



Testimony

Before the Subcommittee on Tactical Air
and Land Forces, Committee on Armed
Services, House of Representatives

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TACTICAL AIRCRAFT

Technical, Delivery, and Affordability Challenges Complicate DOD's Ability to Upgrade Its Aging Fleet

Statement of Jon Ludwigson, Director,
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Accessible Version

GAO Highlights

Highlights of [GAO-23-106694](#), a testimony before the Subcommittee on Tactical Air and Land Forces, Committee on Armed Services, House of Representatives

Why GAO Did This Study

Tactical aircraft—fixed wing fighter and attack planes—provide air-to-air, air-to-ground, and electronic warfare capabilities that are vital to the success of U.S. combat operations and homeland defense.

This testimony discusses DOD's analyses informing tactical aircraft investments, as well as challenges in the F-35 program. This statement is based on GAO's December 2022 report on DOD's tactical aircraft investments ([GAO-23-106375](#)), its April 2022 report on the F-35 ([GAO-22-105128](#)), and preliminary observations from GAO's 2023 F-35 report, expected to be issued in May. For its ongoing work, GAO interviewed DOD officials and contractor representatives, compared the F-35 delivery schedule to actual progress, analyzed F-35 modernization plans, and assessed the program's analysis of engine and thermal management modernization options. Details about the scope and methodology for published GAO reports are included in those products.

What GAO Recommends

Since 2001, GAO has made more than 50 recommendations across 20 reports aimed at improving DOD's acquisition of tactical aircraft, especially the F-35. DOD has agreed with many of these recommendations and taken action to address some of them. Of the 17 recommendations GAO made over the last 5 years, 8 remain open. Among those that are not yet implemented are several intended to address F-35 challenges and tactical aircraft portfolio management.

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What GAO Found

Tactical aircraft are critical to achieving and maintaining air dominance during combat operations. The Department of Defense's (DOD) planned tactical aircraft fleet currently comprises 15 different types of aircraft, such as:

- the Air Force's A-10 Thunderbolt II and F-16 Fighting Falcon,
- the Navy's F/A-18E/F Super Hornet and EA-18G Growler, and
- three variants of the F-35 Joint Strike Fighter (see figure).

F-35 Joint Strike Fighter variants



Source: U.S. Air Force/Staff Sgt. Andrew Lee, U.S. Navy/Petty Officer 1st Class Jeremy Starr, and U.S. Air Force/Defense Visual Information Distribution Service. | [GAO-23-106694](#)

Most of DOD's existing tactical aircraft began flying in the 1970s and 1980s. In December 2022, GAO reported on eight studies including ones by the Air Force, Navy, and Marine Corps that confirmed DOD's longstanding need to modernize or replace its tactical aircraft fleet and emphasized affordability. However, DOD has not conducted an integrated portfolio-level analysis across all of its tactical aircraft investments. Such a review would provide DOD and Congress with needed insight into interdependencies, risks, and trade-offs among some of DOD's highest priority and biggest investments. DOD is in the process of implementing policy changes to improve its portfolio management practices.

The F-35 is key to DOD's tactical aircraft future. As of March 2023, the program has delivered over 800 aircraft, but it is more than a decade behind schedule, and \$165 billion over original estimates. It also faces other challenges:

Simulator and related testing remain incomplete. Until DOD verifies its simulator can conduct complex test scenarios that accurately replicate real-world conditions, the F-35 will be unable to complete initial operational testing.

Contractors continue to deliver late. GAO's ongoing work indicates that the contractor delivered 50 percent of aircraft late in 2022—the worst result in 6 years—and the engine contractor delivered more engines late than on time.

Block 4 content and costs continue to grow. A \$16.5 billion effort, known as Block 4, aims to upgrade the F-35 and address threats that emerged since 2000. The preliminary observations of GAO's ongoing Block 4 work point to increases in scope, costs, and delays.

Engine and thermal management system need upgrades. The system that provides cooling for the F-35's engine is underperforming, resulting in reduced engine life. The program has determined that it must upgrade both.

Chairman Wittman, Ranking Member Norcross, and Members of the Subcommittee:

Thank you for the opportunity to discuss our work examining tactical aircraft and the F-35.

Tactical air forces are critical to achieving and maintaining air dominance during combat operations. These forces include Air Force, Navy, and Marine Corps fixed-wing fighter and attack aircraft with air-to-air, air-to-ground, and electronic warfare missions, along with related equipment and support activities. In their combat role, these aircraft often operate during the first days of a conflict to penetrate enemy air space, defeat air defenses, and achieve air dominance. This allows follow-on ground, air, and naval forces freedom to operate within the battle space. Once air dominance is established, tactical aircraft continue to strike ground targets for the remainder of a conflict. Some tactical aircraft are also essential to protecting the homeland by responding to potential airborne and ground-based threats.

