United States Government Accountability Office

Report to the Committee on Armed Services, House of Representatives

July 2022

F-35 AIRCRAFT

DOD Should Assess and Update Its Engine Sustainment Strategy to Support Desired Outcomes

GAO-22-104678

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GAO Highlights

Highlights of GAO-22-104678, a report to the Committee on Armed Services, House of Representatives

Why GAO Did This Study

The F-35 aircraft, with its advanced capabilities, represents a growing portion of DOD's tactical aviation fleet—with over 400 aircraft in use to date. DOD plans to procure about 2,000 more F-35s with estimated life-cycle costs of the program exceeding $1.7 trillion; $1.3 trillion of those costs are associated with sustaining the aircraft. GAO previously reported that challenges sustaining the F-35 engine may pose its greatest sustainment risk over the next 10 years.

House Report 116-442 included a provision for GAO to review F-35 engine sustainment challenges.

This report evaluates the extent to which (1) the F-35's engine sustainment strategy has been aligned with military service desired outcomes; (2) DOD has met performance goals for sustaining the F-35 engine; and (3) DOD has developed and implemented plans to address any challenges. GAO reviewed program documentation, analyzed sustainment data, and interviewed officials from DOD and the prime contractor for the F-35 engine, Pratt & Whitney.

What GAO Recommends

GAO is making two recommendations to DOD: assess and make changes to the F-35 engine sustainment strategy; and develop a shared model for forecasting spare parts needs with the engine's prime contractor. DOD concurred with both recommendations.

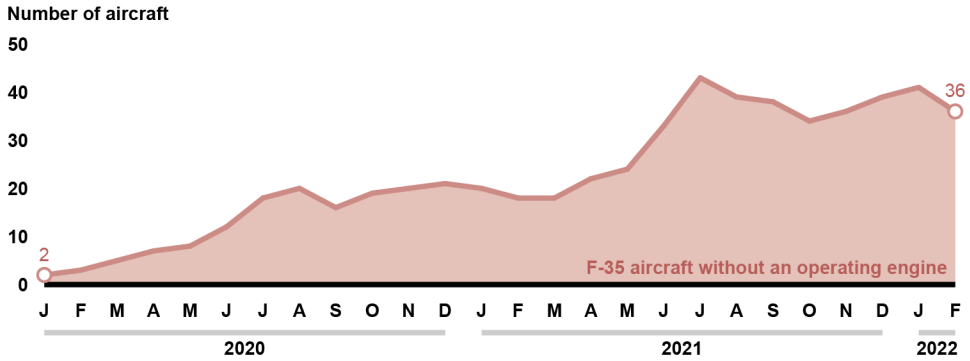
View GAO-22-104678. For more information, contact Diana Maurer at (202) 512-9627 or maurerd@gao.gov.

What GAO Found

The Department of Defense's (DOD) F-35 engine sustainment strategy does not meet the desired outcomes of the military services. DOD's current strategy, if implemented as planned, allows for 6 percent of its F-35 aircraft to be non-mission capable, or unable to perform assigned missions, due to engine issues. 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. Until DOD assesses its F-35 sustainment strategy, including its goals, and reaches agreement on any needed changes, the program will fall short of the desired outcomes of users.

DOD has not met several key performance goals for sustaining the F-35 engine. First, DOD only met its 6 percent or less non-mission capable due to engine issues goal in one month from January 2021 through February 2022. As a result, the number of F-35 aircraft unable to fly due to the lack of an operating engine has been increasing since January 2020 with a slight decrease from July 2021 through February 2022. Second, DOD has met three of five of its reliability and maintainability goals—metrics aimed at ensuring that the F-35 engine will be available for operations as opposed to out of service for maintenance. The goals that DOD has not met have resulted in higher-levels of maintenance.

F-35 Aircraft without an Operating Engine, January 2020–February 2022



Source: GAO analysis of Pratt & Whitney data. | GAO-22-104678

DOD has developed and is implementing corrective-action plans since fall 2020 to improve the capacity of its engine-repair maintenance depots. DOD's plans have resulted in improvements, such as reducing the time to repair a key module of the engine from 207 days in October 2020 to 119 days in January 2022. However, DOD's plans are highly dependent on assumptions about obtaining funding and its ability to address future risks. One area that has not been fully addressed is an agreement between DOD and the prime contractor on a model for forecasting spare parts needs. The prime contractor and DOD are using different data inputs to estimate spare parts needs. Until addressed, the program risks future parts shortages that could affect its ability to repair engines and ensure F-35 aircraft have operating engines.

Contents

Abbreviations

AETP	Adaptive Engine Transition Program
DOD	Department of Defense
NDAA	National Defense Authorization Act

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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July 19, 2022

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

The F-35 Lightning II aircraft (F-35) has the most advanced capabilities of the Department of Defense's (DOD) fighter aircraft, and represents a growing portion of its tactical fighter aviation fleet. The F-35 is also DOD's most ambitious and costly weapon system in history. DOD has estimated overall costs for the program at more than $1.7 trillion over its 66-year life cycle, with the majority of the costs, about $1.3 trillion, associated with sustainment of the aircraft.[1] DOD operates about 450 F-35s and plans to buy about 2,000 more aircraft by the mid-2040s.

The F-35 has a highly advanced single engine (F135 engine), which is built by Pratt & Whitney.[2] However, in July 2021 we reported that challenges related to F-35 engine sustainment, such as longer-than-planned repair times, have affected the program and may pose its greatest sustainment risk over the next 10 years. In March 2021, we reported that Pratt & Whitney continued to have problems with the quality of engines and the timeliness of deliveries.[3] In our F-35 work since 2014, we have reported other significant challenges faced by DOD in sustaining a growing F-35 fleet, such as the availability of spare parts.[4] As a result of those challenges, F-35 performance has not met mission capable rates,

[1]The $1.7 trillion reflects then-year dollars. Then-year dollars include the effects of inflation or escalation. Historically, the official sustainment cost estimate for the F-35 program is produced by the Office of Cost Assessment & Program Evaluation. This estimate was most recently updated in June 2020.

[2]Hereafter, we refer to the F135 engine as the F-35 engine.

[3]GAO, *F-35 Sustainment: DOD Needs to Cut Billions in Estimated Costs to Achieve Affordability,* GAO-21-439 (Washington, D.C.: July 7, 2021) and GAO, *F-35 Joint Strike Fighter: DOD Needs to Update Modernization Schedule and Improve Data on Software Development*, GAO-21-226 (Washington, D.C.: Mar. 18, 2021).

[4]See Related GAO Products page at the end of this report for a full list of F-35 related reports.

which refers to the percentage of total time that the aircraft can fly and perform at least one of its missions.

House Report 116-442, accompanying a bill for the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, included a provision for us to review F-35 engine sustainment challenges.[5] In this report, we evaluate the extent to which (1) DOD's strategy for F-35 engine sustainment aligns with military service desired outcomes; (2) DOD has met performance goals for sustaining the F-35 engine; and (3) DOD has developed and implemented plans to address any F-35 engine sustainment challenges.

For objective one, we reviewed documents related to the sustainment of the engine and the aircraft, including the Life Cycle Sustainment Plan, the Life Cycle Sustainment Plan Supplement, and the contract between DOD and Pratt & Whitney for the sustainment of the engine. These documents comprise the department's strategy for sustaining the F-35 engine, according to DOD officials. We interviewed officials from the F-35 Joint Program Office, the Office of the Under Secretary of Defense for Acquisition and Sustainment, the Air Force, the Navy, the Marine Corps, and Pratt & Whitney on the current sustainment strategy for the F-35 engine as well as any challenges faced in implementing this strategy. Specifically, we interviewed the military services—the users of the aircraft—to understand their current and future desired outcomes from the F-35 and any limitations of the current sustainment strategy in achieving their objectives. We reviewed the F-35 engine sustainment strategy to see how it compared with DOD policy for maintenance programs to be structured to achieve readiness and sustainability objectives.[6] We also determined that the risk assessment component of internal control was significant to this objective, along with the underlying principle that management should identify, analyze, and respond to risks related to achieving the defined objectives.[7]

For objective two, we analyzed data from the F-35 Joint Program Office and Pratt & Whitney, the prime contractor for the F-35's engine, on the

[5]H.R. Rep. No. 116-442, at 89-89 (2020).

[6]DOD Directive 4151.18, *Maintenance of Military Materiel* (Mar. 31, 2004) (incorporating Change 1, Aug. 31, 2018).

[7]GAO, *Standards for Internal Control in the Federal Government,* GAO-14-704G (Washington, D.C.: September 2014).

performance of the engine from fiscal year 2017 through February 2022. In particular, we focused on non-mission capable due to engine rates and on reliability and maintainability metrics because DOD tracked and monitored these measures and told us that these were the key sustainment metrics for the engine.[8] We selected these dates to provide trend information over that 5-year period. We found these data to be sufficiently reliable for the presentation of trends by interviewing officials responsible for and knowledgeable about the collection of the data and by reviewing the data for errors and/or anomalies. We discussed trends in the data, including reasons for any changes in the trends, with DOD and Pratt & Whitney officials.

For objective three, we reviewed plans developed by the F-35 Joint Program Office and Pratt & Whitney for addressing challenges related to the sustainment of the engine. We determined that the information and communication component of internal control was significant to this objective, along with the underlying principles that management should communicate internally and externally the necessary quality information to achieve the entity's objectives.[9] In addition, we examined the collaboration between the F-35 Joint Point Program Office, Pratt & Whitney, and the military services in implementing these plans. Specifically, we reviewed whether agreements were documented among these entities.[10] We interviewed officials from the F-35 Joint Program Office, the Office of the Under Secretary of Defense for Acquisition and Sustainment, the Air Force, the Navy, the Marine Corps, and Pratt & Whitney about the plans, implementation of those plans, and the quality of information DOD has been using to inform its plans.

We conducted this performance audit from December 2020 to July 2022 in accordance with generally accepted government auditing standards.

[8]Non-mission capable due to engine rates generally represent the amount of time an aircraft is inoperable due to engine issues. Reliability measures the probability that an item will perform its intended function for a specified interval, under stated conditions. Maintainability is the probability that an item will be retained in or restored to a specified condition within a given period of time, when maintenance is performed in accordance with prescribed procedures and resources.

[9]GAO-14-704G.

[10]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012). This report identified the range of mechanisms that the federal government uses to lead and implement interagency collaboration by conducting a literature review on interagency collaborative mechanisms, interviewing experts in the field of collaboration, and analyzing more than 300 of our prior reports on collaboration within the federal government.

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

F-35 Program

The F-35 program is a joint, multinational acquisition program intended to develop and field a family of next-generation strike fighter aircraft. As shown in figure 1, program participants include the Air Force, the Navy, and the Marine Corps; seven international partners; and multiple foreign military sales customers.[11]

Figure 1: F-35 Program Participants

Source: GAO analysis of Department of Defense information. | GAO-22-104678

As shown in figure 2, the program has developed and has been delivering three variants of the F-35 aircraft: F-35A, F-35B, and F-35C. DOD is in the process of replacing a variety of its legacy fighter aircraft with the F-35, including the F-16 Falcon in the Air Force and the AV-8B Harrier and the F/A-18 C/D Hornet in the Marine Corps.

