United States Government Accountability Office

Report to Congressional Committees

May 2024

F-35 JOINT STRIKE FIGHTER

Program Continues to Encounter Production Issues and Modernization Delays

GAO-24-106909

GAO Highlights

Highlights of GAO-24-106909, a report to congressional committees

May 2024

F-35 JOINT STRIKE FIGHTER

Program Continues to Encounter Production Issues and Modernization Delays

Why GAO Did This Study

After over 20 years, the F-35 Lightning II Joint Strike Fighter program—the Department of Defense's (DOD) most expensive weapon system program—completed its baseline development phase and moved into full-rate production. DOD is in its sixth year of a hardware and software modernization effort known as Block 4 and is considering other modernization efforts. DOD estimates that these development efforts—as well as the costs to maintain and operate the 2,470 planned aircraft through 2088—will exceed $2 trillion.

Congress included provisions in statute for GAO to review the F-35 program. This report assesses the program's: (1) progress and risks as it approached full-rate production; (2) progress in modernizing the aircraft's capabilities; and (3) progress in upgrading the engine and other subsystems.

GAO collected and analyzed cost, schedule, and production data; reviewed relevant program documentation; and interviewed DOD officials and contractor representatives.

What GAO Recommends

GAO has reviewed the F-35 program annually since 2001 and made 54 recommendations for improvement. In May 2023, GAO made seven recommendations aimed at improving Block 4 cost reporting and the program's modernization efforts (GAO-23-106047). DOD has taken action to address some, but not all, of GAO's recommendations.

View GAO-24-106909. For more information, contact Jon Ludwigson at (202) 512-4841 or ludwigsonj@gao.gov.

What GAO Found

The F-35 program achieved full-rate production in March 2024. Full-rate production is the point when a program has demonstrated an acceptable level of performance and reliability. Further, the F-35 program completed development of its testing simulator and conducted its final simulated tests.

Even with this progress, the F-35's contractors continue to deliver the engines and aircraft late—a trend that worsened in the last few years. According to program officials, late deliveries were partially caused by manufacturing issues and parts shortages. The program and contractors are mitigating these issues.

Percentage of Engines and Aircraft that Contractors Delivered Late in Calendar Year 2023

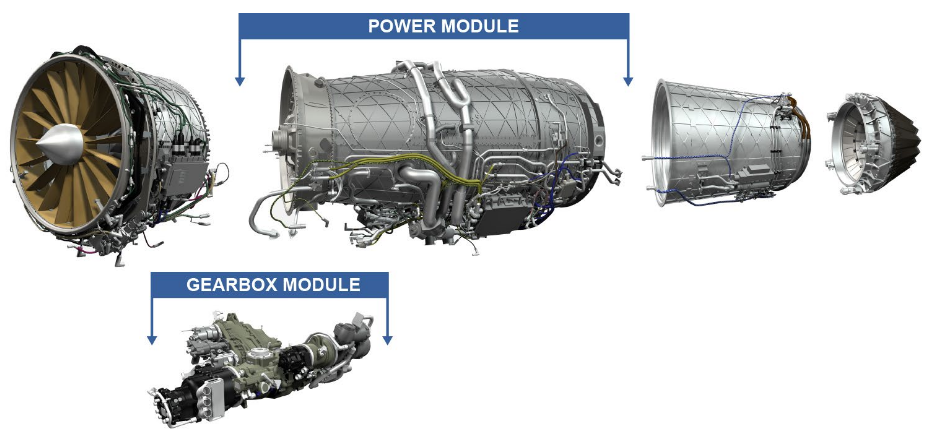
Contractor	Parts delivered	Percentage delivered late
Pratt & Whitney	Engines	100
Lockheed Martin	Aircraft	91

Source: GAO analysis of contractor data. | GAO-24-106909

Hardware and software delays—specifically those associated with Technology Refresh 3 (TR-3)—are another factor driving delays and hindering the program's progress in completing the Block 4 modernization. TR-3 is a $1.8-billion suite of hardware and software upgrades that are critical to the Block 4 modernization effort. TR-3 suppliers have faced setbacks including supply chain issues and software issues. The program and contractor are resolving these issues.

The program made some progress in its recent efforts to modernize the engine and other subsystems but has not awarded a development contract.

Diagram of Engine and Engine Core Components Included in F-35 Modernization Effort



Source: Pratt & Whitney. | GAO-24-106909

The program also has not yet determined how to modernize the thermal management subsystems that provide cooling to the aircraft. These efforts continue to face risks due to undefined requirements, immature technologies, and varying cost estimates. GAO has made recommendations to address these risks, which the program has not yet fully implemented.

Contents

Abbreviations

DOD	Department of Defense
DOT&E	Director of Operational Test and Evaluation
ECU	Engine Core Upgrade
NDAA	National Defense Authorization Act
PTMS	power and thermal management system
TR-2	Technology Refresh 2
TR-3	Technology Refresh 3
TRL	technology readiness level

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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Congressional Committees

The Department of Defense (DOD) is developing and fielding a family of fifth-generation strike fighter aircraft that integrate low-observable (stealth) technology with advanced sensors and computer networking capabilities. The F-35 will be used by DOD, as well as seven international partners, and 10 foreign military sales customers, to perform a wide range of missions.[1] DOD aims to procure 2,470 F-35s to replace several other aircraft used by the Air Force, Navy, and Marine Corps. To date, the program has delivered over 990 aircraft to the U.S. services, international partners, and foreign military sales customers. The program, however, is also more than a decade delayed and has cost $209 billion more than originally planned.

The program ended development of the F-35's original baseline capabilities in 2018. DOD is now in the sixth year of developing its capability modernization effort—known as Block 4—to upgrade the F-35's hardware and software systems. DOD intends for Block 4 to help the aircraft address new threats that have emerged since DOD established the aircraft's original requirements in 2000. In addition, the program is in the process of developmental testing of Technology Refresh 3 (TR-3), the $1.8-billion suite of upgraded hardware and software technologies that will enable many Block 4 capabilities. The program is also planning to modernize the F-35 engine to address engine power and cooling limitations in which post-Block 4 capabilities will need to operate. We have reviewed this program annually since 2001, reported on program risks, and made recommendations for improvement.[2] DOD has taken action to address some, but not all, of our recommendations.

Two statutes include provisions for us to review aspects of the F-35 program. First, the National Defense Authorization Act (NDAA) for Fiscal Year 2015 includes a provision for us to review the F-35 program

[1]Seven partner nations—Australia, Canada, Denmark, Italy, Netherlands, Norway, and the United Kingdom—contribute to F-35 development, production, and sustainment. Ten other nations comprise the program's foreign military sales customers: Belgium, Czech Republic, Finland, Germany, Israel, Japan, Korea, Poland, Singapore, and Switzerland. According to program officials, additional countries are at various stages of consideration for foreign military sales.

[2]A list of recent related GAO products is provided at the end of this report.

annually until the program reaches full-rate production.[3] Second, the NDAA for Fiscal Year 2020 includes a provision for us to submit a report on the F-35 program's manufacturing improvements, Block 4 progress, and other issues within 30 days of the President's budget submission for fiscal years 2021 through 2025.[4]

In this report, we assess (1) the status of the baseline program as it approached full-rate production; (2) the progress that DOD made in developing, testing, and delivering modernization capabilities to the fleet; and (3) DOD's progress in modernization efforts for the F-35 engine and thermal management systems.

To do this work, we interviewed officials and representatives from the F-35 program office; Office of the Director of Operational Test and Evaluation (DOT&E); Lockheed Martin (prime aircraft contractor); Pratt & Whitney (prime engine contractor); and the Defense Contract Management Agency. In these interviews, we discussed the original development program, modernization, the engine, and the thermal management system. We also collected and analyzed cost, schedule, and production data, such as on-time deliveries, labor hours, and technical risks, among other things. This allowed us to describe the program's progress toward completing the original development program.

To assess DOD's progress in developing, testing, and delivering modernization capabilities and risks that remain, we analyzed cost, schedule, and performance documents for Block 4 modernization and compared them against the status we reported last year. We also reviewed schedule and risk mitigation plans for other issues related to Block 4 modernization, such as technology delays.

To assess DOD's progress in modernization efforts for the F-35 engine and thermal management systems, we reviewed relevant program documentation, such as preliminary schedules and planning documents. We also spoke with knowledgeable officials to discuss steps taken to address our prior related recommendations, such as to identify requirements for engine and thermal management systems.

For each objective, we corroborated the data we collected from contractor representatives and program officials with other data sources or

[3]Pub. L. No. 113-291, § 153(a) (2014).

[4]Pub. L. No. 116-92, § 166(b)(1) (2019).

knowledgeable officials, such as DOT&E. We determined that all the data we used were sufficiently reliable for the purposes of our reporting objectives.

We conducted this performance audit from June 2023 to May 2024 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.

Background

DOD started the F-35 program in 2001 to develop a fifth-generation fighter aircraft intended to replace a range of aging aircraft in the U.S. military services' inventories. It was also intended to provide enhanced capabilities that capitalized on technological innovations to warfighters. Among other capabilities, DOD intended that the F-35 aircraft would be difficult to detect using radar and would include sensors that can provide insights into potential targets and other warfighting information. Lockheed Martin is the prime contractor for the F-35 aircraft and is responsible for integrating the engine into the aircraft. Pratt & Whitney is the prime contractor for the engine.[5]

The program is developing, producing, and sustaining three variants of the F-35 aircraft, as shown in figure 1.