The Department of Defense (DOD) tactical aircraft fleet generally comprises nine current Air Force, Navy, and Marine Corps aircraft. Approximately half of this fleet began manufacturing before 2000 and are more than 25 years old. The Air Force, Navy, and Marine Corps—referred to in this statement as the military services—have identified replacement aircraft. Over the past two decades, a central feature of DOD’s tactical aircraft plan has been to develop, produce, deploy, and modernize the development of an advanced aircraft, the F-35. The F-35 program, which started development in 2001, is a family of fifth-generation strike fighter aircraft that integrates low-observable (stealth) technology with advanced sensors and computer networking capabilities.¹ The F-35 will be used by DOD, as well as seven international partners, to perform a wide range of missions. DOD aims to procure a total of 2,470 F-35s for use by the Air Force, Navy, and Marine Corps.

To date, the F-35 program has delivered over 800 aircraft to the U.S. military services, international partners, and foreign military sales customers. The program, however, is also more than a decade delayed

¹The F-35 Joint Strike Fighter program is delivering three variants of the F-35 aircraft: (1) the F-35A conventional takeoff and landing variant for the Air Force, (2) the F-35B short takeoff and vertical landing variant for the Marine Corps, and (3) the F-35C carrier-suitable variant for both the Marine Corps and the Navy.

and \$165 billion over its original plans. Additionally, DOD is now in the fifth year of a \$16.5 billion modernization effort—known as Block 4—to upgrade the hardware and software systems of the F-35. This effort is to address new threats that emerged since the aircraft’s original requirements were established in 2000. DOD uses a development approach for Block 4, referred to as Continuous Capability Development and Delivery (C2D2). This approach is loosely based on Agile software development processes.² With this approach, DOD intends to incrementally deliver capabilities to the warfighter faster and more frequently than it did during the original development program.

This statement discusses (1) DOD’s analyses informing tactical aircraft investments and (2) challenges facing the F-35 program.

This statement is based on findings from our December 2022 report on DOD’s tactical aircraft planning efforts, and our April 2022 report on the F-35 program.³ It is also based on preliminary observations from our ongoing work on risks with completing the original F-35 development program, efforts to modernize the F-35, and efforts to modernize the engine and address thermal management challenges. For our issued reports we analyzed data provided by the contractors, aircraft program offices, and others in DOD. We also interviewed DOD officials and contractor representatives. Each of the reports provides further information on specific objectives, scope, and methodology. In addition, we summarized information from our prior reports, including relevant recommendations and the actions taken by DOD to address them, where appropriate.

For our ongoing work related to risks with completing the original development program, we collected and analyzed cost, schedule, and production data such as on-time deliveries, labor hours, number of deficiencies, and technical risks, among others. For our ongoing work to assess DOD’s Block 4 modernization efforts, we analyzed cost, schedule, and performance documents for Block 4 modernization and compared them against the status we reported last year. For our ongoing work

²Agile is a framework for incremental development, which has been adopted by many federal agencies. Agile emphasizes development of software in iterations that are continuously evaluated on their functionality, quality, and customer satisfaction.

³GAO, *Tactical Aircraft Investments: DOD Needs Additional Portfolio Analysis to Inform Future Budget Decisions*, [GAO-23-106375](#) (Washington, D.C., December 20, 2022). GAO, *F-35 Joint Strike Fighter: Cost Growth and Schedule Delays Continue*, [GAO-22-105128](#) (Washington, D.C.: April 25, 2022).

related to modernizing the engine and thermal management system, we reviewed the F-35 program office's comparative analysis of the modernization options and Air Force and Navy reports on the need to upgrade the engine, and spoke with program officials about their analysis. We corroborated data collected from contractor representatives and program officials with other data sources or knowledgeable officials, such as the Director of Operational Test and Evaluation, and determined that the data we used were sufficiently reliable for the purposes of responding to our reporting objectives.

The work on which this statement is based was conducted in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

DOD Has Not Conducted Portfolio-level Tactical Aircraft Analysis to Inform Future Budget Decisions

Recent DOD Studies Identify the Need to Modernize

In our December 2022 report, we noted that approximately half of DOD's current tactical aircraft fleet, comprising nine aircraft including the A-10, F-15, F-16, and F/A-18, had begun manufacturing before 2000 and were more than 25 years old. We also noted that the four replacement platforms—the multi-service F-35, the Navy's F/A-XX, and the Air Force's F-15EX and Next Generation Air Dominance (NGAD) programs—were in varying stages of development and fielding. Table 1 shows the approximate quantity, age, and intended replacement of aircraft in DOD's tactical aircraft fleet.