[11]Seven partner nations contribute to F-35 development, production, and sustainment. In addition, as of February 2021, the program has six foreign military sales customers. In July 2019, DOD decided to remove Turkey from the development program due to its government's decision to procure Russian-made radar systems. Multiple other countries are at various stages of foreign military sales consideration.

Figure 2: Variants of the F-35 Aircraft

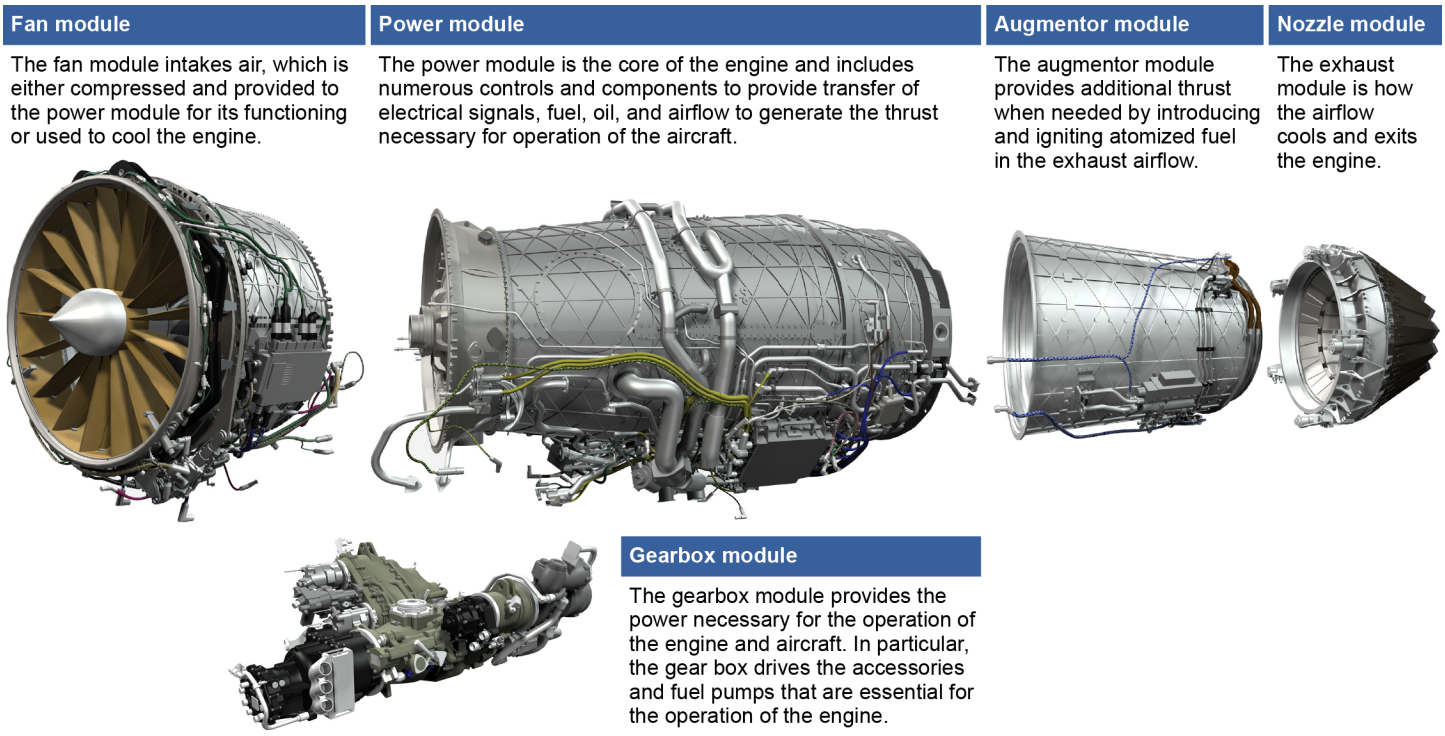
	F-35A Conventional Take-off and Landing	F-35B Short Take-off and Vertical Landing	F-35C Carrier
			
Initial operating capability	2016	2015	2019
Purpose	Counter present and future advanced threats through counter air, strike, and surveillance and reconnaissance missions		
	Air Force variant that supports 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-22-104678

The F-35 Engine and Its Sustainment

The three F-35 variants have the same basic engine design with some variations to support the short take-off and vertical landing capability for the F-35B. 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 operation, in addition to the F-35B unique lift system made by Rolls Royce (lift fan and roll post) hardware.

Figure 3: Diagram of the F-35's Engine



Source: Pratt & Whitney. | GAO-22-104678

In addition to the modules, there are two types of spare parts used to sustain the engine. First, line replaceable components are parts on the engine that can be removed and replaced at the field level. Second, maintenance personnel use piece parts to repair and overhaul engine modules during depot maintenance. During depot maintenance, maintenance personnel disassemble engine modules, inspect the piece parts and replace with new piece parts as necessary, and then reassemble the module.

DOD's sustainment effort for the F-35 aircraft is a large and complex undertaking involving many stakeholders.

- **The F-35 Joint Program Office** manages and oversees the support functions required to field and maintain the readiness and operational capability of the F-35 aircraft across the enterprise.

- **Lockheed Martin**, the prime contractor for the aircraft, maintains the aircraft (i.e., the air vehicle) and the work is largely authorized in annual contracts.
- **Pratt & Whitney**, the contractor that designs and builds the engines, maintains the engine.

All engine maintenance is conducted either at the organizational level—the location in which the aircraft is stationed or deployed—or at maintenance depots, which are industrial installations that maintain, overhaul, and repair military weapons systems and equipment. The depots and field units conduct both scheduled and unscheduled maintenance. Scheduled maintenance is periodic prescribed inspections and/or servicing of equipment accomplished on a calendar, cycles, or hours-of-operation basis. Unscheduled maintenance is maintenance actions that occur outside of the normal schedule. Several key organizations conduct maintenance for the F-35 engine.

- **Military services and their personnel** generally conduct organizational-level engine maintenance.
- The **F-35 Joint Program Office and Pratt & Whitney** jointly manage depot-level engine maintenance through government employees located at military service-operated depots in the continental U.S. and contractor logistics support arrangements inside and outside the continental U.S.
- The **Air Force's Heavy Maintenance Center at Tinker Air Force Base, Oklahoma City, OK**, conducts most of the depot-level engine maintenance and contractor sites conduct the remaining depot-level engine maintenance.

GAO's Prior Work on F-35 Engine Sustainment

In July 2021, we reported that at the end of 2020 the F-35 program had 20 of its approximately 400 aircraft unable to fly because they needed engine repairs primarily related to the power module, according to program officials.[12] This increased number of power modules needing repair was largely due to coating distress of the high-pressure turbine blades. F-35 operations in dusty or sandy environments, as well as the higher running temperatures, have caused accelerated coating distress on the blades. These environments include high sand exposure (Middle East) and moderate sand exposure (primarily US southwest) environments. The exposure leads to early breakdown of the thermal

[12]GAO-21-439.

barrier coating, which exposes the blades to high temperatures. In January 2021, the F-35 Joint Program Office projected that the program would have a deficit of approximately 800 engines by 2030 without the implementation of considerable mitigation actions. A deficit of this size could lead to 43 percent of the F-35 fleet being grounded by 2030.

We also reported that two main factors contributed to F-35 engines needing repairs at the end of 2020. First, F-35 squadrons removed engines for unscheduled maintenance more often than expected, primarily to repair the power module. Second, the F-35 program was able to repair only 43 percent of removed power modules in 2020, thereby resulting in a backlog of power modules needing repair.

The F-35 Engine Sustainment Strategy Is Not Aligned with Military Service Desired Outcomes

DOD developed a sustainment strategy unique for the F-35 engines in an attempt to balance affordability and performance. However, this sustainment strategy does not meet some key operational desired outcomes of the military services, such as having sufficient numbers of aircraft with operating engines available to perform missions. DOD has also not assessed and updated its strategy to address those desired outcomes or reflect additional challenges, such as growing sustainment costs and options for modernizing the engine.

DOD's F-35 Engine Sustainment Strategy Results in More Aircraft without Operating Engines than Other Fighter Aircraft

DOD's F-35 engine sustainment strategy differs considerably from the strategies developed for other fighter aircraft engines—specifically the engines for the Air Force's F-16 Fighting Falcon and F-22 Raptor and the Navy's F/A-18E/F Super Hornets. In developing a sustainment strategy for the F-35 engine, DOD aimed to balance the performance of the aircraft and the engine with the affordability of sustainment, according to DOD, military service, and Pratt & Whitney officials. As a result, the F-35 engine sustainment strategy differs from the sustainment strategy of other Air Force and Navy fighter aircraft in three key areas:

- **DOD's goal is to have no more than 6 percent of F-35s being non-mission capable due to engine issues.** This means that DOD has decided it is acceptable for up to 6 percent of F-35 aircraft at any one time to be without an operating engine, waiting for a repair part, or undergoing engine-related maintenance. DOD has contracted with Pratt & Whitney to achieve this goal and DOD made investments in the F-35 engine program based on this goal. For example, DOD's and Pratt & Whitney's decisions regarding the required number of each type of module for its inventory and the necessary depot maintenance facilities, personnel, and equipment to repair the modules were informed by this goal, according to officials. If DOD desired to have a

lower non-mission capable due to engine rate (e.g., less than 6 percent), then DOD and Pratt & Whitney would need to increase the number of modules in DOD's inventory and/or increase its ability to repair modules at its depots. Both actions—individually and combined—generally would increase the availability of modules, resulting in fewer aircraft being without an operable engine. However, taking these actions to achieve a lower non-mission capable due to engine rate would result in additional costs for sustaining the F-35 engine.

Air Force and Navy officials told us that they do not use non-mission capable rate goals to manage the sustainment of their other fighter aircraft engines. Rather, they calculate a spare engine inventory requirement—as well as a breakdown of the number of engines that need to be ready for use within that inventory—to help ensure that aircraft will be available to meet desired mission outcomes. If an aircraft's engine needs repair beyond what maintenance is able to be conducted at the field level, there is typically an operating spare engine available to replace the inoperable engine. This sustainment approach, in combination with other sustainment aspects discussed in more detail below, has resulted in the number of Air Force F-16 and F-22 aircraft and Navy F/A-18 E/F aircraft considered non-mission-capable due to engine generally being 1 percent or lower since 2017, according to service officials.