[5]The government acquires the engines directly from Pratt & Whitney and delivers them as government-furnished equipment to Lockheed Martin for integration into the aircraft during production.

Figure 1: F-35 Aircraft Variants

	F-35A Conventional Take-off and Landing	**F-35B** Short Take-off and Vertical Landing	**F-35C** Carrier

Initial operating capability	2016	2015	2019
Purpose	Counter present and future advanced threats through counter air, strike, and surveillance and reconnaissance missions		
	Air Force variant that supports primarily air to ground missions and comprises majority of partner aircraft and foreign military sales	Marine Corps variant that is capable of short take-off and vertical landing to support expeditionary basing ashore and deployment at sea	Navy and Marine Corps variant with larger wing span and greater fuel storage to support aircraft carrier operations and expeditionary roles

Source: GAO analysis of Department of Defense documents and interviews with officials. Photos (left to right): 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-24-106909

Note: Initial operational capability is declared by the military services that have the force structure and ability to employ and sustain it for specific operations.

The F-35 program is organized under the Office of the Under Secretary of Defense for Acquisition and Sustainment.[6] DOD leads the F-35 program, but the program also includes several allied partner countries involved in aircraft development. Companies in these countries produce certain parts of the aircraft or engine, according to program office officials.

Baseline Acquisition Cost and Schedule Revisions

Since 2001, DOD has significantly revised the cost and schedule goals for the F-35 program several times. For example, DOD revised these goals in March 2012 after the unit cost of each aircraft grew by an amount that exceeded critical thresholds established by statute—a condition known as a Nunn-McCurdy breach.[7] This 2012 revised baseline increased the program's cost estimate by $162.7 billion and extended

[6]The F-35 program is currently overseen by the Navy Service Acquisition Executive. The service acquisition executive of the military department managing a major defense acquisition program is designated as the milestone decision authority for major acquisition programs initiated after October 1, 2016, unless the Secretary of Defense designates an alternate milestone decision authority. For the F-35 program, the Defense Acquisition Executive, which is the Under Secretary of Defense for Acquisition and Sustainment, has been designated the milestone decision authority. See Pub. L. No. 114-92, § 825(a) (2015) (codified as amended at 10 U.S.C. § 4204). See also 10 U.S.C. § 1704 for functions and responsibilities of the service acquisition executive.

[7]DOD is required to notify Congress whenever a major acquisition program's unit cost experiences cost growth that exceeds certain thresholds, commonly referred to as a Nunn-McCurdy breach. 10 U.S.C. § 4371(a)(1)-(3).

delivery schedules 5 to 6 years into the future. Since 2012, the program has revised its baseline schedule four more times due to delays in development, among other things. As of December 2022, the program's most recent cost estimate reported that acquisition costs are $442 billion, an increase of nearly $47 billion since 2012, as shown in table 1.[8]

Table 1: Total F-35 Acquisition Costs Exceed the 2012 Baseline Estimate by $46.6 Billion

	October 2001 baseline costs	March 2012 baseline costs	Difference from 2001 to 2012	December 2022 estimated costs	Difference from 2012 to 2022
Development	34.4	55.2	20.8	79.8	24.8
Procurement	196.6	335.7	139.1	358.5	22.8
Military construction	2	4.8	2.8	4.0	(0.8)
Total program acquisition	**233**	**395.7**	**162.7**	**442.3**	**46.6**

Source: GAO analysis of Department of Defense data. | GAO-24-106909

Note: Costs in the table are in then-year dollars in billions and reflect data from the December 2022 Selected Acquisition Report, the most recent available. Differences may occur due to rounding. The December 2022 development program cost estimate includes Block 4 modernization costs, as applicable.

In May 2023, we reported that recent cost increases are largely attributable to an increase in scope in the Block 4 modernization effort.[9]

In addition to the acquisition costs, the program office estimates that the costs to operate and sustain the F-35 fleet through its 77-year life cycle is at least $1.58 trillion, bringing the total cost of the F-35 program to over

[8]The program plans to release a new Acquisition Program Baseline and Selected Acquisition Report in July 2024, subsequent to its full-rate production decision. Major defense acquisition programs periodically provide Selected Acquisition Reports to Congress that summarize key cost, schedule, and technical information. However, program officials stated that cost estimates of recent program changes related to Block 4 and engine and thermal management modernization will not be included this estimate. See 10 U.S.C. § 4351(b)(1), (f), with the requirement to submit these reports under this section terminating after the final submission covering fiscal year 2023.

[9]GAO, *F-35 Joint Strike Fighter: More Actions Needed to Explain Cost Growth and Support Engine Modernization Decision*, GAO-23-106047 (Washington, D.C.: May 30, 2023).

$2 trillion.[10] We previously reported on various sustainment issues, most recently in 2024.[11]

Block 4 Modernization Effort

In addition to the F-35 original development program, DOD is pursuing a $16.5-billion modernization effort known as Block 4.[12] Block 4 seeks to produce many new capabilities for the aircraft, enabled by both hardware and software upgrades. Examples of these capabilities include radar enhancements, weapons, and technology to avoid aircraft collisions.

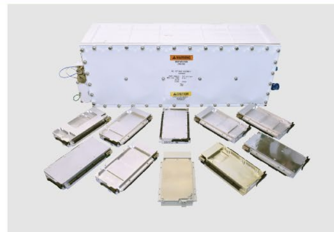
The program continues to develop and produce TR-3, the $1.8-billion suite of upgraded hardware and software technologies that will enable future Block 4 capabilities. In May 2023, we reported that the program originally planned to deliver the first F-35 aircraft with TR-3 hardware and software in July 2023. The upgrades within TR-3 are set to provide improved processing capability and increased memory capacity compared with the current F-35 processor and memory system, known as Technology Refresh 2 (TR-2), as shown in figure 2.

[10]These operation and sustainment costs are reported in the 2023 F-35 program acquisition cost estimate.

[11]GAO, *F-35 Sustainment: Costs Continue to Rise While Planned Use and Availability Has Decreased,* GAO-24-106703 (Washington, D.C.: Apr. 15, 2024).

[12]This is the program's most recent Block 4 cost estimate and is from August 2021. It reflects total Block 4 costs through fiscal year 2029. The program has yet to release an updated Block 4 cost estimate because it is in the process of reevaluating the Block 4 effort to document its overall cost, schedule, and scope, which we discuss in detail later in this report.

Figure 2: F-35 Technology Refresh 3 (TR-3) Components and Improvements

Component	Component Photo	Functionality	Improvement from TR-2
Integrated Core Processor		processes data for each mission Processing: Memory:	 16x 4.5x
Panoramic Cockpit Display		processes cockpit images Processing: Memory:	 8x 12x
Aircraft Memory System		stores aircraft memory	20x

Source: GAO analysis of Department of Defense data | GAO-24-106909

The projected cost of the Block 4 effort exceeds the statutory and regulatory thresholds for what constitutes a major defense acquisition program.[13] In April 2016, we recommended that the program manage Block 4 modernization as a separate program from the F-35 baseline program, in part, to provide more visibility and to hold the program accountable for meeting cost, schedule, and performance goals.[14] DOD

[13]Major defense acquisition programs are those identified by DOD or that have a dollar value for all increments estimated to require eventual total expenditure for research, development, test, and evaluation of more than $525 million, or for procurement of more than $3.065 billion, in fiscal year 2020 constant dollars. Department of Defense, DOD Instruction 5000.85, *Major Capability Acquisition* (Aug. 6, 2020) (Change 1, Nov. 4, 2021). See also 10 U.S.C. § 4201.

[14]GAO, *F-35 Joint Strike Fighter: Continued Oversight Needed as Program Plans to Begin Development of New Capabilities*, GAO-16-390 (Washington, D.C.: Apr. 14, 2016).

did not concur with our recommendation and continued to manage Block 4 as part of the F-35 baseline program. Congress subsequently required reporting on Block 4, which was consistent with the intent of our recommendation, and later directed the program office to manage Block 4 and TR-3 collectively as a major subprogram, thereby requiring certain acquisition reporting until all Block 4 capabilities are fielded.[15]