Table 1: Current and Replacement Tactical Aircraft Inventories

Current aircraft	Generation ^c	Service	Total inventory (fiscal year 2020) ^d	Average age-years (fiscal year 2021)	Replacement aircraft
A-10 (Thunderbolt II)	4 th	Air Force	281	40.4	F-35A
F-15C/D (Eagle)	4 th	Air Force	234	37.2	F-15EX
F-16 (Fighting Falcon)	4 th	Air Force	936	31	To Be Determined ^f
F/A-18A-D (Hornet)	4 th	Navy/Marine Corps	305	28.2	F-35B/F-35C
F-15E (Strike Eagle)	4 th	Air Force	218	29.5	F-15EX ^e
AV-8B (Harrier II)	4 th	Marine Corps	77	24.5	F-35B
F/A-18E/F (Super Hornet)	4 th	Navy	530	13.5	F/A-XX
F-22A (Raptor)	5 th	Air Force	186	14	NGAD
EA-18G (Growler)	4 th	Navy	131	8.4	To Be Determined

Replacement aircraft acquisitions	Generation ^c	Service	Total inventory (fiscal year 2020) ^d	Average age-years (fiscal year 2021)
F-35A	5 th	Air Force	231	3.8
F-35B	5 th	Marine Corps	91	4.3
F-35C	5 th	Navy/Marine Corps	43	4.3
F-15EX	4 th	Air Force	e	e
Next Generation Air Dominance (NGAD) ^a	6 th	Air Force	a	a
F/A-XX ^b	6 th	Navy	b	b

Source: GAO analysis of DOD data and information provided by agency officials. | GAO-23-106694

^aNGAD information is omitted due to classification.

^bF/A-XX information is omitted due to classification.

^cFourth generation indicates aircraft that generally do not possess stealth characteristics. Fifth generation indicates aircraft that generally possess stealth characteristics.

^dCurrent aircraft inventory totals as of September 2020.

^eThe F-15EX is expected to supplement or reinforce F-15E aircraft. As of April 2021, two F-15EX test aircraft had been delivered.

^fThe Air Force once intended the F-16 to be replaced by the F-35A. However, Air Force officials now state that the F-16 replacement is yet to be determined.

DOD completed eight studies between 2020 and early 2022 that confirmed the need to modernize DOD’s tactical aircraft fleet to address capability gaps and, to a lesser degree, capacity shortfalls.⁴ Seven of eight military service and Joint Staff studies we reviewed identified future tactical aircraft capability gaps, but only three studies identified capacity shortfalls. Specifically, three of the four Navy studies identified tactical aircraft capacity shortfalls, which the Navy refers to as “strike fighter shortfalls.” The Air Force, Marine Corps, and Joint Staff studies did not identify capacity shortfalls. While all of the studies assumed or addressed funding constraints, assumptions made about the threat and time frame varied. Table 2 summarizes each of the tactical aircraft studies that we reviewed.

Table 2: Overview of Eight Studies Related to Tactical Aircraft Capability and Capacity Completed from January 2020 through January 2022

Study publication date	Organization	Study purpose	Study findings		Study assumptions		
			Capacity shortfalls identified	Capability gaps identified	Threat scenario	Funding constraints	Time frame
May 2020	Navy	Response to mandate	Yes	Yes	Single threat	Yes	Time frame assumptions varied ^a
August 2020	Air Force	Response to mandate	No	Yes	Multiple threats	Yes	
December 2020	Navy	Response to mandate	Yes	Yes	Single threat	Yes	
December 2020	Navy	Internal review	No	Yes	Single threat	Yes	
March 2021	Navy	Response to mandate	Yes	Yes	Multiple threats	Yes	
March 2021	Marine Corps	Internal review	No	No	Multiple threats	Yes	
August 2021	Air Force	Internal review	No	Yes	Multiple threats	Yes	
January 2022	Joint Staff	Internal review	No	Yes	Single threat	Yes	

Source: GAO analysis of Department of Defense documents | GAO-23-106694

Note: This table reflects eight of nine studies GAO reviewed. These studies were selected because they were completed in response to mandates or internal reviews and were not supplemental to previous studies. We excluded a study by the Office of the Secretary of Defense’s Cost Assessment and Program Evaluation office due to security classification. Our review of each study included a review of the findings and assumptions to provide a description of the study content. We did not assess the completeness, validity, or quality of data used to conduct any study. Mandates refer to the National Defense Authorization Act for Fiscal Year 2020, Pub. L. No. 116-92, § 134 and § 143 (2019); William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, Pub. L. No.

⁴We also reviewed an analysis conducted by the Office of the Secretary of Defense (OSD) Cost Assessment and Program Evaluation office. This study analyzed tactical aircraft capacity and capabilities across the Air Force, Navy, and Marine Corps and according to officials, provided recommendations to support the fiscal year 2023 budget request. We provided details on the Cost Assessment and Program Evaluation study to congressional staff in a classified setting. [GAO-23-106375](#).

116-283, § 123 (2021); and S. Rep. No. 116-236, at 11 (2020) (accompanying a bill for the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021).

^aDetailed information is not available due to classified nature of the content.