- **F-35 program has limited spare engines:** The F-35 engine is modular, meaning that specific modules of the engine can be removed and replaced without having to replace the entire engine. Program officials told us that this strategy resulted in the F-35 having fewer spare engines than other programs, since individual modules can be replaced. However, according to officials this approach necessitates that the F-35 program have a sufficient number of engine modules, and associated depot repair capacity—i.e., the personnel, facilities, and support equipment to repair modules to meet demand—to meet the 6 percent goal. If the F-35 program does not maintain the optimal number of each type of engine module along with the corresponding depot repair capacity, then the program will experience module shortages that will negatively affect engine and aircraft readiness. This situation developed in mid-2020, when the F-35 program was unable to repair power modules quickly enough, resulting in an increasing shortage of power modules. This led to non-mission capable due to engine rates over 9 percent in February 2022 for the entire fleet of F-35s, including all variants.

In contrast, Air Force and Navy officials told us that the F-16, F-22, and F/A-18 E/F programs designed their engine sustainment strategies to ensure they have a certain number of spare engines designed to meet their wartime needs. Service officials stated that these programs plan to ensure a ready supply of spare engines, commonly referred to as war readiness engines, and work to ensure sufficient sustainment resources—depot capacity and spare parts—to support the services' war readiness engine requirements.[13] As a result, these aircraft engine programs have invested additional funding to ensure an engine supply safety net so that aircraft almost always have an operable engine. As previously stated, these aircraft have experienced non-mission-capable due to engine rates generally below 1 percent since 2017. The availability of war readiness engines is one key reason for this success.

- **F-35 program uses a two-level maintenance approach for the F-35 engine:** The F-35 program uses a two-level maintenance approach comprising organizational-level and depot-level maintenance, unlike the strategy used for other DOD fighter aircraft that includes intermediate-level maintenance.[14] As a result, all repairs that cannot be conducted at the organizational-level must be performed at the depot. Some DOD officials noted that it was assumed that organizational-level repairs would be minimal to conduct and depot-level repair would be easy. We found that the two-level approach has likely contributed to a depot maintenance backlog because all but the most basic maintenance must be performed at a depot. F-35 Joint Program Office officials stated that the two-level

[13]The Air Force uses the term war readiness engines, which are engines required to support a weapon system from the start of the war until resupply is established. The Navy uses a similar concept referred to as the engine readiness goal, which is the number of ready-for-issue engines, modules, or propulsion subsystems that must be available to execute the national military strategy and its Optimized Fleet Response Plan.

[14]There are three levels of maintenance: organizational (or unit), intermediate, and depot. Organizational- or unit- level maintenance is usually performed in the field, on the flight line, or at the equipment site by maintenance personnel and equipment operators. It normally includes inspecting, servicing, lubricating, and adjusting, as well as replacing parts, minor assemblies, and subassemblies. Intermediate-level maintenance generally involves material maintenance or repair in direct support of using organizations. Some examples of intermediate-level maintenance include calibration, repair, or replacement of damaged or unserviceable parts, components, or assemblies. Depot-level maintenance includes major overhaul, upgrading, or rebuilding of parts, assemblies, subassemblies, and end items, as well as support to organizational and intermediate-level maintenance. Depot-level maintenance generally involves extensive industrial facilities, specialized tools and equipment, or uniquely experienced and trained personnel that are not available in other maintenance activities. Field-level maintenance consists of organizational- and intermediate-level maintenance.

approach costs less than a three-level approach, which would include an intermediate level of maintenance. However, an intermediate-level of maintenance is able to perform more intensive maintenance, such as diagnostic testing and repair or replacement of damaged or unserviceable parts, than the organizational-level.

In contrast, the Air Force and Navy maintain legacy fighter aircraft engines using all three levels of maintenance. For example, the Air Force maintains the F-22 Raptor engine (also manufactured by Pratt & Whitney) under a three-level maintenance approach with intermediate maintenance shops at installations that can make minor repairs on the engine, preventing some engine maintenance beyond the most basic repairs from being sent to the depot.

Figure 4 shows differences between the sustainment of the F-35 engine and selected Air Force and Navy fighter aircraft engines.

Figure 4: Sustainment for F-35 Engines Compared with Other DOD Fighter Aircraft Engines

	F-35 Lightning II *Joint*	**F/A-18E/F** Super Hornet *Navy*	**F-16** Fighting Falcon *Air Force*	**F-22** Raptor *Air Force*
				
Engine	F135-PW-100 Pratt & Whitney F135-PW-600 Pratt & Whitney	F414-GE-400 General Electric	F100-PW-200/220/229 Pratt & Whitney F110-GE-100/129 General Electric	F119-PW-100 Pratt & Whitney
Number of engines	Single engine	Twin engine	Single engine	Twin engine
Engine attributes	• More than 40,000 pounds of thrust • 1,227 miles per hour	• 22,000 pounds of thrust per engine • 1,381 miles per hour	• 27,000 pounds of thrust • 1,500 miles per hour	• 35,000 pounds of thrust per engine • 1,534 miles per hour
Engine non-mission capable rate goal	No more than 6 percent	None	None	None
War readiness engines (WRE)[a]	None	Yes	Yes	Yes
Levels of maintenance	Two-level maintenance: organizational and depot	Three-level maintenance: organizational, intermediate, and depot	Three-level maintenance: organizational, intermediate, and depot	Three-level maintenance: organizational, intermediate, and depot
Depot maintenance	Led by the contractor and conducted by service and contractor personnel	Led by the Navy and conducted by Navy personnel	Led by the Air Force and conducted by Air Force, Air National Guard, and civil service personnel	Led by the contractor and conducted by Air Force, contractor, and government personnel

Source: GAO analysis of Department of Defense and Pratt & Whitney information. Photos (left to right): U.S. Air Force/Staff Sgt. Brian Kelly, U.S. Navy/Chief Petty Officer Shannon Renfroe, U.S. Air Force/Airman 1st Class Matthew Seefeldt, and U.S. Air Force/Tech. Sgt. Natasha Stannard. | GAO-22-104678

[a]The Air Force uses the term war readiness engines, which are engines required to support a weapon system from the start of the war until resupply is established. The Navy uses a similar concept referred to as the engine readiness goal, which is the number of ready-for-issue engines, modules, or propulsion subsystems that must be available to execute the national military strategy and its Optimized Fleet Response Plan.

DOD's F-35 Engine Sustainment Strategy Does Not Position Military Services to Meet Operational Desired Outcomes and Support National Defense Strategy Missions

DOD's sustainment strategy for the F-35 engine does not meet the desired outcomes of the military services. As a result, each military service either has taken steps or is in the process of taking steps, such as purchasing additional spare engines or modules, to improve their availability of operating engines. These actions have resulted in additional costs for F-35 sustainment.

The military service officials told us that a goal of no more than 6 percent for the non-mission capable due to engine rate—even if met—would not allow the military services to effectively support *National Defense Strategy* missions, such as those related to China and Russia.[15] F-35 Joint Program Office and Pratt & Whitney officials told us that the F-35 engine sustainment strategy did not align with the desired outcomes of the military services. Specifically, we found the following concerns among military service officials.

- **Air Force.** Officials told us their missions require operable engines for their F-35 aircraft at all times and that the goal of not more than 6 percent non-mission capable due to engine rate was not acceptable. Since mid-2020, the Air Force has experienced shortages of operable engines due to issues with the power module resulting in aircraft not being able to fly. For example, in August 2021, Air Force officials told us they had 35 aircraft without operating engines. In addition, they said that the F-35 is the only engine using a two-level maintenance concept, placing a heavier burden on depots performing two levels of maintenance (both depot and intermediate). As a result, the Air Force received $175 million in funding for fiscal year 2022 to purchase additional power modules to reduce the number of aircraft without operating engines.[16] This amount is in addition to the funding the Air Force already provides the F-35 program office for F-35 sustainment, including F-35 engine sustainment.
- **Marine Corps and Navy.** Officials from both military services told us that although they have not experienced the severity of engine availability issues the Air Force has at this point, they are concerned

[15]Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge.

[16]The Chief of Staff of the Air Force submitted a request to Congress on the unfunded priorities list for more power modules to support the Air Force's needs. The National Defense Authorization Act for Fiscal Year 2022 and the Joint Explanatory Statement accompanying the Consolidated Appropriations Act, 2022, listed $175 million for F-35 power modules under Aircraft Procurement, Air Force. Pub. L. No. 117-81, § 4101 (2021); 168 Cong. Rec. H2039 (daily ed. Mar. 9, 2022).

about the sustainment strategy as more F-35s are fielded across the fleet and in particular to the Marine Corps and Navy. Further, to ensure engines are available for their F-35 aircraft, in fiscal year 2018 the Marine Corps began to purchase their own spare F-35 engines. For fiscal years 2019-2021, the Marine Corps spent about $186 million and purchased seven spare engines. Navy officials also told us that the level of spare modules in the program is not sufficient to meet their desired outcomes—especially to maintain operational tempo during deployments. According to Navy officials, the Navy explored additional funding for spare engines during the budgeting process for fiscal year 2023, but decided against pursuing that funding as it needed additional information before making a decision. In addition, Navy officials stated they would like to have intermediate-level maintenance for the F-35, similar to other aircraft in the Navy, to improve the capacity and responsiveness of the repair network.

Engine Sustainment Costs and Modernization Efforts Pose Additional Challenges

Annual engine sustainment costs, a portion of total sustainment costs, have increased from $79 million in fiscal year 2016 to $315 million in fiscal year 2020.[17] According to F-35 Joint Program Office officials, this cost increase was due to several factors including an increase in the number of aircraft from 154 to 357 and a 184 percent increase in total flight hours. As a percentage of the total operating and support costs, engine sustainment costs have increased from 7 percent of the total in fiscal year 2016 to 11 percent of the total in fiscal year 2020. DOD plans to begin performing scheduled maintenance on F-35 engines in 2023. This scheduled maintenance will significantly increase sustainment costs, in addition to generating additional demand for spare parts and depot resources. By fiscal year 2028, maintenance costs for the F-35 engine are projected to be over $1 billion annually. According to Pratt & Whitney officials, scheduled maintenance has the potential to be over 70 percent of total engine maintenance costs by 2030.

The F-35 Joint Program Office and Pratt & Whitney have ongoing efforts to improve the affordability of engine sustainment including improving the efficiency of maintenance activities, keeping the engine on the aircraft longer, and improving the reliability of engine parts. For example, as part of its Keep Engines on Wing Initiative, Pratt & Whitney is working to keep engines on the aircraft for longer intervals before they go in for scheduled maintenance events. This effort could decrease the overall amount of

[17]In July 2021, we reported that the costs of the F-35's estimated life-cycle sustainment have increased steadily since 2012 even though DOD has taken actions to try to reduce them. See GAO-21-439.

maintenance required for the engines and therefore decrease engine sustainment costs. Pratt & Whitney estimates that these efforts could avoid about $14 billion in sustainment costs out of approximately $90 billion in total engine sustainment costs over the life-cycle of the aircraft. However, these efforts are in various stages of implementation and approval. According to DOD officials, these efforts must be balanced with long-term engine performance to ensure that efforts to keep engines on the aircraft for longer periods of time does not increase risk of engine problems when in flight.