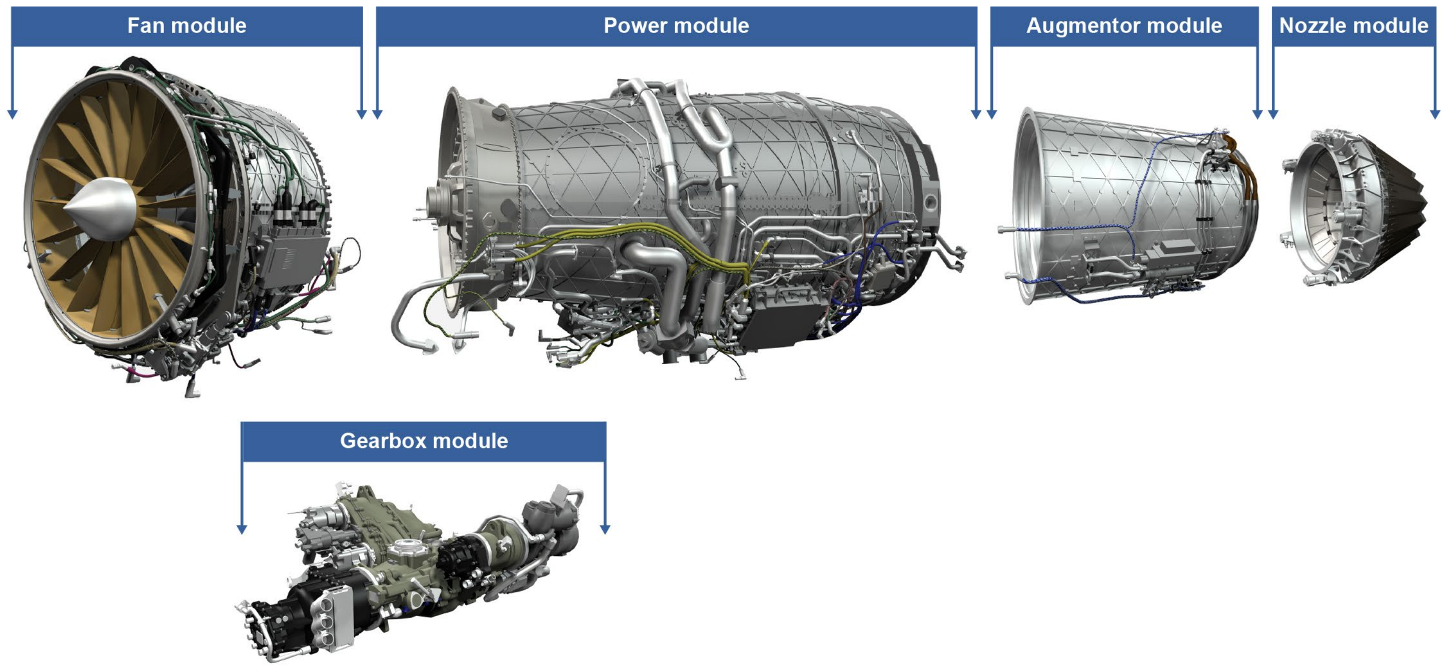
Engine and Thermal Management Modernization

The F-35 has a single engine—called the F135—that is built by Pratt & Whitney as a major acquisition subprogram. That subprogram then provides the engine as government-furnished equipment to Lockheed Martin, which integrates it into the airframe during production.[16] The three F-35 variants have the same basic engine design with some variations. Specifically, the F-35A and F-35C have the same engine with four modules: fan, power, augmentor, and nozzle (see fig. 3). The gearbox module is included in the power module. The F-35B's engine also has four main engine modules, though the power, augmentor, and nozzle modules have F-35B-specific parts and features that enable short takeoff and vertical landing operations, in addition to the F-35B unique lift system made by Rolls Royce.

[15]Pub. L. No. 114-328, § 224(d) and Pub. L. No. 116-92, § 166. The NDAA for Fiscal Year 2024 directed the program to designate Block 4 and all TR-3 elements as a major subprogram under the F-35 baseline program. Pub. L. No. 118-31, § 225 (a) (2024).

[16]Government-furnished equipment is provided to a contractor by the government, for performance of a contract, and includes tangible items that are functionally complete for their intended purpose, durable, nonexpendable, and needed for the performance of the contract. Federal Acquisition Regulation Part 45.101.

Figure 3: Diagram of an F-35A/C Engine



Source: Pratt & Whitney. | GAO-24-106909

The program identified that the F-35's overall design would not meet cooling needs over 16 years ago and made the decision not to change engine requirements to address those cooling needs. While Pratt & Whitney's F135 engine met the original power and thermal management requirements, program officials stated that, in 2008, Lockheed Martin discovered that the thermal management system 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 system that cools the aircraft and its systems. However, program officials determined that it was too late to redesign the engine given the cost and schedule effects of such a change because the program had completed design and verification activities. Furthermore, Pratt & Whitney representatives stated that they continued to advocate for an engine modernization plan and developed modernization options that could support the F-35's Block 4 and post-Block 4 capabilities.

Program officials decided to continue with the F135 engine's original design with the understanding that there would be increased wear and tear, more maintenance, and reduced life on the engine. As a result, the program has 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.

In May 2023, we reported that the F-35 program was in the early stages of planning to modernize the F-35 engine.[17] According to program officials, the program will need to modernize the current engine to provide the additional power and thermal management capabilities that are necessary to support post-Block 4 F-35 aircraft modernization efforts. We also identified several challenges with the program's engine and thermal management modernization approach and made recommendations to address them. Specifically, we found that the military services had not fully defined the power and cooling requirements. Additionally, we found that the program office had not fully assessed the costs and some of the technical risks of the different engine and thermal management system upgrade options. Further, we reported that the program planned to manage engine and thermal management upgrade options as part of the overall F-35 program, which presented oversight and transparency risks similar to those we identified with Block 4. We made six recommendations aimed at addressing these issues. DOD concurred with two, partially concurred with three, and did not concur with one recommendation.

F-35 Program Completed Initial Operational Testing, but Late Deliveries Continue

The F-35 program has completed initial operational testing and achieved full-rate production in March 2024. However, the program continues to experience production delays. Specifically, the contractors delivered all engines and almost all aircraft late in 2023.

Program Completed Initial Operational Testing

The program completed development of the F-35 Joint Simulation Environment, which we refer to as the simulator, and conducted the remaining tests in a simulated environment to finish initial operational

[17] GAO-23-106047.

testing and evaluation.[18] 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 complex mission scenarios for testing that the program cannot replicate in a real-world environment. We previously reported that the simulator experienced years of delays due to developmental challenges, which prevented DOD from completing the simulation-based testing required to fully assess the F-35's operational effectiveness.[19] In September 2023, however, the program completed the verification, validation, and accreditation process, certifying the simulator as ready for completing the remaining 64 test scenarios in September.

Moreover, after over 20 years, the F-35 program achieved full-rate production in March 2024. DOT&E evaluated the results of the initial operational tests and issued a classified report in February 2024, according to DOT&E officials. The February 2024 report contains information about the results of the initial operational test and evaluation of the F-35's overall effectiveness, suitability, and survivability, which informed the full-rate production decision. Full-rate production generally is the point when a program has demonstrated an acceptable level of performance and reliability and is ready for higher manufacturing rates. In the case of the F-35, manufacturing has already been producing at or near full rate for several years in advance of completing this determination.[20]

Although the program recently achieved full-rate production, it continues to discover and resolve technical risks with the aircraft. For example, in 2023, the program identified a new technical risk related to the F-35C landing gear being overloaded and continued to resolve previously identified risks, such as issues with the aircraft canopy coating. F-35 program officials and Lockheed Martin representatives are working to mitigate and resolve technical risks as they are identified. Late discovery

[18]DOD conducts initial operational test and evaluation to determine whether systems are operationally effective and suitable to support a full-rate production decision. Before a final decision to proceed with a major defense acquisition program beyond low-rate initial production, the Director of DOT&E must submit to the Secretary of Defense and the congressional defense committees, among others, a report with respect to that program. 10 U.S.C. § 4171(b)(4).

[19]GAO-23-106047.

[20]See Department of Defense, Department of Defense Instruction 5000.85, *Major Capability Acquisition* (Aug. 6, 2020) (incorporating change 1, Nov. 4, 2021). In May 2023, we reported that DOD had delivered over 900 aircraft—more than one-third of all planned F-35 aircraft—before achieving full-rate production. GAO-23-106047.

of technical risks may lead to redesigns, incorporation of fixes into production aircraft, retrofitting aircraft in the fleet with the fix, or other costly or schedule-delaying tasks. See appendix I for a description of selected technical risks.

Contractor Continues to Deliver Engines and Aircraft Late

The F-35 program continued to experience late deliveries of engines and aircraft in 2023.