Additionally, all eight studies addressed funding constraints in their analyses. Some officials we spoke with noted that not considering funding constraints can lead to capacity and capability requirements that are unachievable. Most of the studies we analyzed stressed affordability, and some studies provided recommendations for investment decisions within an individual military service's tactical aircraft portfolio. For example, the Air Force studies recommended divesting of some fourth-generation tactical aircraft to release funding for modernization and development efforts such as the F-35 and NGAD. Air Force officials acknowledge near-term divestments are risky but maintain that the approach is less risky than not having the necessary capabilities in the future. Similarly, to address acquisition and sustainment affordability and maintain the right mix of capability and capacity, one Navy study recommended maintaining a mix of fourth- and fifth-generation aircraft while investing in an NGAD family of systems to address future threats.

Finally, all of the studies in our review assumed that pressing threats would emerge in the future. As a result, the Air Force and Navy identified capability gaps as some fourth-generation aircraft may not be able to operate effectively in high-end scenarios in the assumed time frame. Specifically, the Air Force identified the need to advance capabilities of its tactical aircraft fleet to address threats it believes will exist in the future. One Air Force study noted moderate risk in meeting the 2018 National Defense Strategy demands even with the Air Force's planned modernization efforts. Additionally, one Navy study stated that the Navy should begin transitioning to the NGAD family of systems to meet the capability required to defeat peer adversaries in the future.

DOD Has Not Conducted Integrated Portfolio-Level Analysis across Tactical Aircraft Investments

In December 2022, we reported that DOD took a number of actions to address tactical aircraft capacity shortfalls and capability gaps. Specifically, the military services proposed investments in aircraft modernization, new aircraft procurement and development, and the divestment of some existing tactical aircraft in their fiscal year 2023 budget request.⁵ The annual average cost of more than \$20 billion

⁵[GAO-23-106375](#).

associated with these efforts, in addition to rising sustainment costs for existing aircraft, makes affordability a DOD-wide concern.

Specifically, the Air Force and Navy are using several strategies, including modernizing some existing tactical aircraft with new capabilities and structural enhancements in addition to developing new aircraft. In their fiscal year 2023 budget requests, for example, the military services proposed investments in modernization of selected aircraft such as the F/A-18E/F, F-22A, and F-35s to keep their fleets operationally viable into the future. Specifically, the Navy planned to invest in F/A-18E/F radar enhancements and service life extension upgrades. Additionally, the Air Force planned to invest in F-22A sensor system improvements and F-35 software and hardware upgrades. Additionally, both the Air Force and Navy proposed investments in the development of future air dominance capabilities such as NGAD and F/A-XX to address projected high-end threats.

In addition to the investments in modernization and procurement, and given affordability concerns due to budget constraints, the military services are considering divestments of some older tactical aircraft. They believe these aircraft no longer provide capabilities required to meet the demands of highly contested threat environments and can be costly to operate and maintain. In particular, Air Force leaders have stated that these divestments are also necessary to free up funding to continue modernizing other existing tactical aircraft. As part of the Air Force's documentation supporting its fiscal year 2023 budget request, and again in its fiscal year 2024 request that was recently released, the service proposed divesting a significant number of aircraft. Service officials stated that maintaining a specific quantity of aircraft without regard for the capabilities they might provide in the future is not a prudent approach. As mentioned previously, Air Force leaders believe that while this divestment approach may present some capacity risk, this risk is acceptable to avoid capability risks associated with failing to modernize in preparation for future threats.

Further, DOD will need to address higher than expected sustainment costs for the F-35. In July 2021, we reported that since 2012, estimated F-35 life-cycle sustainment costs have steadily increased from \$1.11 trillion to \$1.27 trillion, even though DOD has made efforts to reduce

costs.⁶ We found that DOD does not have a pathway to close the substantial gap between estimated sustainment costs for the F-35 and service-established affordability constraints. We made a number of recommendations to address these concerns and, as of July 2021, DOD officials stated they were working to address our recommendations.

Our August 2015 report found DOD drafted investment plans that reflect individual military service preferences that were not affordable over the long term.⁷ We concluded that DOD defaulted to optimizing and addressing problems in individual programs instead of focusing on portfolios of programs that might provide greater military capability at lower risk or cost. As a result, we recommended that the Secretary of Defense revise a DOD directive to reflect leading practices and promote development of better tools to enable integrated portfolio reviews and analyses of weapon system investments. We also recommended that the Secretary of Defense direct the military services to update or develop policies that require them to conduct annual portfolio reviews.

Although our recommendations remain open, DOD is in the process of implementing policy changes aimed at improving its portfolio management practices. As part of these efforts, in 2021, the Under Secretary of Defense for Acquisition and Sustainment began conducting portfolio-level reviews, known as Integrated Acquisition Portfolio Reviews (IAPR), aimed at identifying acquisition portfolio interdependencies and critical risks across services and agencies to shape future investment decisions. According to Office of the Secretary of Defense (OSD) officials, they conducted an IAPR of specific tactical aircraft weapons in September 2021 and planned to conduct another tactical aircraft weapons-focused review in 2022. While these efforts may be steps in the right direction, OSD officials noted that as of August 2022, they had not conducted an IAPR that assesses the portfolio of tactical aircraft platforms.