Further, the F-35 program is in the early stages of planning to modernize the F-35 engine. According to F-35 Joint Program Office officials, the F-35 program will need to modernize the current engine to provide the additional power and thermal management capabilities that are necessary to support F-35 aircraft modernization.[18] According to Joint Program Office officials, DOD is considering two options: (1) upgrading the current engine via enhanced engine package options, produced by Pratt & Whitney, or (2) developing a new engine through an Adaptive Engine Transition Program, which would be competed among interested contractors.

- **Enhanced engine package:** The enhanced engine package is a Pratt & Whitney program that would build on the technology of the existing engine and be applicable to all aircraft variants. The enhanced engine package would result in an increase in capability, such as improved range and thrust. However, Pratt & Whitney representatives stated that if the enhanced engine is required to work with all variants of the F-35, some degradation in performance would be experienced to accommodate the lift fan that is part of the engine for the F-35B. Further, these officials noted that Pratt & Whitney has also developed an option that would increase performance for the F-35A and F-35C engines. These options would be integrated into the fleet over time, resulting in minimal effects on sustainment, according to F-35 Joint Program Office officials.
- **Adaptive Engine Transition Program (AETP):** The Air Force is sponsoring this approach, which would result in an entirely new engine for the U.S. fleet of F-35As and F-35Cs. Air Force officials told us that the F-35 is being flown harder than originally anticipated, and

[18]The modernization effort—known as Block 4—upgrades the hardware and software systems of the F-35. See GAO, *F-35 Joint Strike Fighter: DOD Needs to Update Modernization Schedule and Improve Data on Software Development*, GAO-21-226 (Washington, D.C.: Mar. 18, 2021).

an upgraded engine is imperative for meeting increasing demands. AETP aims to produce adaptive engines that provide increased thrust during combat conditions and increased fuel efficiency during cruise conditions. Fielding such engines would enable air power with increased range and additional cooling air for thermal management.

However, according to F-35 Joint Program Office officials, this option would pose three challenges that will affect engine life-cycle costs. First, the F-35C aircraft would likely need some sort of modification so that the new engine could be placed in the aircraft. Second, a new engine would present sustainment challenges as the program would have two different engines to sustain—one for F-35As and F-35Cs, and another for F-35Bs—likely requiring changes to the existing infrastructure that supports engine sustainment. Third, this approach will not work for the F-35B variant, according to F-35 Joint Program Office officials. Therefore, if an engine modernization is a requirement for all three variants—F-35A, F-35B, and F-35C—and AETP is selected for the F-35A and F-35C, then another engine modernization effort would still be required for the F-35B. According to program officials, this would result in two separate engine development efforts and have an effect on sustainment strategies and sustainment costs due to the fleet of F-35s operating two unique engines.

The NDAA for Fiscal Year 2022 directed DOD to take actions to plan for F-35 engine modernization. Specifically, the NDAA directed:

- The Air Force, within 14 days after the date of submission to Congress of the President's budget for fiscal year 2023, to provide details of a competitive acquisition strategy for the integration of an AETP engine into the F-35A aircraft. The Air Force also has to develop a plan for implementing that strategy, including beginning to retrofit all F-35As with that engine no later than fiscal year 2027.
- The Navy, within 14 days after the date of submission to Congress of the President's budget for fiscal year 2023, to report on the integration of an advanced engine—either one derived from the AETP or from prior efforts associated with the current F-35 engine—into the F–35B and F-35C. This report would include an assessment of the effects of integrating an advanced engine on combat effectiveness and sustainment costs, among other things. Based on its assessment, the Navy is also required to submit a competitive acquisition strategy and implementation plan for integrating an advanced engine into the F-35B and F-35C fleets, beginning no later than fiscal year 2027.

DOD Has Not Assessed Its F-35 Engine Sustainment Strategy to Address Shortcomings and Future Challenges

DOD has not aligned the F-35 engine sustainment strategy with military service desired outcomes because the Joint Program Office, in collaboration with the military services, has not assessed its F-35 sustainment strategy. Specifically, the department has not assessed and documented whether the goal of not more than 6-percent non-mission capable due to engine rate, spare engine and module inventory levels, and the two-level maintenance approach remain appropriate for achieving DOD's desired outcomes now and in the future.

The F-35 Joint Program Office and Pratt & Whitney have begun to take action to address some of the shortcomings in the engine sustainment approach. For example, DOD is developing a new concept of operations for F-35 engine sustainment. This new concept has been under development since January 2021 and was supposed to be complete by the end of May 2021. However, according to Joint Program Office officials, the concept has not been finalized by the department and the department projects that the earliest it will be finalized is summer of 2022.

The F-35 Joint Program Office and military services officials told us that they had met to discuss how the military services manage other engine sustainment efforts, future military service requirements for the F-35 engine, as well as how the sustainment strategy should be adapted. According to DOD officials, the department is considering adapting its approach to F-35 engine sustainment to more closely align with the approaches used by the military services for their engine sustainment programs (as previously discussed). For example, based on discussions about the effort with F-35 Joint Program Office and military service officials, DOD is considering, among other things, increasing the number of spare modules in an effort to reduce the non-mission capable due to engine rate. F-35 Joint Program Office officials told us that it is also considering implementing some actions before the new concept is finalized and approved. According to these officials, the department recognizes that the current sustainment strategy is falling short of desired outcomes (as discussed in more detail later in this report).

However, the F-35 Joint Program Office has not updated its F-35 engine sustainment strategy. Most importantly, DOD has not assessed and documented whether the overall goal of its strategy—6 percent or less of aircraft being designated non-mission capable due to engine—needs to be updated to meet the desired outcomes of the military services. The overall goal of the F-35 engine sustainment strategy affects other sustainment decisions, such as the required number of spare engines and modules and the levels of maintenance and capacity needed to

repair the modules. Specifically, a goal of F-35 aircraft almost always having an operating engine like other DOD tactical fighter aircraft—a less than 1 percent non-mission capable rate due to engine—requires that the number of spare engines and modules and levels of maintenance are planned in a collaborative manner. Achieving such a goal, while improving F-35 aircraft availability, would undoubtedly increase sustainment costs for the F-35 engine. Furthermore, decisions on these elements cannot be made without consideration of future decisions on engine modernization and the effect of that modernization on sustainment planning and needs.

DOD policy requires maintenance programs, including those for weapons systems, to be structured for meeting readiness and sustainability objectives, including surge capabilities, to meet national defense requirements.[19] Further, DOD's highest priority is to provide warfighters with the capabilities urgently needed to overcome unforeseen threats, achieve mission success, and reduce risk of casualties. In addition, the *Standards for Internal Control in the Federal Government* states that management should identify, analyze, and respond to risks related to achieving the defined objectives.[20]

Without assessing and updating, as appropriate, the F-35 engine sustainment strategy, including the goal of the strategy and the necessary actions to achieve its goal, the F-35 program may continue to not meet the desired outcomes of the military services. DOD and the military services will not be positioned to make informed, cost-effective decisions given the interrelated nature of the potential actions—such as the required number of spare engines and modules and the levels of maintenance and capacity needed to repair the modules—to better meet the desired outcomes of the military services. Moreover, these decisions as well as potential implications associated with engine modernization will affect the costs necessary to sustain engines for the F-35. In addition, without documenting its assessment, any update to the F-35 program's goal for the engine sustainment strategy—and the necessary actions to achieve its goal—the F-35 program risks not ensuring that all

[19]DOD Directive 4151.18, *Maintenance of Military Materiel* (Mar. 31, 2004) (incorporating Change 1, Aug. 31, 2018).

[20]GAO, *Standards for Internal Control in the Federal Government,* GAO-14-704G (Washington, D.C.: September 2014).

stakeholders understand the strategy and whether the approach is meeting the desired outcomes of the military services.

The F-35 Engine Has Not Met Several Key Sustainment Performance Goals

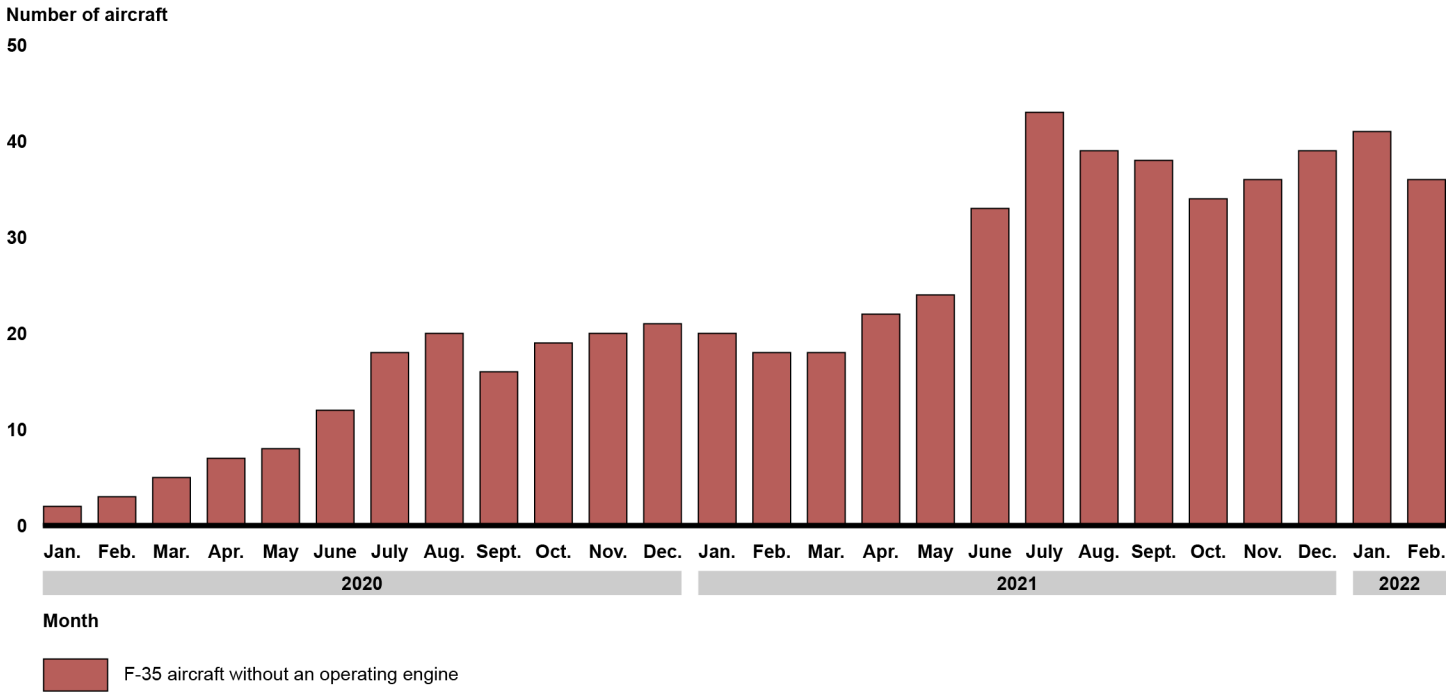
An increasing number of F-35 aircraft have not been able to fly because they are non-mission capable due to engine, including not having an operating engine or waiting for specific parts to repair the engine. In addition, the F-35 engine has not met all of its reliability and maintainability performance goals.