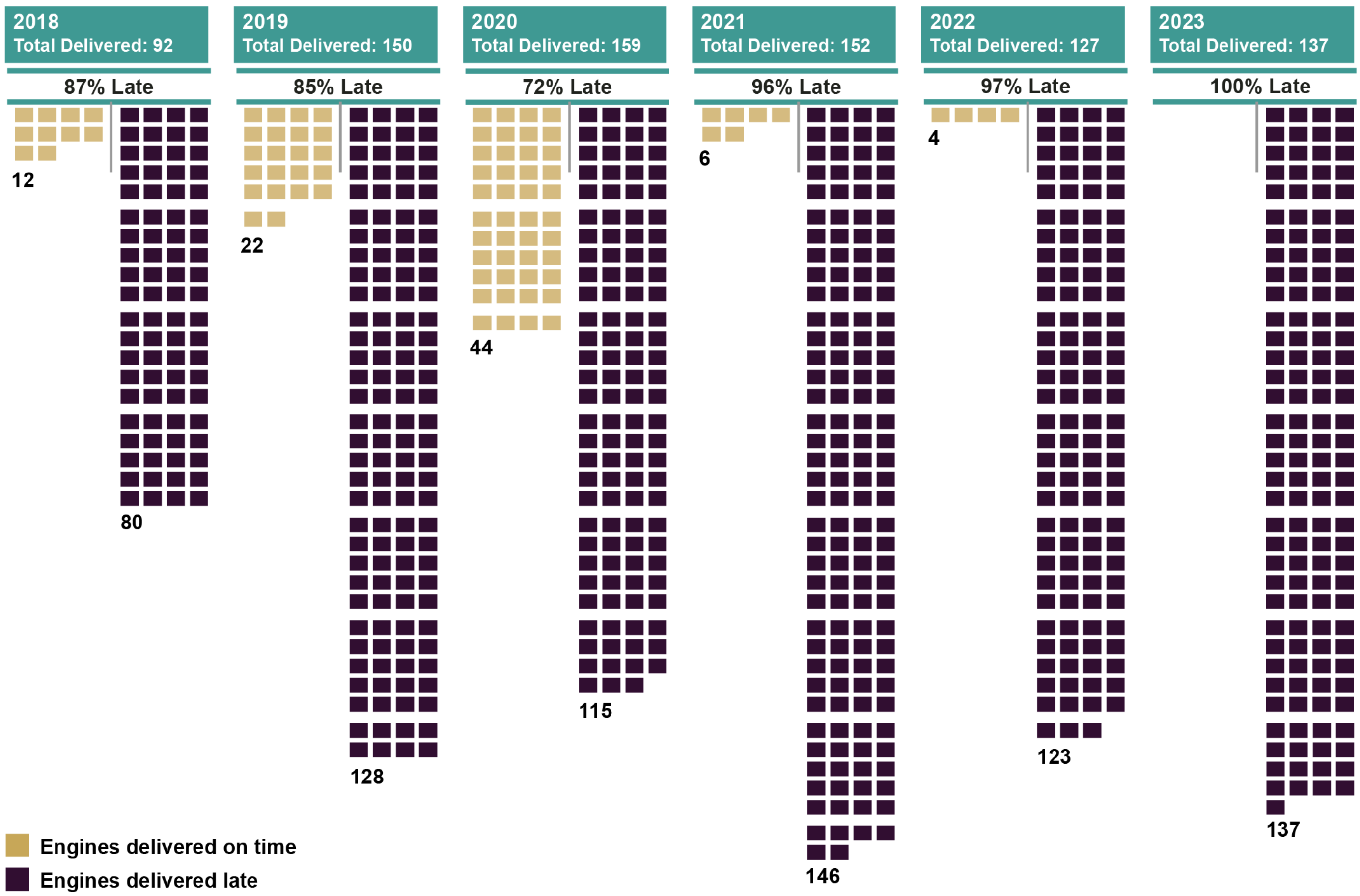
Engine

The engine contractor—Pratt & Whitney—did not deliver any engines on time in 2023. Furthermore, in 2023, engines were delivered more than 2 months late, on average, compared with 1 month late in 2022. Defense Contract Management Agency officials attributed late engine deliveries over the past year to hardware issues, such as late delivered parts and engines failing a specification or requirement during testing.[21] In addition, Pratt & Whitney continued its practice of halting engine deliveries as it discovered quality issues with parts, which further contributed to these delays.

Pratt & Whitney has faced challenges with delivering engines on time since 2018. In 2021 and 2023, DOD requested that Pratt & Whitney address issues with late deliveries. In response, the contractor submitted a corrective action plan and implemented steps to enhance delivery performance. DOD agreed with and accepted the corrective action plan, but the percentage of engines delivered late has not improved (see fig. 4).

[21]According to Defense Contract Management Agency officials, while test failures count for a small percentage of the engines, they can cause multiple engines in assembly to be delayed.

Figure 4: F-35 Engine Contractor Delivered All Engines Late in 2023



Source: GAO analysis of Pratt & Whitney data. | GAO-24-106909

Late engine deliveries have not yet affected aircraft production due to the presence of an engine inventory buffer. Pratt & Whitney delivers engines to DOD earlier than Lockheed Martin needs them for production. DOD holds these engines until either Lockheed Martin needs them for production or the military services need them to replace engines for F-35s in the field. In May 2023, we reported that the buffer was temporarily depleted as of February 2023 due to a pause in engine deliveries after an F-35B crash in December 2022.[22] During this pause in engine delivery, Pratt & Whitney continued engine production while the program identified

[22] GAO-23-106047.

a root cause and way to fix the issue. The program determined that a fuel tube vibration contributed to the accident and approved a redesigned fuel tube as the final solution for resolving the issue. We discuss the fuel tube vibration issue in more detail in appendix I.

According to DOD officials, the program resumed engine deliveries in mid-February 2023 and built up the buffer to 40 engines, about 10 less than in 2022. However, program officials stated that the short takeoff and vertical-landing engines in the buffer need to be monitored closely as there are fewer scheduled for production.

Although Pratt & Whitney continues to experience challenges with delivering engines on time, it has made quality improvements over the last year. As a result of an over $100 million self-funded quality improvement plan, Pratt & Whitney reduced quality notification line items per engine by 60 percent since 2021, according to contractor representatives.[23] Specifically, the contractor went from 1,443 average quality notifications per engine in 2021 to 647 in 2023. These quality improvements have been demonstrated in manufacturing processes and throughout the supply chain. Further, according to Pratt & Whitney representatives, 99 percent of quality issues are addressed prior to engine delivery.

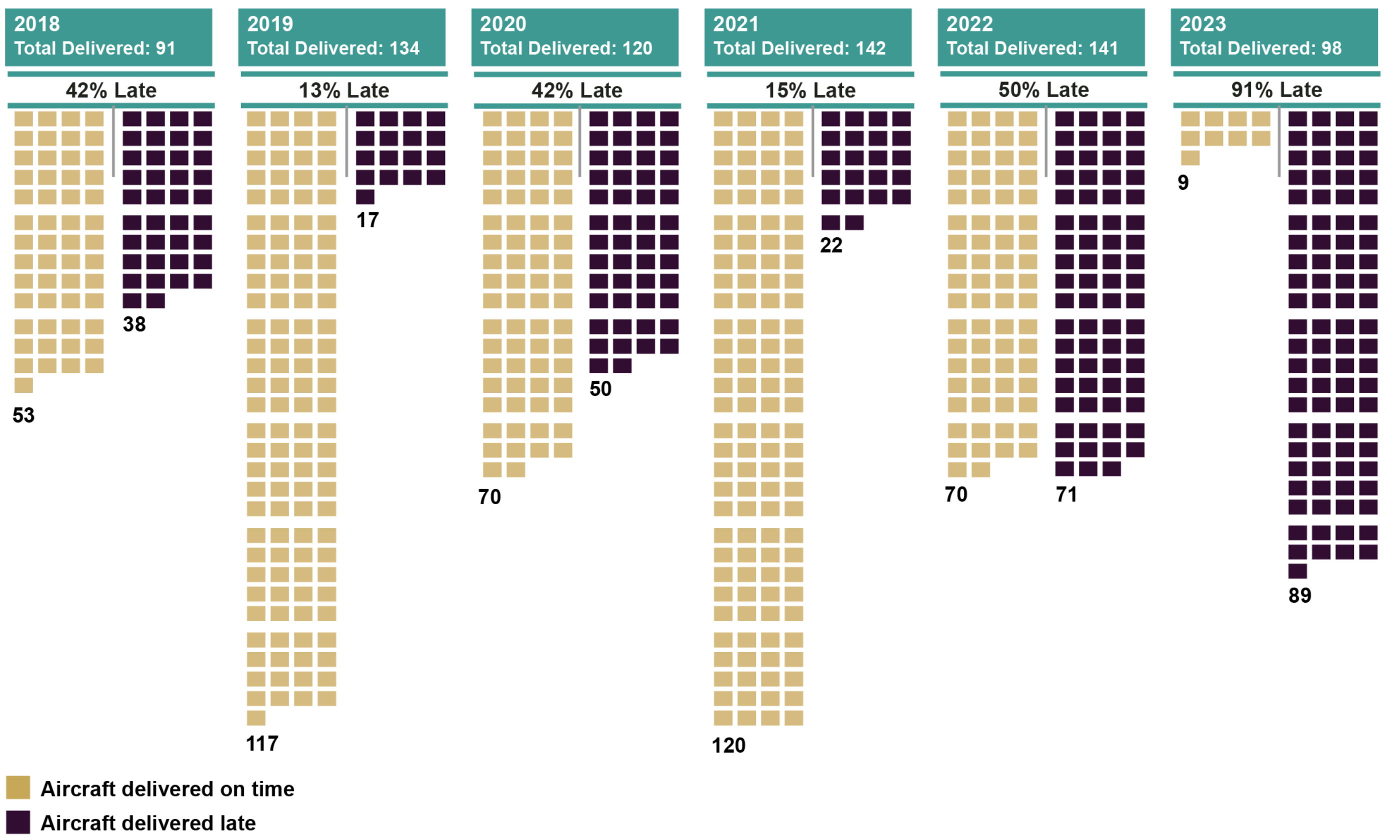
Aircraft

In 2023, Lockheed Martin delivered 91 percent of aircraft late, which represents the highest proportion of late deliveries over the past 6 years and is almost double the percentage of late deliveries in 2022. In our July 2021 testimony, we identified challenges with the contractor's plans to accelerate production given its ongoing challenges with delivering aircraft on time.[24] Since that time, the program reduced the number of aircraft it plans to produce each year, moving some aircraft production into the future. However, the contractor continues to deliver aircraft late. Figure 5 shows recent late deliveries.