Because DOD had not conducted a comprehensive integrated acquisition portfolio-level analysis of its tactical aircraft platforms, in our December

⁶GAO, *F-35 Sustainment: DOD Needs to Cut Billions in Estimated Costs to Achieve Affordability*, [GAO-21-439](#) (Washington, D.C.: July 7, 2021) and *Additional Opportunities to Reduce Fragmentation, Overlap, and Duplication and Achieve Billions of Dollars in Financial Benefits*, [GAO-22-105301](#) (Washington, D.C.: May 11, 2022).

⁷GAO, *Weapon System Acquisitions: Opportunities Exist to Improve the Department of Defense's Portfolio Management*, [GAO-15-466](#) (Washington, D.C.: Aug. 27, 2015).

2022 report, we recommended that DOD (1) conduct an IAPR of all piloted fixed-wing tactical aircraft platforms and (2) establish a requirement that ensures the congressional defense committees receive information explaining DOD's IAPR of all piloted fixed-wing tactical aircraft platforms.⁸ DOD concurred with our first recommendation and in January 2023 officials noted that an integrated acquisition portfolio review of DOD's piloted fixed-wing tactical aircraft platforms would be conducted by the end of fiscal year 2024. DOD partially concurred with our second recommendation, but subsequently reported to us that it does not plan to establish a requirement to provide information that explains DOD's IAPR of all piloted fixed-wing tactical aircraft platforms to congressional decision makers. We continue to believe that a DOD reporting requirement would provide assurance that Congress receives this information as it makes decisions about funding for piloted fixed-wing tactical aircraft.

Completion of F-35 Baseline Development Continues to be Delayed and Modernization Efforts Face Challenges

The F-35 program remains DOD's most expensive weapon system program, with an estimated cost of over \$1.7 trillion to buy, operate, and sustain. Although it started development in 2001, DOD has not yet authorized the F-35 program to begin full-rate production.⁹ The delay in reaching this milestone stems largely from problems and delays developing the F-35 simulator, needed for crucial testing. DOD is also 5 years into development of its \$16.5 billion modernization effort, known as Block 4, which is continuing to experience cost growth and schedule delays. These issues, which I summarize below, underscore the importance of ensuring that DOD makes informed acquisition decisions going forward if it is to minimize the risk that its engine and thermal management efforts will follow the same flight path as the Block 4 program.

⁸[GAO-23-106375](#).

⁹Full-rate production generally is the point when a program has demonstrated an acceptable level of performance and reliability; and in the case of the F-35, is ready for higher manufacturing rates.

Baseline Development Program Remains Incomplete and Faces Challenges

Simulator and Related Testing Remain Incomplete

As we reported in April 2022, the program office delayed completion of F-35 initial operational test and evaluation to an undetermined date because of challenges developing the Joint Simulation Environment, which we refer to as the simulator.¹⁰ The simulator runs the F-35's mission systems software along with other software models (such as other weapons and modern threat systems) to provide a simulated environment for conducting complex test scenarios that cannot be replicated in real-world conditions. The program office completed the final remaining open-air weapons test in June 2021 but needs to complete 64 simulated tests before initial operational testing will be finished. Initial operational testing is aimed at validating that the aircraft and its systems meet the requirements initially established for the F-35 program, particularly the remaining 64 simulated test flights. The simulator, however, must be fully developed before DOD can conduct these tests. Our ongoing work indicates that the program made progress with fixing most of the remaining simulator issues over the last year, but six "must-fix" deficiencies remain and must be resolved. Once resolved, the Director of Operational Test and Evaluation must accredit the simulator, verifying that the simulator accurately replicates real-world conditions. This will enable DOD to conduct the final tests, which are currently planned to begin in August 2023.

Aircraft and Engines Continue to be Delivered Late

The program has tried to ensure the contractor delivers aircraft on time, but late deliveries continue. As we reported in April 2022, the program office stated that they modified the contracted delivery date of near-term aircraft to help the contractor and the production line recover from ongoing supply chain challenges exacerbated by the COVID-19 pandemic.¹¹ Our preliminary results indicate, however, that the contractor delivered 50 percent of aircraft late in 2022, which represents the highest

¹⁰[GAO-22-105128](#).

¹¹[GAO-22-105128](#).

level of late deliveries over the past 6 years. According to program officials, in 2021, the contractor delivered 16 percent of aircraft late.

Similarly, engine deliveries have been problematic. As we reported last year, the engine contractor—Pratt & Whitney—had delivered more engines late than those it delivered on time.¹² Program officials stated the later deliveries were primarily due to quality issues that required resolution before engines could be accepted by the government. These officials stated that quality issues resulted in the contractor delivering nearly all of the engines late in 2021. In September 2021, the engine contractor submitted a corrective action plan to address issues with late deliveries and quality control, but our preliminary results indicate that the contractor again delivered nearly all engines late in 2022.

