies would participate in the F-35 program, because DOD has decided that foreign companies that participate in the F-35 program, and which have signed reciprocal procurement agreements with DOD to promote defense cooperation, are eligible for a waiver.

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[173] For more on this issue, see CRS Report RL33543, *Tactical Aircraft Modernization: Issues for Congress*.

[174] For more information, see CRS Report RL31360, *Joint Strike Fighter (JSF): Potential National Security Questions Pertaining to a Single Production Line*, by Christopher Bolkcom and Daniel H. Else (out of print; available to congressional clients from the author upon request).

[175] General Accounting Office, *Joint Strike Fighter Acquisition: Observations on the Supplier Base*, GAO-04-554, May 2004.

Future Joint Fighter Programs

Congress consolidated the JAST and ASTOVL programs after finding "no apparent willingness or commitment by the Department to examine future needs from a joint, affordable, and integrated warfighting perspective."[176] DOD states that the F-35 program "was structured from the beginning to be a model of acquisition reform, with an emphasis on jointness, technology maturation and concept demonstrations, and early cost and performance trades integral to the weapon system requirements definition process."[177] A subsequent RAND Corporation study found that the fundamental concept behind the F-35 program—that of making one basic airframe serve multiple services' requirements—may have been flawed.[178] Congress may wish to consider how the advantages and/or disadvantages of joint programs may have changed as a consequence of evolutions in warfighting technology, doctrine, and tactics.

[176] U.S. Congress, House Committee on National Security, *National Defense Authorization Act for Fiscal Year 1996*, report to accompany H.R. 1530, 104th Cong., 1st sess., June 1, 1995, H.Rept. 104-131.

[177] Department of Defense. *Selected Acquisition Report (SAR)[for] F-35 (JSF)*, December 31, 2007, p. 4.

[178] Mark A. Lorell, Michael Kennedy, Robert S. Leonard, Ken Munson, Shmuel Abramzon, David L. An, Robert A. Guffey, *Do Joint Fighter Programs Save Money?*, RAND Project Air Force, Santa Monica, CA, 2013, http://www.rand.org/pubs/monographs/MG1225.html.

Appendix. F-35 Key Performance Parameters

Table A-1 summarizes key performance parameters for the three versions of the F-35.

Table A-1. F-35 Key Performance Parameters (KPPs)

Source of KPP	KPP	F-35A Air Force CTOL version	F-35B Marine Corps STOVL version	F-35C Navy carrier-suitable version
Joint	Radio frequency signature	Very low observable	Very low observable	Very low observable
	Combat radius	590 nm Air Force mission profile	450 nm Marine Corps mission profile	600 nm Navy mission profile
	Sortie generation	3 surge / 2 sustained	4 surge / 3 sustained	3 surge / 2 sustained
	Logistics footprint	< 8 C-17 equivalent loads (24 PAA)	< 8 C-17 equivalent loads (20 PAA)	< 46,000 cubic feet, 243 short tons
	Mission reliability	93%	95%	95%
	Interoperability	Meet 100% of critical, top-level information exchange requirements; secure voice and data		
Marine Corps	STOVL mission performance – short-takeoff distance	n/a	550 feet	n/a
	STOVL mission performance – vertical lift bring-back	n/a	2 x 1K JDAM, 2 x AIM-120, with reserve fuel	n/a
Navy	Maximum approach speed	n/a	n/a	145 knots

Source: F-35 program office, October 11, 2007.

Notes: PAA is primary authorized aircraft (per squadron); vertical lift bring back is the amount of weapons with which plane can safely land.

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