[23]A quality notification is an indication that a defect has been discovered.

[24]GAO, *F-35 Joint Strike Fighter: Cost and Schedule Risks in Modernization Program Echo Long-Standing Challenges*, GAO-21-105282 (Washington, D.C.: July 13, 2021).

Figure 5: F-35 Contractor Continues to Deliver Aircraft Late



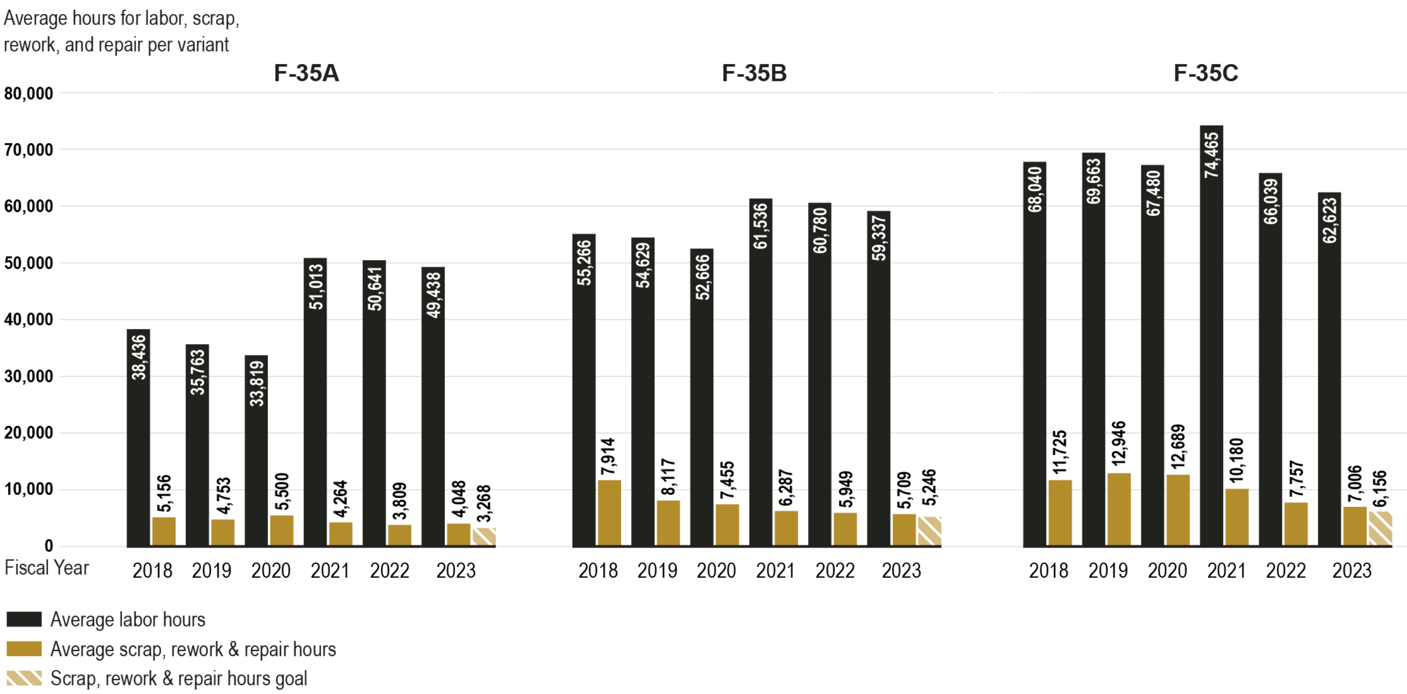
Source: GAO analysis of Department of Defense data. | GAO-24-106909

According to program officials, in 2023, more aircraft were delivered late for several reasons including that the program paused deliveries due to engine quality issues, TR-3 delays, ongoing parts shortages, and manufacturing issues.

- **Delivery pause.** The contractor delivered some aircraft late in 2023 because F-35 program officials paused all engine deliveries after an aircraft crash. In early 2023, the F-35 program office decided to temporarily pause aircraft deliveries to identify a root cause of an accident that resulted in an F-35B crashing in December 2022. The program resumed engine deliveries in mid-February 2023 and resumed aircraft deliveries in March 2023, after identifying that the crash was due to an engine fuel tube vibration issue, which is described in more detail in appendix I.

- **TR-3 delays.** Issues with developing and delivering TR-3 hardware and software were a significant driver for late deliveries in 2023. Specifically, Lockheed Martin is taking longer to develop, test, and deliver TR-3 hardware and software than originally planned. While Lockheed Martin is working to improve its TR-3 development issues, it continues to produce aircraft at the contracted rate without TR-3 fully installed. The program will not accept those aircraft, however, until TR-3 is fully installed, which we discuss in greater detail later in this report.
- **Parts shortages.** Ongoing supply chain issues are a major factor causing an increase in parts shortages, leading to work being performed out of its assigned production station, and creating additional risk of late deliveries. For example, one reason that aircraft production is falling further behind schedule is shortages of the flap on the front of the wing caused by tooling, staffing, and raw material constraints.
- **Manufacturing issues**. Lockheed Martin is not meeting its goals for the number of hours its workforce spends on scrap, rework, and repair. This continues to affect delivery time frames because scrap, rework, and repair occurs when production defects, such as holes drilled incorrectly, result in additional work to fix the defect. Furthermore, although it is generally taking less time to build the aircraft, the contractor's time spent on scrap, rework, and repair for the F-35A increased since last year. Out of station work—work that is not completed in its assigned production station—also increased in early 2023. According to program officials, this increases the risk of mistakes during production. The contractor has steadily improved in this area since April 2023, and reduced the time spent on scrap, rework, and repair for the F-35B and F-35C variants (see fig. 6).

Figure 6: Lockheed Martin Reduced Aircraft Construction Time but Has Not Met Its Goals for Scrap, Rework, and Repair



Source: GAO analysis of Lockheed Martin data. | GAO-24-106909

To address these parts shortages and manufacturing issues, Lockheed Martin is developing improvement plans and monitoring its suppliers to improve quality and timely performance. For example, to address shortages of the flap on the front of the wing, the contractor procured additional tooling and is implementing performance improvement plans to increase production capacity. The contractor expects the shortage of the wing flap to recover by January 2025. Similarly, the program is working with Lockheed Martin and its suppliers to resolve issues with TR-3, which we discuss further below.

Hardware and Software Delays and Limited Testing Capacity Hinder Block 4 Modernization Progress

The program continues to experience TR-3 hardware and software issues, causing delays to both capability development and aircraft delivery. The program is also evaluating the Block 4 cost, schedule, and scope as the effort transitions into becoming a major subprogram under the broader F-35 effort. Further, to address testing capacity limitations, the program is taking steps to increase testing capacity and expects new testing aircraft to be ready in 2029.

Late TR-3 Deliveries Are Causing Program to Reevaluate Full Block 4 Schedule

The F-35 program is facing a range of issues due to the late deliveries of TR-3 hardware and software. These upgrades are intended to enable many Block 4 capabilities once installed on the aircraft, but suppliers have faced various setbacks. TR-3 was originally planned to be delivered on aircraft starting in July 2023, but has since been delayed until June 2024 and will be less capable than originally planned.

TR-3 Hardware Delays

According to Lockheed Martin, the supplier that produces the integrated core processor is delivering this component late and with quality issues. The integrated core processor is a key hardware component of TR-3 hardware. According to program officials, as of February 2024, the supplier delivered about 61 percent of the integrated core processor sets. Lockheed Martin representatives stated that the hardware supplier has faced setbacks in increasing production to meet the F-35 assembly line's needs due to supply chain issues, workforce shortages, and product quality testing challenges. While supplier deliveries have improved over the past year, the supplier continues to experience delays and integrated core processor shortages persist, according to program officials. The program office stated its goal is for the supplier to return to sufficient production capacity by December 2024.

These hardware shortages caused Lockheed Martin to implement workarounds in aircraft assembly. For example, to mitigate the integrated core processor shortages, Lockheed Martin uses a pool of eight rotatable TR-3 hardware kits—that include integrated core processors—to keep aircraft assembly moving at a normal pace. These rotatable TR-3 hardware kits are installed only for production and are removed prior to the completion of the aircraft. However, all aircraft will need to have permanent TR-3 hardware kits reinstalled before they can be delivered to the military services, international partners, and foreign military sales customers, according to program officials. This mitigation plan is expected to end when the supplier's integrated core processor manufacturing can fully meet production requirements.

In addition to the TR-3 hardware shortages, Lockheed Martin is resolving other hardware-related issues with TR-3. For example, contractor representatives stated that during initial testing, the integrated core processor experienced startup failure under certain conditions. The integrated core processor acts as the main computer processor for the entire plane, meaning that the aircraft is not flyable if it is not functional. The program office and Lockheed Martin determined that this issue will require a minor hardware fix to correct, but have found other workarounds in the short term.