Modernization Efforts Face Familiar Challenges

Block 4 Content and Costs Continue to Grow

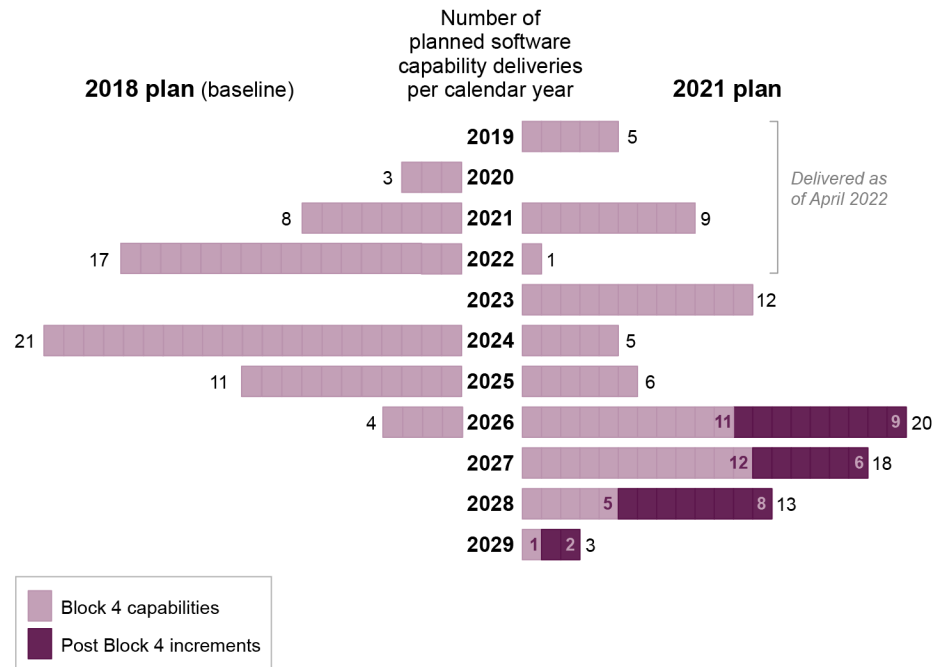
Over the past few years, we have reported that the Block 4 modernization effort has grown—both in terms of the capabilities the program plans to add to the aircraft, as well as in cost. As we have previously reported, in 2019 the Block 4 modernization effort consisted of 66 capabilities, costing \$10.6 billion, with an estimated completion as early as 2024 or as late as 2026. In April 2022, we reported the F-35 Block 4 development cost estimate increased to \$15.1 billion, which is \$700 million more than its 2020 estimate of \$14.4 billion. The primary drivers for the increase in the 2021 cost estimate include the increased costs of the Technology Refresh 3 (TR-3), which is the suite of hardware and some software technologies that will provide updated processing capability, display units, and increased memory to the aircraft.

We also reported that, in addition to the cost increase, the program office continues to face delays in delivering Block 4 capabilities and added new, post-Block 4 efforts. As of 2021, the program office planned to complete Block 4 capability deliveries 3 years later than the original schedule, due to software quality issues, funding challenges, and the addition of new capabilities, among other things. In addition, the program office is planning to develop and deliver additional, post-Block 4 capabilities beyond the original capabilities planned for Block 4. Figure 1 shows the

¹²[GAO-22-105128](#).

overall delay of planned capabilities in the 2018 baseline schedule compared to the 2021 schedule as well as the added post-Block 4 modernization capabilities.

Figure 1: Revised Delivery Plan for Block 4 and Post-Block 4 Capabilities



Source: GAO analysis of Department of Defense data. | GAO-23-106694

Text of Figure 1: Revised Delivery Plan for Block 4 and Post-Block 4 Capabilities

Number of planned software capability deliveries per calendar year:

2018 plan (Baseline)

- 2020: 3
- 2021: 8
- 2022: 17
- 2024: 21
- 2025: 11
- 2026: 4

2021 Plan

-
- 2019: 5
 - 2021: 9
 - 2022: 1
 - 2023: 12
 - 2024: 5
 - 2025: 6
 - 2026: 11 block 4 capabilities; 9 post block 4 increments
 - 2027: 12 block 4 capabilities; 6 post block 4 increments
 - 2028: 5 block 4 capabilities; 8 post block 4 increments
 - 2029: 1 block 4 capabilities; 2 post block 4 increments

Notes:

This figure represents the F-35 program office's Block 4 and post-Block 4, software-enabled capability delivery plans from 2018 and 2021, respectively. We have previously reported that Block 4 is composed of 66 capabilities. However, some of those capabilities such as those related to the use of new weapons that required changes to hardware, like modifications to the aircraft's weapons bay, and the hardware elements are not represented in this graphic. Furthermore, since the program issued the 2018 plan, program officials explained that the program has removed some capabilities, added new capabilities, and split capabilities up into multiple increments, in part, due to Turkey's removal from the program and new or changing priorities. Therefore, the total number of capabilities and the program office's time frame for delivering those capabilities has changed.