Increasing Number of F-35 Aircraft Have Not Been Able to Fly Due to the Lack of an Operating Engine

Since the beginning of 2020, an increasing number of F-35 aircraft have not been able to fly due to the lack of an operating engine, as shown in figure 5. Almost all of the aircraft affected by the lack of an operating engine are operated by the Air Force. For example, in August 2021, the Air Force had 35 aircraft unable to fly because they did not have an operating engine, according to Air Force officials. Air Force officials stated this level of aircraft unable to operate due to engine availability negatively affects Air Force preparedness to execute its mission. Furthermore, although the F-35 program and the military services manage engine spares by prioritizing combat-coded units over test and training units, the shortage of operating engines has adversely affected deployed combat units as well.[21]

[21]Director, Operational Test & Evaluation, *FY 2021 Annual Report*, January 2022.

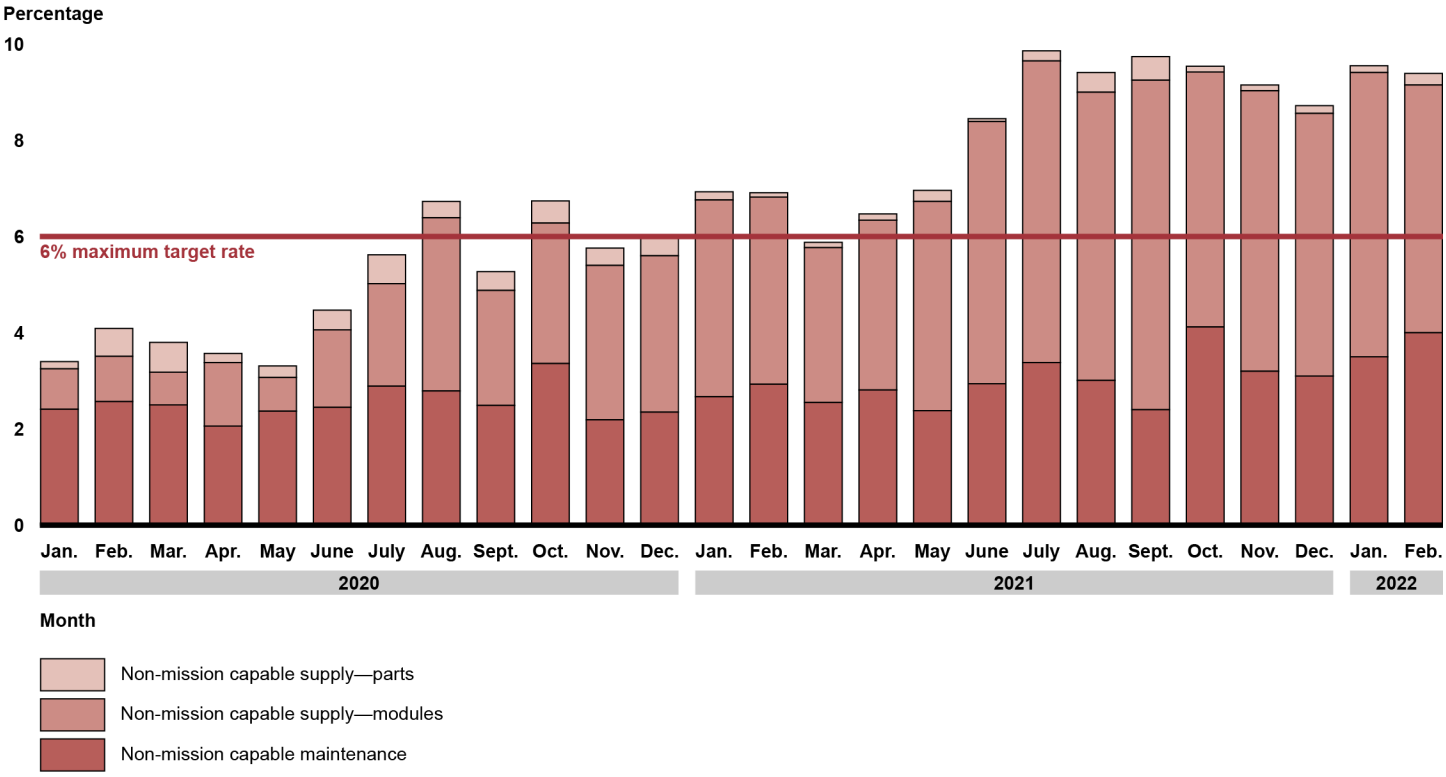
Figure 5: F-35 Aircraft without an Operating Engine, January 2020 – February 2022



Source: GAO analysis of Pratt & Whitney data. | GAO-22-104678

DOD has set a goal for the F-35 program that no more than 6 percent of available aircraft time be in a status of non-mission capable due to engine. However, DOD has achieved the 6 percent goal in only 1 month from January 2021 through February 2022, as shown in figure 6. Prior to January 2021, the F-35 program met the goal for engine mission-capable rates in 45 of 49 months from December 2016 through December 2020.

Figure 6: F-35 Fleet Engine-Related Non-Mission Capable Rates from January 2020 through February 2022, Compared with Goal



Source: GAO analysis of Pratt & Whitney data. | GAO-22-104678

DOD's goal of no more than 6 percent of aircraft being non-mission capable due to engine includes these goals for three components:

- a 1 percent goal for non-mission capable supply—parts (i.e., when an aircraft is unable to fly because non-module engine parts are removed and replacement parts are not available),
- a 4 percent goal for non-mission capable supply—modules (i.e., when an aircraft is unable to fly because a module of the engine needs replacing and is not available), and
- a 1 percent goal for non-mission capable maintenance (i.e., when an aircraft is not able to operate due to a maintenance issue).

DOD has been meeting its 1 percent goal for non-mission capable supply-parts. However, DOD has not met its 4 percent goal for non-mission capable supply-modules or its 1 percent goal for non-mission

capable maintenance. The increase in the rate of aircraft that are designated as non-mission capable due to engine is primarily due to the lack of operating modules, specifically the power module, and reliability issues with line replaceable components that have driven increased organizational-level maintenance.

Inability to Complete Repairs as Planned Has Led to Power Module Shortages

The F-35 engine's non-mission capable rate due to supply of modules has increased since June 2020, and has not met its goal of 4 percent since April 2021. In particular, as of February 2022, the lack of available power modules was the number one driver of non-mission-capable aircraft.

Engine modules sent to depot have taken significantly more time to repair than planned. The F-35 Joint Program Office has a goal for depots to repair engine power modules in 122 days. However, in October 2020, the repair turnaround time—the time required to return an item to use after removal—for a power module was about 200 days. According to DOD officials, the 122-day goal was based, in part, on DOD and Pratt & Whitney assumptions about the extent of necessary repairs when an engine went to depot for maintenance. The repair turnaround time has been higher than expected for two primary reasons:

1. The Heavy Maintenance Center (Tinker Air Force Base, Oklahoma City, OK) where most F-35 engine repairs have occurred through 2021, has not had the capacity—i.e., the personnel, facilities, and support equipment to repair modules to meet demand—to handle the volume or level of complexity of the repairs to the power module.
2. DOD and Pratt & Whitney officials stated that power modules undergoing depot maintenance required more extensive repairs than initial work scope estimates determined by field maintenance personnel at the time of engine removal from the aircraft at the organizational-level, resulting in more time- and labor-intensive repairs than the depot had planned. According to DOD and Pratt & Whitney officials, numerous actions were taken to improve this issue, such as improving inspection protocols at the organization level to ensure accurate information being communicated to the depot.

Depot maintenance personnel at the Heavy Maintenance Center told us that their facility was originally projected to do primarily low- to mid-level maintenance, but has actually been doing approximately 75 percent heavy maintenance. For example, they stated that they have had engines come into the depot estimated to need only moderate repairs, but then

were found to have more extensive damage that required full disassembly of the engine and hundreds of more work hours than expected.

Since the unscheduled maintenance of power modules took significantly longer than anticipated, depots have repaired fewer engine modules than planned. For example, in 2020, the F-35 engine program repaired 30 F-35 power modules, significantly fewer than the 86 power modules the F-35 program had projected.[22] As a result, 65 power modules were awaiting depot maintenance at the end of 2020.

Reliability Issues with Line Replaceable Components Have Driven Increased Organizational-Level Maintenance

The F-35 program has not met the 1 percent goal for non-mission capable due to engine maintenance (i.e., the engine is undergoing or awaiting organizational-level maintenance and the aircraft is not able to fly). Pratt & Whitney officials stated that the goal has not been met in part because of reliability issues with line replaceable components, which has resulted in the engine needing more maintenance than planned. For example, a speed sensor on the engine has a difficult installation path that often causes damage to the sensor, resulting in an oil leak and replacement of the sensor. Additionally, the sensor has been difficult to thread into its location, causing damage to the sensor. Therefore, this sensor had been the subject of 33 maintenance malfunction reports, making it a major driver of line replaceable component reliability metrics and increased non-mission capable maintenance rates.

The F-35 Engine Has Not Met All of Its Reliability and Maintainability Goals

The F-35 engine has met three out of DOD's five goals for reliability and maintainability, as shown in table 1.[23] A reliability metric measures the duration of time that an item performs its intended function. A maintainability metric measures the duration of time that it takes for an item to be repaired to a specific condition. Reliability and maintainability goals present specific quantitative objectives aimed at ensuring that an aircraft will be available for operations as opposed to being out of service for maintenance. These metrics are measured in mean flight hours—the

[22]The Heavy Maintenance Center repaired 14 power modules and the contractor sites repaired 16.

[23]We have previously reported on the F-35 program not meeting its reliability and maintainability goals for the F-35 aircraft. As of December 2021, the program was meeting or close to meeting 13 of its 24 goals. See *F-35 Joint Strike Fighter: Cost Growth and Schedule Delays Continue*, GAO-22-105128 (Washington, D.C.: Apr. 25, 2022), *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) and GAO-21-226.

average time an aircraft is in flight between particular events, such as failures or maintenance events.