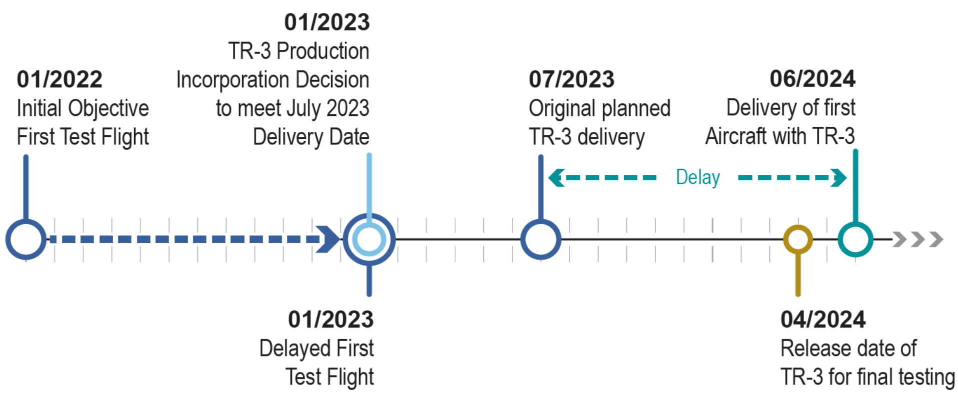
TR-3 Software Delays

Ongoing software stability issues identified during final development have delayed the program from enabling TR-3 to function on aircraft. In May 2023, we reported that the program had expected to deliver TR-3 equipped aircraft beginning in July 2023. However, the program was forced to delay full TR-3 installation due to the unfinished state of the software. Problems with aircraft software supporting the radar and electronic warfare systems have been especially prevalent, with some test pilots reporting that they had to reboot their entire radar and electronic warfare systems mid-flight to get them back online. Program officials stated that early versions of radar and in-flight systems software can commonly experience rebooting issues. However, even after being nearly a year delayed, TR-3 software continues to be unstable, according to test officials.

These problems are compounded by separate issues with the hardware and software that support data recording, which has made it more difficult for software engineers to quickly identify the causes of the various glitches. Lockheed Martin is installing upgrades to this data recording system and has implemented workarounds until the issue is resolved, according to testing officials.

These challenges, collectively, will delay the full delivery of TR-3 with new capabilities into 2025. As of January 2024, Lockheed Martin expects to deliver a less capable version of TR-3-enabled software for flight testing in April 2024, which is 9 months behind its original plan, and to start installing it on the fleet in June 2024 (see fig. 7). According to program officials, this initial TR-3 software will allow the program to accept delivered aircraft but not deliver any new capabilities to the aircraft. TR-3 software with new capabilities will not be delivered until 2025, 2 years later than originally planned. This means the warfighter will continue to wait for these critical upgrades.

Figure 7: F-35 Technology Refresh 3 (TR-3) Testing Delay and Production Decision Schedule



Source: GAO Analysis of Department of Defense data. | GAO-24-106909

Effects of TR-3 Delays on the Program

TR-3 hardware and software delays have caused significant challenges to the program by delaying both aircraft deliveries to the government and Block 4 capability development.

Aircraft delivery delays. TR-3 delays have caused substantial issues because the program and military services will not accept aircraft until the TR-3 hardware and software are installed and stable. As a result, upon completing aircraft production, Lockheed Martin—in cooperation with the program office—is parking every TR-3-enabled F-35 at production facilities to await the permanent TR-3 hardware kits and new software, which will not be available for installation until June 2024 at the earliest. If Lockheed Martin delivers the software on this timeline, it will need to park aircraft produced over the last several months at various facilities.[25] DOD deemed reporting the specific quantity of aircraft to be unsuitable for public release. While parked, Lockheed Martin is responsible for the security and maintenance of the aircraft. If TR-3 software is delayed past April 2024, Lockheed Martin is projected to exceed its maximum parking

[25]This includes planes that are currently in production or awaiting parts other than TR-3 kits.

capacity and will need to develop a plan to accommodate more parked planes.

The process for delivering all the stored aircraft, as well as those coming off the assembly line, will take time. According to Defense Contract Management Agency and F-35 program officials, to clear these parking facilities as quickly as possible, Lockheed Martin and DOD are planning to certify an average of 20 planes (parked and new production) per month until the backlog is gone—a far faster rate than previously accomplished. Program officials stated that at present, the program typically averages 13 certifications a month. Even at this faster rate, delivering the parked aircraft will take about a year once TR-3 software has been completed and certified. While Defense Contract Management Agency officials told us that they believe the rate is feasible, officials said that issues related to workforce and work schedules between their office and Lockheed Martin could lead to coordination challenges.

The parking arrangement, however, presents additional risk to the government should damage occur to some or all of the parked aircraft.[26] It is unique for so many critical DOD aircraft to be waiting for DOD acceptance, instead of stored at lower densities across many military locations throughout the world. This creates unique financial and schedule risks to DOD.

Block 4 capability delays. TR-3 delays have contributed to Block 4 capability development, testing, and delivery delays.

- TR-3 delays slow the program's ability to develop and test Block 4 capabilities. Because the program has prioritized the TR-3 effort, TR-3 is taking up the bulk of the current testing capacity in the software laboratories and flight testing. This means that the program is using fewer test resources to mature Block 4 capability development, which, in turn, creates risk of delaying further Block 4 capability development and testing.
- As noted above, the program delayed the TR-3 software version that would enable new Block 4 capability to 2025. As a result, these TR-3

[26]According to Defense Contract Management Agency officials, the government will have significant liability for the loss or damage to the parked aircraft. Under the Ground Flight and Risk Clause on the Lot 12 to Lot 14 contracts, the government assumes the risk of loss of aircraft "in the open," which is subject to the contractor's share of loss and deductible under the contract. See Defense Federal Acquisition Regulation Supplement 252.228-7001 (June 2020).

enabled Block 4 capabilities have been delayed because they rely on TR-3 hardware and software to function. The program originally planned to deliver aircraft with TR-3 and new Block 4 capabilities beginning in July 2023. Moreover, the longer it takes the program to deliver fully functional TR-3 software, the longer the warfighter will wait for the critical Block 4 capabilities they need to perform their mission.

Program Office Is Reevaluating Cost, Schedule, and Scope of Block 4 Effort

According to program officials, as of February 2024, the program office is in the process of reevaluating the Block 4 effort to document its overall cost, schedule, and scope. The program is undertaking this effort because, after years of being managed as a part of the broader F-35 aircraft acquisition program, Block 4 and TR-3 elements are now anticipated to be managed as a major subprogram in accordance with requirements in the NDAA for Fiscal Year 2024.[27] As a major subprogram, Congress will have insight into Block 4 cost, schedule, and performance, allowing it to make more informed decisions about the F-35 modernization effort.[28]

As part of the reevaluation process, the program assessed technical aspects of the Block 4 capability delivery schedule and proposed 84 recommendations to improve it to the program executive officer, according to program officials. For example, recommendations included constructing additional hardware and software labs, extending the life of test aircraft, and implementing the use of new predictive planning tools. These recommendations were under advisement as of February 2024, and no decisions have been made. The program has yet to release an updated Block 4 schedule and cost estimate reflecting any of these proposed changes, according to program officials.

In addition to its reevaluation, the program office anticipates the scope of Block 4 will change as it becomes a major subprogram by removing capabilities that cannot be supported by the current F-35 engine and thermal management system. According to program officials, capabilities that will require more power and cooling than the current engine and

[27]Pub. L. No. 118-31, § 225 (a) (the Secretary of Defense shall designate all Block 4 and TR–3 elements of the F-35 aircraft acquisition program, collectively, as a single major subprogram of the F-35 aircraft acquisition program).

[28]A major subprogram may be designated when a major defense acquisition program requires the delivery of two or more categories of end items which differ significantly from each other in form and function, and each major subprogram will be considered a major program for reporting purposes. 10 U.S.C. § 4203(a).

thermal management system can provide will be reclassified as "post-Block 4" for future development. Program officials stated that the earliest the program expects to deliver post-Block 4 capabilities is 2029.

In 2023, the program shifted its future Block 4 contracting strategy. After prolonged contract negotiations for Block 4 follow-on modernization with Lockheed Martin, according to program officials, the program office decided to restart negotiations. This resulted in the award of the Block 4 contract in May 2023. According to program officials, a key aspect of the Block 4 contract is that it allows for refinement of technical guidance and reprioritization of capabilities without contract modifications. Modifying a contract can be a lengthy process.[29] To achieve this, the Block 4 contract included two key decision points in the development process through the Statement of Work.

- The first decision point initiates the advanced development of a capability and allows Lockheed Martin to develop capability through its preliminary design.
- The second decision point confirms the specifics of the capability and takes place after preliminary design is complete. This better informs the program office and Lockheed Martin about design maturity and sets a commitment date for production.

We will continue to monitor the program's reevaluation of its cost, schedule, and scope, as well as its progress in adopting a new contracting approach for Block 4.

Program Is Taking Steps to Expand Testing Capacity

The program is taking steps to increase Block 4 and TR-3 testing capacity. The current developmental testing fleet contains four flight science aircraft, all of which are over 10 years old and have frequent maintenance issues.[30] These issues are exacerbated by increasing difficulties with procuring spare parts for the testing fleet, which leads to aircraft being unavailable because repairs are needed. Program officials

[29]Federal Acquisition Regulation 43.102.