In prior years, based on information provided to us at that time, we have reported that the F-35 program office estimated that Block 4 development and delivery would be completed as early as 2024. This year, the program office provided us with a document from October 2018, which identified that Block 4 capabilities would be delivered as late as 2026. We have updated this statement to reflect this new information.

Our preliminary observations point to continued increases in planned capabilities, cost increases, and schedule delays for Block 4. Our ongoing work also continues to identify that the program does not provide a holistic Block 4 cost estimate, inclusive of all years incurred and expected costs, or fully explain cost growth in its annual Block 4 reports to Congress.

F-35 Requires Engine Modernization and Thermal Management Upgrades

The F-35 uses its engine and Power and Thermal Management System (PTMS) to provide power and cooling to the aircraft's subsystems that generate heat. The engine generates power to fly the aircraft, support the energy needs of aircraft subsystems, and power other systems by redirecting air pressure that would otherwise be used to cool the engine. The PTMS, a system designed by a Lockheed Martin subcontractor, uses air pressure from the engine to provide cooling to aircraft subsystems,

such as the radar, to ensure they do not overheat and fail. The PTMS is a complex subsystem that includes the equipment necessary to provide aircraft main engine start, emergency power, cockpit conditioning, equipment cooling, and some electrical power, among others.

Based on our preliminary observations, the PTMS needs more air pressure from the engine to cool subsystems than originally anticipated, which means that the engine is working harder than it was designed to, resulting in reduced engine life. Program officials explained that Pratt & Whitney designed the engine to provide a certain amount of air pressure to the PTMS, which Lockheed Martin defined early in the development program. While Pratt & Whitney's F135 engine met those specifications, program officials stated that in 2008, Lockheed Martin discovered that the PTMS would need more air pressure from the engine than originally anticipated to help cool aircraft subsystems. According to program officials, in 2013, Lockheed Martin requested to change the F135's design to provide more air pressure to the PTMS, but program officials determined that it was too late to redesign the engine given the cost and schedule impacts of such a change at that stage of the overall program. Program officials decided to continue with the F135 engine's original design with the understanding that there would be increased wear and tear on the engine because it would need to provide more air pressure to the PTMS than its design intended. However, the higher air pressure needs results in the engine working harder than intended, which increases maintenance and reduces engine life. As we reported in July 2022, the engine is witnessing higher than expected maintenance and resulting in higher than expected levels of F-35s being not mission capable.¹³

According to program officials, these cooling needs will continue to grow as the program adds new capabilities to the aircraft. Modernization capabilities—including Block 4 capabilities already installed and future ones planned for through 2035—require even more cooling capacity and air pressure than the PTMS and the engine can support, respectively. Program officials noted that Lockheed Martin did not anticipate needing higher cooling from the PTMS when it proposed Block 4. However, the addition of Block 4 will require more cooling capacity. Therefore, the program expects the engine will need to provide even higher air pressure

¹³GAO, *F-35 Aircraft: DOD Should Assess and Update its Engine Sustainment Strategy to Support Desired Outcomes*, [GAO-22-104678](#) (Washington, D.C.: Jul 19, 2022).

to the PTMS to support future capabilities, which will further reduce engine life.

Based on our preliminary observations, the program has already added \$38 billion to the program's life-cycle cost estimate because of these cooling challenges, largely due to the increased wear and tear on the engine.¹⁴ As we reported in March 2005, DOD began development of the F-35 aircraft in 2001 without adequate knowledge of its critical technologies or a solid design.¹⁵ We have reported that, as a result, the program has incurred additional costs, because it has had to redesign and retrofit the aircraft. The misalignment of requirements with the engine and PTMS illustrates why it is important to fully understand the proposed designs at the beginning of an acquisition, prior to committing to development.

Further, the program determined that it must upgrade the PTMS and upgrade the engine. The current design of the engine and PTMS, collectively, will not meet the cooling capacity needed to support future capabilities planned beyond 2029. If the program does not upgrade the PTMS by 2029, the program will not be able to support the new capabilities planned through 2035 or beyond. In contrast, program officials stated the current engine could support capabilities planned through 2035, albeit with a significantly degraded engine lifespan. As a result, officials stated that they would need to upgrade the engine to improve its lifespan and potentially avoid at least some of the \$38 billion in increased life-cycle costs.