Table 1: F-35 Engine Reliability and Maintainability Metrics' Performance against Goals, as of September 2021

Metric	Measures the mean flight hours between…	F-35A	F-35B	F-35C
Failures	Corrective maintenance events discovered when the engine is installed. These events are associated with hardware or software malfunctions identified at the organizational-level of maintenance on the ground.	●	○	●
Maintenance events	Engine-related maintenance, unscheduled inspections, and servicing actions, including consumables.	○	○	○
Operational mission failure	Failures of the engine that result in the loss of capability to perform an essential mission function during a strike mission.	●	●	●
Removal	Unscheduled engine removals from the aircraft for replacement from the supply chain.	●	●	●
Line replaceable component[a] removal	Unscheduled removals of these components from the engine.	○	○	○

Legend:
●: Metric is at or above current goal
○: Metric is below current goal

Source: GAO analysis of Pratt & Whitney data. | GAO-22-104678

Note: A 12-month rolling average (September 2020–September 2021) is used to measure these metrics and the outcomes from the most recent production configuration of the engine are used to assess performance against the goals, according to Pratt & Whitney officials. According to Pratt & Whitney, about 55 percent of F-35 engines at the end of 2021 were in the most recent production configuration. Multiple configurations of the engine exist due to the concurrency of development and production, according to Pratt & Whitney officials.

[a]A higher level assembly that can be removed and replaced at the field level.

According to Pratt & Whitney data, the F-35 engine generally has been exceeding the program's goals for three reliability and maintainability metrics—mean flight hours between failure, operational mission failure, and removal.

- **Engine failure.** This metric measures the mean flight hours between corrective maintenance events discovered when the engine is installed. The F-35A and F-35C have been exceeding the goal for the metric while the F-35B has not been meeting the goal. Specifically, the F-35B is falling short of its 220 mean flight hour goal by about 40 hours (or 19 percent). This performance means that engines on the F-35B are requiring more maintenance due to software or hardware malfunctions than originally planned.
- **Engine operational mission failure.** This metric measures the mean flight hours between failures that result in a loss of capability to

perform an essential function for a strike mission (e.g., a ground/air abort or in-flight emergency). All three F-35 variants have been exceeding their goals for this metric by wide margins. For example, the F-35A has been exceeding its 1,400 mean flight hour goal by over 1,000 hours (or 77 percent). This performance means that the engine is extremely reliable during flight, allowing the aircraft to complete a higher frequency of missions without engine issues during the mission.

- **Engine removal.** This metric measures the mean flight hours between unscheduled removals of the engine from the aircraft. All three F-35 variants have been exceeding their goals for this metric by wide margins. For example, the F-35A has been exceeding its 950 mean flight hour goal by almost 1,000 hours (or 105 percent). This performance means that the engine is not required to be removed as much as anticipated for unscheduled events, reducing demand for maintenance.

According to the F-35 Joint Program Office and Pratt & Whitney officials, these metrics and experience have shown that the F-35 engine is extremely reliable in its performance on the aircraft.

On the other hand, the F-35 engine has not been meeting the program's goals for the two other reliability and maintainability metrics—mean flight hours between maintenance events and line replaceable component removals.

- **Maintenance events.** This metric measures the mean flight hours between unscheduled maintenance events when the engine is installed in the aircraft. All three F-35 variants have been falling far short of their goal. For example, the F-35A has fallen short of its 140 mean flight hour goal by almost 100 hours (or 67 percent). This performance means that the F-35 engine is requiring a significant higher number of maintenance events than originally planned, requiring more than the planned work for maintenance personnel at the organizational level.
- **Line replaceable component removals.** This metric measures the mean flight hours between unscheduled replacements of these components when the engine is installed in the aircraft. None of the three F-35 variants have met their goals. For example, the F-35A has fallen short of its 410 mean flight hour goal by about 60 hours (or 14 percent). This performance means that line replaceable components are failing more often than desired, requiring them to be removed and replaced by maintainers more frequently than planned.

According to the F-35 Joint Program Office and Pratt & Whitney officials, frequent failure of line replaceable components has been a major contributor to the failure to meet both of these metrics. However, when a component is removed an investigation is completed to isolate the root cause and to incorporate corrective action, according to Pratt & Whitney officials.

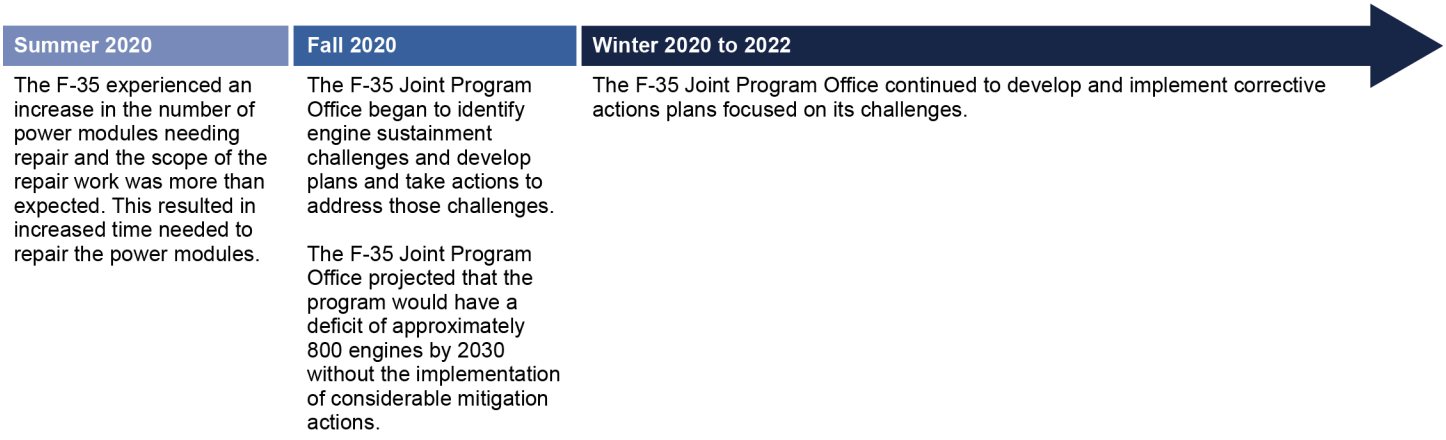
Addressing Challenges Will Take Years and There Is Disagreement on Parts Funding

DOD has developed and was in the process of implementing corrective-action plans to address insufficient depot capacity to repair power modules and to reduce the demand for maintenance on the F-35 engine. DOD began implementing these plans during the fall and winter of 2020, but execution will take years and require the department to spend more sustaining the engine than it had originally planned. DOD's efforts have resulted in improved projections for engine availability, but significant risks remain that will require sustained management attention. In particular, DOD and Pratt & Whitney disagree on how much additional spending is needed to close a gap in spare parts funding.

DOD Has Developed and Begun Implementing Multi-Year Plans to Address Engine Sustainment Challenges

Beginning in the fall of 2020, the F-35 Joint Program Office simultaneously developed and implemented corrective action plans (see fig. 7). These plans focus on (1) improving depot capacity—the facilities, personnel, support equipment, and necessary spare parts—to make the necessary repairs to the engine's power module and (2) taking actions to reduce maintenance demands by improving the reliability and maintainability of spare parts and extending the time the engine can remain on the aircraft.

Figure 7: Timeline of F-35 Joint Program Office Engine Sustainment Corrective Action Plans, 2020-2022

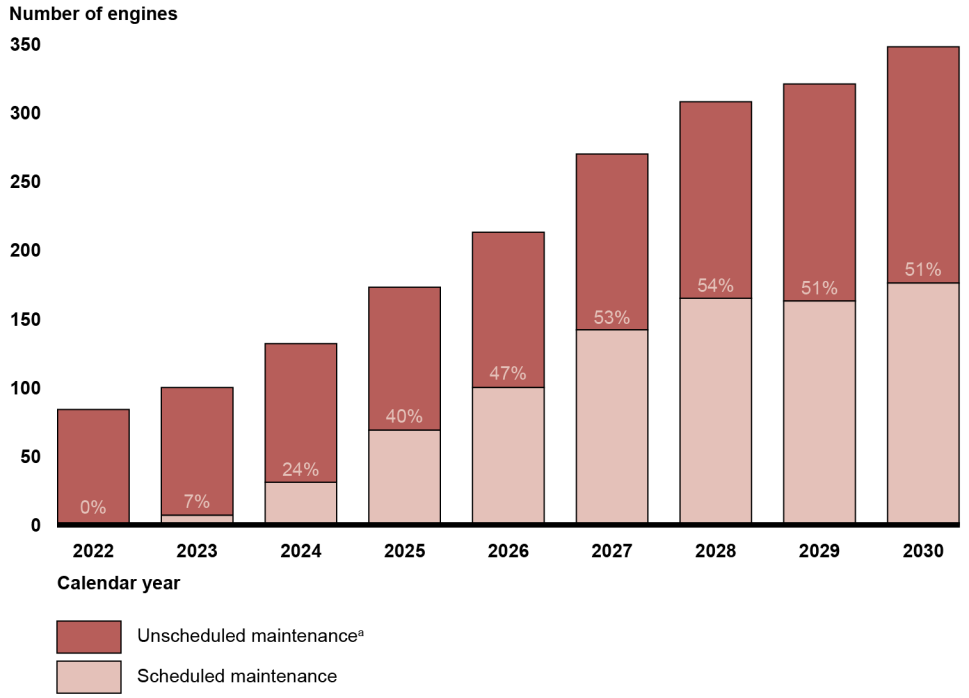


Source: GAO analysis of Department of Defense information. | GAO-22-104678

DOD Has Plans to Improve Depot Capacity That Will Take Years to Implement

DOD officials stated they recognize that they have not had the adequate depot capacity to repair engines and do not have sufficient capacity to adequately meet the demand of future unscheduled and scheduled engine repairs. The program has not begun to conduct scheduled maintenance but plans to do so in 2023. Scheduled engine maintenance will increasingly become a larger portion of engine depot maintenance events through 2030, as shown in figure 8.

Figure 8: F-35 Engine Scheduled and Unscheduled Depot Maintenance, 2021-2030



Source: GAO analysis of Pratt & Whitney data. | GAO-22-104678

[a]Unscheduled maintenance projections also include major variance requests, which are replacements to parts that did not meet their full service life, according to Joint Program Office officials.

Since the fall of 2020, the F-35 Joint Program Office and Pratt & Whitney have taken actions and have plans to take additional actions to increase depot repair capacity to meet current and future engine maintenance needs. These efforts have begun to improve depot capacity. For example, in 2020, the F-35 depot engine repair network—comprised of the Heavy Maintenance Center at Tinker Air Force Base, Oklahoma, and contractor logistic sites—was projected to repair 86 power modules but could repair only 30. However, in 2021 the network repaired 76 of a projected 80

power modules. This improvement and planned continued improvements included plans to:

- **Increase maintenance personnel, space, and equipment at the Heavy Maintenance Center.** In December 2020, the F-35 Joint Program Office established a repair turnaround time goal for power modules of 122 days by January 2022 at the Heavy Maintenance Center. This goal would be an improvement of 85 days over the actual 207-day repair turnaround time in October 2020. The program has taken actions to meet this goal, such as establishing a second maintenance shift at the Heavy Maintenance Center to conduct repairs so that work is being performed more hours of the day. Further, program officials were in the process of expanding the physical space at the Heavy Maintenance Center and were adding additional technicians, tooling, and machinery to help improve repair turnaround time.