[30]Flight science developmental testing aircraft differ significantly from typical F-35 aircraft in the amount of additional instrumentation and wiring incorporated into their frames. Developmental testing is intended to provide feedback on the progress of a system's design process and its combat capability as it advances toward initial production or deployment. Operational testing aircraft also differ from typical F-35 aircraft but are not built with the same instrumentation as developmental testing aircraft, according to testing officials. Operational testing is intended to evaluate a system's effectiveness and suitability.

said that, in the past, three of the four testing aircraft have been down for maintenance simultaneously, severely limiting testing.

The program has experienced delays due to capacity issues with the developmental testing fleet. For example, according to DOT&E officials, one F-35B developmental test aircraft was down for extended maintenance, which delayed associated weapons testing. However, testers attributed their ability to generally stay on schedule to the delayed rollout of software to the testing fleet, such as the delayed TR-3 software discussed above. However, testers predicted that once software deliveries for TR-3 and Block 4 capabilities are back on schedule, the current testing fleet could face significant challenges in meeting testing demands.

The program is building four modified developmental testing aircraft, scheduled for completion in 2026, to help achieve its current testing schedule. These modified aircraft, which are not full developmental testing aircraft, are F-35 aircraft with additional instrumentation attached after production, allowing them to conduct basic developmental weapons tests.[31] In addition to this mitigation effort, the program is currently borrowing testing aircraft from other test fleets across the program, such as operational testing. Although these planes are not equipped with the same sensors as developmental testing aircraft, testers are able to use the aircraft for many tests with some workarounds, according to testing officials.

In addition, the program plans to replace the current testing fleet with nine new full developmental testing aircraft, although according to the program office, as of March 2024, six have been authorized for procurement. These aircraft are scheduled to be completed and available for testing purposes between 2029 and 2034. The new developmental testing aircraft will be produced in staggered sets of three at a time. However, according to DOD testing officials, the current replacement plan will leave them without any available testing aircraft in 2028 and 2029.

[31]These modified testing aircraft would only be able to test weapons loaded in the internal weapons bays—where test instrumentation will be installed—and not on the external stations on the wings due to lack of instrumentation. According to DOD officials, this is a problem for F-35Bs, which need to test more weapons on their wings.

F-35 Program Has Made Some Progress in Its New Engine and Thermal Management Modernization Efforts

The F-35 program has made some progress in its recent efforts to modernize the engine and related thermal management subsystems. In March 2023, DOD officials announced that they would pursue an engine upgrade to enable post-Block 4 capabilities beyond 2029, but the program has not awarded a development contract. Furthermore, the program is considering options for an upgraded Power and Thermal Management System (PTMS), which is needed to provide additional cooling to the aircraft's subsystems. DOD will manage the engine and thermal management modernization efforts as a major subprogram of the F-35 aircraft acquisition program with its own cost, schedule, and performance baselines, which we recommended last year.[32] Finally, the program continues to face risks in modernizing the engine and thermal management subsystems related to defining requirements, maturing technologies, and assessing costs.

F-35 Program Is Upgrading the Engine but Has Not Determined How to Modernize Other Subsystems

In March 2023, DOD officials announced that they would pursue an engine upgrade to enable post-Block 4 capabilities beyond 2029. The program evaluated engine modernization options that could provide additional power and cooling to the aircraft, which we described in detail in our May 2023 report.[33] The program is considering the Engine Core Upgrade (ECU), which would upgrade the power module and gearbox—two components of the current engine that work in tandem to extract more power from the core of the engine. The ECU would support all three aircraft variants, reduce overall life-cycle costs, restore the life of the current F135 engine, enable future mission system capability growth, and require minimum changes to the existing support infrastructure. Table 2 describes the engine components included in the modernization efforts.

[32] Pub. L. No. 118-31, § 226 (c) (the Secretary of Defense shall designate all activities relating to the modernization, upgrade, and integration of the major subsystems collectively, as a single major subprogram of the F-35 aircraft acquisition program).

[33] GAO-23-106047.

Table 2: Description of Engine Components Included in the F-35 Engine and Thermal Management Modernization Efforts

Engine component	Description
Engine Core Upgrade (ECU)	The ECU will incorporate upgrades to two components of the current engine—power module and gearbox.
Power module	The power module is the core of the engine. It is where fuel is burned and includes numerous controls and components to provide transfer of electrical signals, fuel, oil, and airflow to generate the thrust necessary to operate the aircraft.
Gearbox	The gearbox extracts power from the engine to drive auxiliary systems and accessories and fuel pumps that are essential for operating the engine.
Power and Thermal Management System (PTMS)	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.
Fuel thermal management system	The fuel thermal management system is responsible for providing fuel to the engine and transferring heat away from the PTMS and other mission systems.
Electrical power system	The electrical power system generates and distributes power throughout the aircraft.

Source: GAO analysis of Department of Defense and Pratt & Whitney data. | GAO-24-106909

The program has been conducting risk reduction and technical maturation efforts for the ECU since its decision to pursue an engine upgrade. Although these efforts have been extended, program officials stated that the overall development effort is on track as of March 2024. The program held an ECU preliminary design review in February 2024 and plans to hold another review in May 2024.[34] The program has not received approval to award a contract for ECU development. Program officials told us they expect to receive approval in the near future.

If approved, the program plans to finalize the award of the ECU development contract—which will cover technical maturation, risk reduction, and the detailed design of the ECU—in the fall of 2024. Technology maturation and risk reduction activities will include ECU design, analysis, testing, engine test preparation, hardware procurement, and integration into the aircraft. If the program awards an ECU contract, development, testing, and integration with related subsystems is expected to last 7 years and the program plans to deliver F-35 aircraft equipped with the upgraded engine in 2032.

In addition to modernizing the engine, the program is considering upgrades to subsystems, including PTMS, electrical power system, and

[34]A preliminary design review assesses the maturity of the preliminary design and confirms that the system is ready to proceed into detailed design with acceptable risk.

fuel thermal management system, that may be needed to provide power and cooling to post-Block 4 capabilities. The program has not determined a specific solution for modernizing these subsystems. As of February 2024, the program is considering options for modernizing the current PTMS or developing a completely new PTMS. The options range significantly in estimated costs, development time frames, and the amount of increased cooling capacity that each will provide the aircraft.

According to program officials, the program must first award a contract to a prime system integrator to determine how to modernize these subsystems. Program officials expect to award a prime system integrator contract in August 2024. Prior to selecting a modernization solution for these subsystems, the program and the system integrator must conduct technology maturation and risk reduction activities. These activities will include studying the technical feasibility and risks of potential system upgrades, according to program officials. While the program will determine the requirements for these subsystems, a prime system integrator will select a specific modernization option by the end of 2026 and eventually deliver the upgrades to the aircraft as contractor-acquired property.[35]

The limitations of the current cooling capacity could impede post-Block 4 capabilities and mission systems as soon as 2029. The earliest the program could field any of the thermal management system upgrades it is considering would be in 2030. Program officials told us, however, that delivering the modernized subsystems in 2032 is a more realistic time frame. As we noted earlier, the program currently plans to move Block 4 capabilities that will require more power and cooling than the current engine and thermal management system can provide to post-Block 4. The program expects to start delivering post-Block 4 capabilities as early as 2029. However, if the thermal management system upgrades come after 2029, post-Block 4 capabilities will also be delayed. The program is currently evaluating how this potential power and cooling deficit will affect the delivery of post-Block 4 capabilities and what actions it could take to address it.

[35]Contractor-acquired property means property acquired, fabricated, or otherwise provided by the contractor for performing a contract, and to which the government has title. Federal Acquisition Regulation 52.245-1(1)(a).

Program Will Manage Engine and Thermal Management Modernization as a Subprogram

The program will manage the engine and thermal management modernization efforts as a major subprogram under the F-35 aircraft acquisition program.[36] In May 2023, we recommended that DOD manage these modernization efforts as a separate program with its own cost, schedule, and performance baselines.[37] DOD partially concurred with the recommendation. Subsequently, the NDAA for Fiscal Year 2024 included a provision requiring DOD to do so.[38] According to officials, the program is working with DOD and the military services to determine how to establish these efforts as a subprogram.

In support of establishing a new subprogram, the program is currently developing and obtaining approval for its acquisition documentation for the engine and thermal management modernization efforts. For example, the Under Secretary of Defense for Acquisition and Sustainment approved a new F-35 acquisition strategy in January 2024. Further, the concept of operations, which details the roles and responsibilities of key stakeholders, was approved in November 2023. Formalizing the engine and thermal management modernization efforts as its own major acquisition subprogram under the F-35 aircraft acquisition program will provide decision-makers with key information to assess the progress of the efforts.

Engine and Thermal Management Modernization Efforts Continue to Face Risks

The F-35 program continues to face risks in modernizing the engine and thermal management subsystems relating to the need to define requirements, mature technologies, and assess costs. In May 2023, we made recommendations to help the program address these risks, but the program has taken limited steps to implement them.[39]

Undefined Requirements

The F-35 program has made some progress in defining preliminary requirements for engine modernization, but they are not finalized. The program defined the engine modernization preliminary requirements in an August 2023 draft statement of requirements, which was approved

[36]Pub. L. No. 118-31, § 226 (c).