Based on our preliminary observations, the program did not conduct an analysis of alternatives when determining which engine and PTMS upgrade options to evaluate. To support informed acquisition decisions, DOD typically requires programs following the major capability acquisition pathway to conduct planning activities to support the decision to move to

¹⁴In July 2022, we also reported that DOD's F-35 engine sustainment strategy allows 6 percent of F-35s to be unavailable for missions at any given time due to engine issues. However, the military services desire outcomes similar to their other tactical fighter aircraft, which since 2017, have generally experienced 1 percent or less of aircraft being unable to operate due to engine issues, according to officials. We recommended that DOD assess and make changes to the F-35 engine sustainment strategy and the department is in the process of taking actions. See [GAO-22-104678](#).

¹⁵GAO, *Tactical Aircraft: Opportunity to Reduce Risks in the Joint Strike Fighter Program with Different Acquisition Strategy*, [GAO-05-271](#) (Washington, D.C.: Mar. 15, 2005).

technology development.¹⁶ For example, programs usually conduct an analysis of alternatives to identify and assess a range of possibilities to meet requirements during the material solutions analysis phase and prior to technology development.¹⁷

In lieu of completing an analysis of alternatives, our ongoing work indicates that the program office completed what it refers to as a business case analysis in March 2023 to compare different PTMS and engine options.¹⁸ The analysis evaluated preselected options for improving power and cooling by upgrading the PTMS as well as modernizing or replacing the engine. It also compares some risks associated with each option and identified potential improvements needed for multiple other air vehicle subsystems. According to program officials, they intended for the analysis to provide the services with information to help them make engine and PTMS modernization decisions. Program officials acknowledged, however, that the analysis did not follow any particular DOD guidance related to business case analysis or analysis of alternatives.

Our preliminary observations indicate that the program's analysis does not address key aspects of how we define a business case analysis.¹⁹ For example, the analysis does not yet include an approved acquisition strategy for engine modernization or a completed independent cost estimate. Therefore, we consider it a comparative analysis and not a business case analysis.

Based on our preliminary observations of the comparative analysis, the program evaluated three modernization categories.²⁰ These include:

¹⁶Department of Defense Instruction, Major Capability Acquisition, 5000.85.

¹⁷Office of Secretary of Defense, Cost Assessment and Program Evaluation, Analysis of Alternatives Cost Estimating Handbook, Jan. 12, 2022.

¹⁸The analysis and findings of the F-35 program's engine and thermal management comparative analysis were complete at the time of our review, but the program did not release it until March 2023.

¹⁹In GAO's prior work, we identified five key elements of a business case. They include: approved requirements, an approved acquisition strategy, a completed technical risk assessment, a completed schedule risk assessment, and a cost estimate based on an independent assessment. GAO, *Defense Acquisitions Annual Assessment: Drive to Deliver Capabilities Faster Increases Importance of Program Knowledge and Consistent Data for Oversight*, [GAO-20-439](#) (Washington, D.C.: June 3, 2020).

²⁰The analysis compared 20 engine and PTMS combinations. However, not all were feasible options due to the modernization timelines.

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- the current F135 with an upgraded PTMS,
 - an upgraded F135 engine with an upgraded PTMS, and
 - a fully redesigned engine with an upgraded PTMS.

For each category above, the program also evaluated different upgrades to the PTMS. Two of the PTMS upgrade options enhance the existing PTMS to varying degrees and one option is a totally redesigned PTMS. Each engine and PTMS combination presents different trade-offs based on levels of commonality, cooling capacity, costs, schedules, and other factors.

The program provided the results of its assessment to the military services to inform their modernization decisions. Program officials explained that the military services will each define their own performance requirements based on their needs and each service will be able to select its own PTMS and engine modernization path. This means the military services could select different modernization options, which could affect the commonality of the F-35s engine, potentially resulting in increased sustainment costs if multiple engines need to be supported. Program officials said they provided the comparative analysis to the military services for their consideration.

We are currently evaluating the program's comparative analysis of these engine and PTMS modernization options and will report on our assessment later this spring.

In conclusion, tactical aircraft are a critical element in DOD's ability to operate and achieve its strategic objectives and facilitate the combined force. DOD faces a number of challenges in ensuring it has the right mix of tactical aircraft with capabilities that are effective against future threats while ensuring it is making choices that it can afford. Until DOD conducts a broader, portfolio-level evaluation of its total investments in tactical aircraft, it risks making inefficient budget decisions. This broader perspective is particularly important as the linchpin of DOD's tactical aircraft fleet, the F-35, continues to experience engine challenges that will likely require billions in additional funding to address. The F-35 program has tough choices ahead to ensure it picks the right combination of engine and PTMS upgrades so the F-35 can support future capabilities, and these decisions should not be made without fully considering its long-term needs.

Chairman Wittman, Ranking Member Norcross, and Members of the Subcommittee, this completes my prepared statement. I would be pleased to respond to any questions you may have at this time. We look forward to continuing to work with the Congress as we continue to monitor and report on the progress of the F-35 program.

GAO Contact and Staff Acknowledgments

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