  The implementation of these efforts has shown results. DOD exceeded its January 2022 repair turnaround time goal of 122 days, improving it to 119 days according to Pratt & Whitney officials. Whereas the Heavy Maintenance Center was able to repair only 14 power modules in 2020, it exceeded its projected repair of 40 power modules in 2021 by 11 power modules—repairing 51. According to Joint Program Office officials, these and other continued actions were projected to increase the Heavy Maintenance Center's repair capacity to 75 power modules in 2022 and 120 power modules by 2025.

- **Expand the number of depots as well as the quantities of power modules repaired by those depots.** As of March 2022, the F-35 enterprise had seven active depots for repairing F-35 engines, was in the process of activating one other, and had plans to establish three additional engine depot maintenance facilities in the United States and abroad by the end of 2024 (see fig. 9).[24] The F-35 Joint Program Office has identified key milestones associated with facilities, support equipment, and personnel training for the expansion of current operating depots and activation of additional depots. According to F-35 Joint Program Office and Pratt & Whitney officials, this additional capacity would allow the program to repair more modules on an annual basis. For example, a contractor-managed depot repair facility in West Palm Beach, Florida, began operating in 2021 and the F-35

[24]These 10 depots will support engine maintenance for the entire international fleet of F-35s.

Joint Program Office plans for it to improve its repair capacity from 12 power modules to 24 when it is operating at full capacity in 2024.

Similar improvements were planned for contractor-managed depot facilities at Edwards Air Force Base, CA, and Naval Air Station Patuxent River, MD. The F-35 Joint Program Office is planning to open an engine depot repair facility at the Navy Fleet Readiness Center Southeast in Jacksonville, Florida, by 2024. This new facility is a key to the future expansion of repair capacity with projected power module repairs growing to 12 in 2026, 24 in 2027, and 36 in 2028, based on currently funded plans.

Figure 9: Map of Current and Future F-35 Engine Maintenance Depots, as of March 2022

Source: Pratt & Whitney; Map Resources. | GAO-22-104678

DOD Has Plans to Address Reliability and Maintainability of and Demand for Spare Parts

Improving the reliability and maintainability of and decreasing the demand for repairs of the engine can reduce the need for maintenance at both the organizational and depot levels. DOD has developed and begun to implement plans to reduce demands for maintenance over the next several years. Specifically, these plans are focused on:

- **Improving the reliability and maintainability of spare parts.** DOD and Pratt & Whitney have efforts underway to increase the reliability and maintainability of engine spare parts—in particular line replaceable components. For example, the Component Improvement Program provides engineering solutions for operational issues including safety problems and airworthiness. Funding for this program has been approximately $70 million per year over the past 3 years. As part of this program, the F-35 Joint Program Office funded an effort in 2021 to be completed by September 2023 to improve the design of a speed sensor—a line replaceable component—on the engine so that it is more reliable and maintenance actions are less time consuming. Improvements to the reliability and maintainability of the line replaceable components, such as the speed sensor, reduce the number of parts needed to sustain the engine as well as the time for conducting field maintenance.
- **Increasing the time an engine can remain on an aircraft based on performance data of the engine and its parts:** Given the engineering data collected on the performance of the engine at this point of its life cycle, DOD and Pratt & Whitney officials stated that adjustments can be made to maintenance requirements. In particular, some engineering limits—such as the degree and progression of cracking on high pressure turbine blades in the power modules—that drive additional maintenance actions or replacement of parts at the field and depot level could be broadened. Such actions could decrease the demand for maintenance as well as spare parts.

DOD and Pratt & Whitney have been working to increase the time that an engine is able to stay on an aircraft by expanding the engineering limits for some parts so that they do not need to be replaced as frequently. For example, based on extensive testing, the F-35 Joint Program Office has taken actions to extend current limits for the high pressure turbine blades in the power module. F-35 maintainers inspect the blades every 50 flight hours and make decisions on whether a blade needs to be replaced based on technical measurements (i.e., limits) of coating loss, burn through, and cracking. According to the F-35 Joint Program Office, the current limits that resulted in a power module being sent to the depot for repair due to the blades were based on conservative estimates and experiences with legacy engines. After developing and carrying out tests to assess the durability of the blades, the F-35 Joint Program Office and Pratt & Whitney concluded that the blades were more durable, even with a significant amount of coating missing, and could be safely used longer than previously assumed. The F-35 Joint Program Office and Pratt & Whitney also more frequently used government and Pratt & Whitney

engineers to track engine blade distress and ensure F-35 maintainers were properly conducting engine blade inspections.

These actions enabled the F-35 Joint Program Office to approve a new set of interim limits in October 2021 for assessing coating loss, cracking, erosion and tip distress during 50-flight hour inspections. According to Joint Program Office officials, the F-35 Joint Program Office finalized the limits in March 2022. Under these expanded limits, engines are able to safely stay in the aircraft for longer periods of time, resulting in fewer engine removals and fewer required repairs by depots. The F-35 Joint Program Office officials told us that the reduction in blade maintenance would free up resources to address other engine maintenance needs, helping the engine repair network to more quickly recover to meet demand.

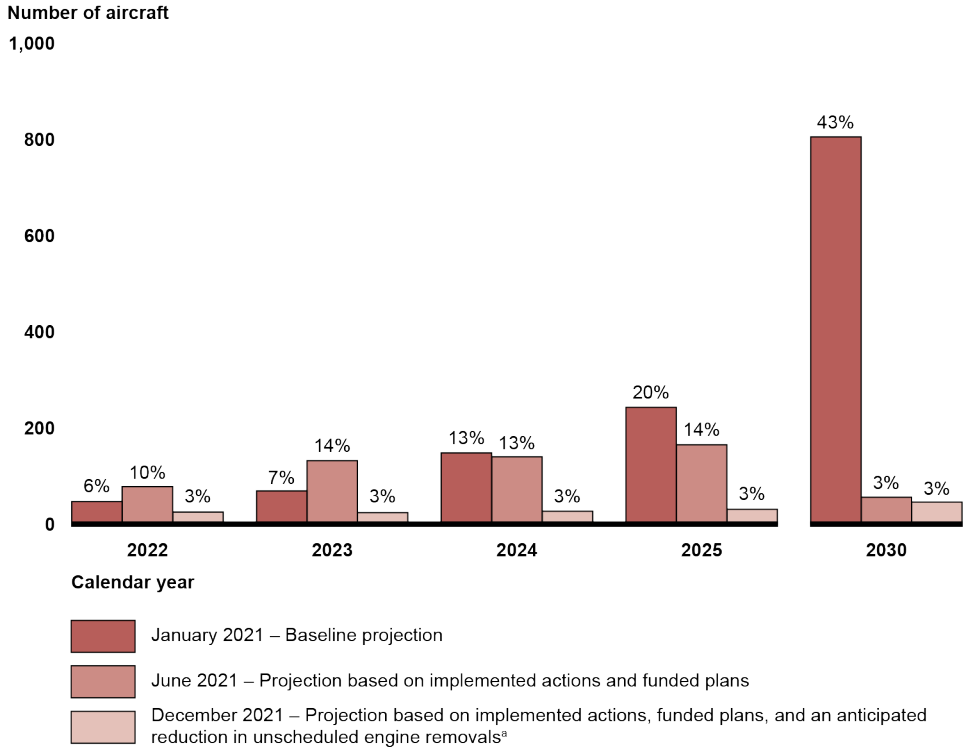
The F-35 Joint Program Office and Pratt & Whitney have other similar efforts underway for other parts of the engine, and plan to complete these actions in 2022. Collectively, the broadening of engineering limits for particular parts that have demonstrated longer durability could result in less field- and depot-level maintenance, and a decrease in the need to replace spare parts. According to Heavy Maintenance Center officials, expanding parts limits is part of the standard process for all engines, including the F119 engine that powers the F-22 Raptor. However, the F-35 Joint Program Office and Pratt & Whitney also must weigh these potential changes against any safety and long-term performance issues that could arise due to expanding such limits. Officials from the Heavy Maintenance Center said any changes would need to be made before the end of 2022 to mitigate potential shortages of spare parts necessary for planned depot maintenance in 2023.

DOD Efforts Have Improved Projections for Engine Availability, but Significant Risks Remain and DOD and Pratt & Whitney Disagree on Spare Parts Funding

DOD's implementation of its plans has resulted in improvement in its projected capacity to repair power modules and reduce the number of aircraft without operating engines over the course of the 2020s, as shown in figure 10. The F-35 Joint Program Office's June 2021 projections based on its actions and funded plans show improvements from the January 2021 baseline projections beginning in 2025—with a 6-percentage point decrease in F-35 aircraft without operating engines. Based on DOD's June 2021 projection, in 2030 the percentage of F-35 aircraft operating without an engine will have been reduced to 3 percentage points from the 43 percent it projected in January 2021. However, DOD's June 2021 projections are worse for 2022 and 2023. Specifically, DOD in January 2021 projected 6 percent of aircraft in 2022 and 7 percent of aircraft in 2023 being without operating engines;

however, in June 2021 these projections had worsened to 10 and 14 percent, respectively. As previously discussed, this is largely due to the F-35 engine repair network not having sufficient capacity to repair power modules at the quantities needed and the actions required to improve this capacity having long lead times, such as facilities expansion.

Figure 10: Projected Percentage of F-35 Aircraft without Operating Engines, 2022–2025 and 2030



Source: GAO analysis of DOD data. | GAO-22-104678

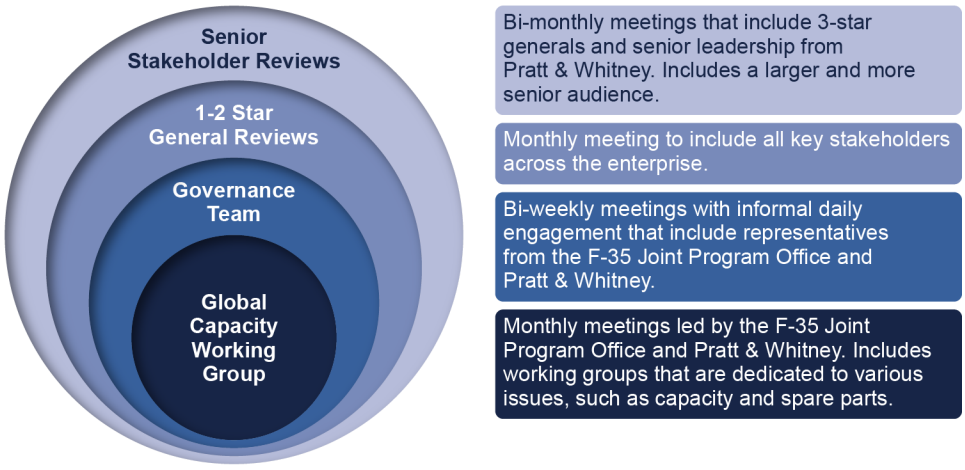
[a]This projection is based on the latest removal forecast (April–June 2021) for F-35 engines that was provided by Pratt & Whitney to the Department of Defense (DOD) and other factors, such as the projected repair capacity of depots.