[37]GAO-23-106047.

[38]Pub. L. No. 118-31, § 226 (c).

[39]GAO-23-106047.

through the F-35 governance process.[40] Program officials expect to finalize these requirements when the program awards the engine modernization development contract by the fall of 2024.

The program has also developed high-level requirements for other related subsystems, including the PTMS and fuel thermal management system, but lower-level technical requirements remain undefined. Program officials identified 17 technical studies, either ongoing or completed, that it will use to determine lower-level requirements of PTMS and other related subsystems and aircraft components. The studies will provide additional information on how PTMS and related subsystems affect each other, such as whether the loss of cooling in one area of the aircraft can be recovered within the system. Officials told us that they will consider the key aspects of these studies as the program continues to define the lower-level system requirements.

However, the results from all of the studies will not be available as they approach the award of the engine upgrade development contract in fall of 2024. Until these studies are complete, the program cannot fully define the requirements for related subsystems, such as PTMS. Therefore, DOD will not have the full complement of information to support which modernization option will meet the requirements. In May 2023, we recommended that the program reevaluate its analysis of the engine and thermal management modernization options after defining the power and cooling requirements and before proceeding with development.[41] Proceeding with engine upgrade development without defined requirements for related subsystems increases the risk that the engine and thermal management modernization subprogram will not meet its cost, schedule, and performance objectives.

Immature Technologies

The F-35 program is proceeding with engine modernization development, although five subcomponent technologies are immature. While the engine modernization effort leverages the current engine configuration and utilizes proven technology from prior engine development, not all

[40]While there is no formal requirements document, the program is moving forward with further definition of the top-level requirements as noted in the August 2023 draft statement of requirements. Requirements planning involves the creation of a requirements document that establishes a need for a material approach to resolve a capability gap. See 10 U.S.C. § 4251(a)(1); Joint Capabilities Integration and Development System Manual, Manual for the Operation of the Joint Capabilities Integration and Development System (Oct. 30, 2021).

[41]GAO-23-106047.

technologies are mature. For example, one of the five immature subcomponents has only reached technology readiness level (TRL) 4, meaning that it is immature because its components have only been validated in a laboratory environment.[42]

We previously recommended that the program matures all critical technologies and systems for engine and thermal management modernization to TRL 7 prior to starting development.[43] At TRL 7, a fully functional prototype has been demonstrated in an operational environment. However, the engine modernization detailed design statement of work requires technologies to be matured to a TRL 5, whereby the component is validated in a relevant environment. Program officials told us they will not demonstrate the upgraded engine on the actual F-35 aircraft in a relevant or operational environment during development. Therefore, the technologies will remain immature until ground testing, which is scheduled to begin in 2026.

Other thermal management modernization efforts are also reliant on immature technologies. Currently, the available PTMS designs are at varying TRLs, but all of them are immature at a TRL 5 or below. Other system modifications, including the fuel thermal management system and electrical power system, are also at varying levels of technology immaturity. The risk reduction studies that the program is currently conducting will help determine the technical shortcomings of the interrelated subsystems and how to integrate them into the F-35. The studies conducted to date indicate key integration challenges, such as the removal of heat generated by mission systems. Once the program completes additional risk reduction studies, officials told us the program will develop plans to mature technologies in the PTMS and related subsystems. Program officials acknowledge that keeping the development efforts of the engine and thermal management systems in sync is a significant program risk.

Unassessed Costs

The program has made some progress in estimating the engine modernization development costs, but it has not estimated costs for other related subsystems, including the PTMS, electrical power system, and

[42]Government agencies, including DOD, use TRLs to measure a technology's maturity and readiness for development. There are nine levels, with TRL 1 being studies of a basic concept and TRL 9 being a technology that has proven itself in successful mission operations.

[43]GAO-23-106047.

fuel thermal management system. In May 2023, we recommended that the program report the full life-cycle costs and obtain an independent cost estimate for all elements of the engine and thermal management modernization efforts, including integration of interrelated subsystems.[44] The program has conducted its own cost estimates for upgrading the engine and made progress toward obtaining an independent cost estimate. The development cost estimates, however, range from $3.7 billion to $4.5 billion. In January 2024, program officials told us that they are working to develop a comprehensive cost estimate for the engine and thermal management subprogram using the information from the ongoing studies that they are conducting.

We will continue to monitor the program's progress in defining requirements, maturing technologies, and assessing costs of the engine and thermal management modernization systems.

Agency Comments

We provided a draft of this report to DOD for review and comment. DOD provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Defense, the Under Secretary of Defense for Acquisition and Sustainment, the Secretary of the Air Force, the Secretary of the Navy, and the Commandant of the Marine Corps. In addition, the report is available at no charge on the GAO website at https://www.gao.gov/.

If you or your staff have any questions about this report, please contact me at (202) 512-4841 or ludwigsonj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix II.

Jon Ludwigson
Director, Contracting and National Security Acquisitions

[44] GAO-23-106047.

List of Committees

The Honorable Jack Reed
Chairman
The Honorable Roger Wicker
Ranking Member
Committee on Armed Services
United States Senate

The Honorable Jon Tester
Chair
The Honorable Susan Collins
Ranking Member
Subcommittee on Defense
Committee on Appropriations
United States Senate

The Honorable Mike Rogers
Chairman
The Honorable Adam Smith
Ranking Member
Committee on Armed Services
House of Representatives

The Honorable Ken Calvert
Chair
The Honorable Betty McCollum
Ranking Member
Subcommittee on Defense
Committee on Appropriations
House of Representatives

Appendix I: Status of Selected F-35 Technical Risks

The F-35 program continues to address technical risks identified in the field. Since our 2023 report, the program office identified new risks with F-35C landing gear. The program office also identified final solutions to resolve technical risks we previously identified. This appendix provides the status of the Department of Defense's (DOD) efforts to address these issues.

Newly Identified Technical Risks

F-35C landing gear drag brace. The F-35C landing gear drag brace—which ensures that the gear remains extended during landing—is experiencing more force during landings than it was originally designed to take. When the drag brace fails, the gear collapses and could potentially result in a crash. The risk is currently mitigated by inspections beginning at 1,300 landings and a recurring inspection every 200 landings. Lockheed Martin and the part supplier are analyzing the issue to determine a permanent solution.

Technical Risks Identified in Our Previous Reports

Fuel tube vibration. A high-pressure fuel tube failed on a production aircraft in December 2022 due to a malfunction with the main fuel throttle valve. The program originally discovered this issue in 2020, and the contractor mitigated it at that time by identifying and removing problematic valves. However, this approach failed on at least one occasion and the contractor sought a different solution. The final fix for the issue was approved in July 2023 with the first production engine incorporation scheduled for December 2023. The program expects to complete fleet retrofits in 2025.

F-35A gun blast panel cracking. Some newer aircraft are again experiencing blast skin cracking on a redesigned area next to the F-35A internal gun. This was originally observed on earlier delivered aircraft and is a result of pressure conditions exceeding design thresholds when firing the gun. The program observed these cracks on Lot 13 aircraft and expects the issue to affect Lots 14 and 15 aircraft due to similar designs. Undetected crack growth could result in part of the panel breaking off, with material potentially going into the engine. However, the program has not identified any foreign object debris among the panels that have had issues. The program is managing the risk with post-flight inspections of the panel after gun use and by having contractor field teams replace cracked panels. The program plans to begin live-fire testing to validate the durability of the replacement panel in 2024.

Electro-Optical Targeting System window durability. The program office identified a problem with window durability on the Electro-Optical Targeting System. In particular, the window does not meet requirements when operating in certain environments—like those with high amounts of sand and dust. The program office is using recurring inspections to mitigate the issue. To address this issue, the program completed testing and fielded new equipment in 2024, according to program officials. The program is also working with Lockheed Martin and its window suppliers to improve window durability and expects to qualify a new window in 2024.

Air Separation Module delamination. The Air Separation Module, common to all F-35 variants, is part of the On-Board Inert Gas Generating System, which provides nitrogen enriched air to the fuel tanks. Within the module, a fiber bundle has been separating from the unit's core, affecting the amount of nitrogen being produced and degrading the inerting of the aircraft fuel tanks.[1] This degradation increases the risk of explosion in the event of a lightning strike or hit from a weapon. According to program officials, a software fix in 2022 provided a solution for one of the issues related to lightning restrictions and the program office uses air separation module life limits as an additional partial mitigation. Flight testing is planned to begin in April 2024 to identify the root cause and potential mitigations and fixes. A redesign effort was planned at the same time, which will leverage data obtained from the flight testing.

Canopy delamination issues. Some F-35 canopies have experienced delamination of the external coating, which affects the pilots' ability to see clearly through the canopy and can reduce mission effectiveness. Program officials and contractors are working to identify the root cause and corrective actions for these issues. In 2019, as a temporary modification, the contractor added a vent hole in the canopy of production aircraft to help prevent delamination, which does not affect pressure of the cockpit. The program approved a second source supplier in 2022 to produce canopies for F-35As and F-35Cs, and is currently working to qualify a new supplier for the F-35B in 2024.

[1]Inerting refers to the process of changing gas from a flammable to a nonflammable state.

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

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Staff Acknowledgments

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