With additional planned actions, the assumed approval of further funding for the expansion of the engine repair network and an expected reduction in demand for repairs, DOD's December 2021 projection shows substantially improved outcomes beginning in 2022 and flowing over the remainder of the 2020s—as shown in figure 10. This projection shows significant improvements in outcomes in 2022 and beyond with the percentage of F-35 aircraft without an operating engine hovering at 3 percent. In this projection, the F-35 Joint Program Office is assuming a

reduction in demand for power module repairs based on the successful implementation of their initiatives to keep engines on the aircraft longer and to improve the reliability of engine parts.

The F-35 Joint Program Office is working to implement its plans, develop and execute solutions to identified risks, and monitor the status of efforts. To implement its plans, monitor risks, and ensure mitigating actions to those risks, the F-35 Joint Program Office has developed a monitoring and oversight approach as shown in figure 11.

Figure 11: Oversight Mechanisms for Implementation of F-35 Engine Sustainment Corrective Action Plans



Source: GAO analysis of Department of Defense information. | GAO-22-104678

These oversight mechanisms do not ensure success, but they help the F-35 program to monitor actions and to make improvements as necessary. For example, the one- and two-star general review meetings are regularly attended by representatives of the Joint Program Office, the military services, the Office of the Secretary of Defense, Pratt & Whitney, and the Heavy Maintenance Center, among others. We observed the August 2021 meeting where the Joint Program Office briefed the participants on the status of the program and attendees were able to ask questions, engage in dialogue, and discuss solutions to ongoing challenges and risks.

However, our review of the F-35 Joint Program Office plans determined that these plans were highly dependent on assumptions about (1) the level of funding the F-35 Joint Program Office receives during the fiscal year 2023 and 2024 appropriations processes and (2) addressing risks

that could hinder implementation of its plans over the coming years. First, F-35 Joint Program Office and military service officials told us that its plans were highly dependent on receiving funding in the fiscal year 2023 and 2024 appropriations processes—with the exact amounts to be determined through the department's budget development process. According to DOD officials, the program requested additional funding for military construction to support depot expansion and purchasing more spare parts. To increase depot capacity faster, the F-35 Joint Program Office was seeking to adjust funding planned for military construction for the Navy Fleet Readiness Center Southeast in Jacksonville, FL, from fiscal year 2026 to fiscal year 2024. This would allow them to accelerate the number of power modules repaired in the mid- and late-2020s on an annual basis. Further, to support the repair of power modules across the enterprise at the expected levels in the 2020s, additional spare parts—specifically the piece parts used to repair and rebuild the engines in depot maintenance—are required and will be requested through the department's budget process in 2023, 2024, and 2025.

F-35 Joint Program Office officials stated that these additional funds will be necessary to avoid engine non-mission capable rates increasing to 20 percent in the next few years—over double the average rate of 8 percent in 2021. According to F-35 Joint Program Office officials, such a rate would severely limit F-35 operations and training conducted by the military services.

Second, DOD has identified several factors that could affect its ability to implement its plans, meet its milestones, and improve production outcomes for engine sustainment. These factors include:

- **Depot staffing:** Additional maintenance personnel will be needed to support increased capacity at existing and future depots. This requires the hiring of depot maintenance personnel to ensure that depots are operational and able to produce the expected quantities of repaired engine modules.
- **Technical training of organizational and depot maintenance personnel:** DOD will need to provide additional training to its current and future maintenance personnel to increase technician proficiency, reduce rework, and improve the efficiency of repair activities.
- **Depot facilities improvement:** As DOD expands repair capacity to additional depot locations, DOD must complete facility improvements to accommodate F-35 engine repairs. This requires military construction projects, such as those in Jacksonville, FL, to be

completed on-schedule. If not completed on-schedule, then this would delay DOD's ability to meet repair demands.

- **Support equipment at depots:** Adding additional depot capacity throughout the F-35 engine repair network and accelerating power module production at the Heavy Maintenance Center requires sufficient support equipment—equipment items that are required to support the operation and maintenance of the engine. Without sufficient support equipment at the depot repair facilities, repair processes are less efficient and the ability of DOD to meet repair demands may be at risk.
- **Spare parts availability:** Some of the spare parts used by the F-35 engine program to sustain and repair the engine require long lead times, meaning that they can take several years to produce. F-35 Joint Program Office and Pratt & Whitney officials emphasized the importance of ensuring that sufficient spare parts are available to support both the field and depot maintenance.

There is general agreement and alignment across the F-35 enterprise on how to address these issues with the exception of spare parts availability. In that past and through 2021, the F-35 Joint Program Office and Pratt & Whitney officials reported that generally there were sufficient spare parts to support field and depot maintenance activities. The F-35 Joint Program Office and Pratt & Whitney agreed that the program needs to purchase more spare parts to address the future demand for spare parts as the fleet grows and scheduled depot maintenance occurs at an increasing rate. The F-35 Joint Program Office and Pratt & Whitney have worked together to increase spare parts funding during the department's fiscal year 2023 budget deliberations. DOD had originally projected needing about $421 million in spare parts to support depot maintenance across fiscal years 2023 through 2025. However, based on its corrective action plans, DOD is working to increase that funding by $333 million to about $754 million across that timeframe.

However, according to Pratt & Whitney, the program continues to have a spare parts funding gap—such as line replaceable components and piece parts needed to repair the engine modules during depot maintenance—due to underfunding of spare parts prior to 2022. Specifically, Pratt & Whitney stated that this gap was over $400 million and that it will negatively affect the program in the future. DOD stated that this gap was about $170 million and officials were working to recover this $170 million in funding as part of the department's increase to spare parts funding for fiscal years 2023 through 2025.

This lack of agreement on the scope of future spare part shortfalls has been an issue within the program since at least 2019. According to Pratt & Whitney officials, they have raised the issue with DOD multiple times since 2019. We also observed in August 2021 when Pratt & Whitney officials raised this issue with F-35 Joint Program Office and military service officials in an engine sustainment review meeting. Officials of the F-35 Joint Program Office and Pratt & Whitney emphasized that they must order spare parts in advance to accommodate long production lead times—sometimes 2 to 3 years in advance because of the highly specialized manufacturing process to make F-35 parts.

Standards for Internal Control in the Federal Government states that management should use quality information to achieve the entity's objectives.[25] Further, a key component of best practices related to collaboration is a written agreement.[26] Specifically, organizations should articulate their agreements in formal documents to strengthen their commitment to working collaboratively and achieving objectives.

According to program officials, the F-35 Joint Program Office and Pratt & Whitney have been using different data inputs for the model to estimate future spare parts needs. This has resulted in insufficient funding to replenish the spare parts to an acceptable level.[27] As of August 2021, F-35 Joint Program Office officials stated that Pratt & Whitney's model was more accurate than they had originally recognized. F-35 Program Office and Pratt & Whitney officials stated that they have been in discussions around reconciling the differences and developing a shared model, but DOD has not ensured an agreement on a shared model with agreed-upon data inputs that would produce accurate information for planning and budgeting purposes.

If DOD does not ensure that the F-35 Joint Program Office and Pratt & Whitney collaborate and agree on and document a shared spare parts forecasting model and data inputs for that model, the department and the military services of the F-35 program will lack quality information for their decisions. In addition, without agreement on a shared model with agreed-

[25]GAO-14-704G.

[26]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

[27]According to Pratt & Whitney official, they have been projecting future spare parts costs using an F-35 specific model that they first developed in 2003 based on previous Pratt & Whitney modeling experience.

upon data inputs, the program is at risk of decreased readiness due to a lack of spare parts. Pratt & Whitney estimated that the lack of spare parts will begin to affect depot maintenance, causing about 251 engines to not be repaired as planned between 2024 and 2025. This would also likely increase depot maintenance backlogs for engine modules. Parts shortages would also affect organizational-level maintenance. According to Pratt & Whitney officials, shortfalls in line replaceable components will have a significant effect by 2025 on non-mission capable due to engine rates.

Conclusions

DOD has developed an overall strategy for sustaining the F-35 engine, but the strategy has not aligned with engine sustainment goals for other fighter aircraft and it is not aligned with the desired outcomes of the military services. DOD has not assessed the F-35 engine sustainment strategy and its overall goals, reached agreement on any needed changes to the strategy to meet desired outcomes, or documented those changes. Moreover, these decisions as well as potential implications associated with engine modernization will affect the costs necessary to sustain engines for the F-35. Without collaboration on an assessment of the F-35 engine sustainment strategy, its goals, and the actions to achieve those goals and agreement among the relevant parties on the way forward, the F-35 program will continue to fall short of desired performance outcomes and not meet the desired outcomes of the military services or national defense requirements.

Additionally, inadequate maintenance depot capacity leading to a shortage of operating power modules have grounded F-35s more often and for longer time periods than expected. DOD has begun to address the challenges, but expects mitigation to take years. DOD's efforts to sustain the F-35 engine will likely be confronted with continuing challenges—some currently known and others not known—that will require additional attention and resources to resolve. Continued attention from the F-35 Joint Program Office, military services, and Pratt & Whitney management will be critical to implementing the department's plans and overcoming risks and challenges to improving F-35 engine sustainment.

One unresolved issue is DOD's program office and the contractor using different forecasting models to plan adequate supplies of parts and funding to meet maintenance goals. DOD has not ensured an agreement on a forecasting model that would produce accurate information for planning and budgeting purposes. If DOD could ensure that the relevant DOD and Pratt & Whitney officials collaborated and agreed on a joint model for spare parts forecasting and then documented their agreement,

the department and military services could better ensure they have the quality information needed to make decisions about quantities of spare engine parts and required funding. The ongoing differences in spare parts forecasting creates risks for the program as it seeks to balance readiness needs and competing funding requirements.

Recommendations for Executive Action

We are making the following two recommendations to the Secretary of Defense:

The Secretary of Defense should ensure that the F-35 Joint Program Office, in collaboration with the military services, assesses and updates the F-35 engine sustainment strategy, including its goals and the necessary actions to achieve its goals—such as the required number of spare engines and modules and the levels of maintenance and capacity needed to repair the modules. The assessment and any corresponding decisions and actions should be documented and take into consideration engine sustainment costs and modernization plans. (Recommendation 1)

The Secretary of Defense should ensure that the F-35 Joint Program Office collaborates with the military services and Pratt & Whitney on developing a shared model for spare part forecasts, reaches agreement with the military services and Pratt & Whitney on a model for spare parts forecasting, and documents that agreement to ensure common understanding of the model. (Recommendation 2)

Agency Comments

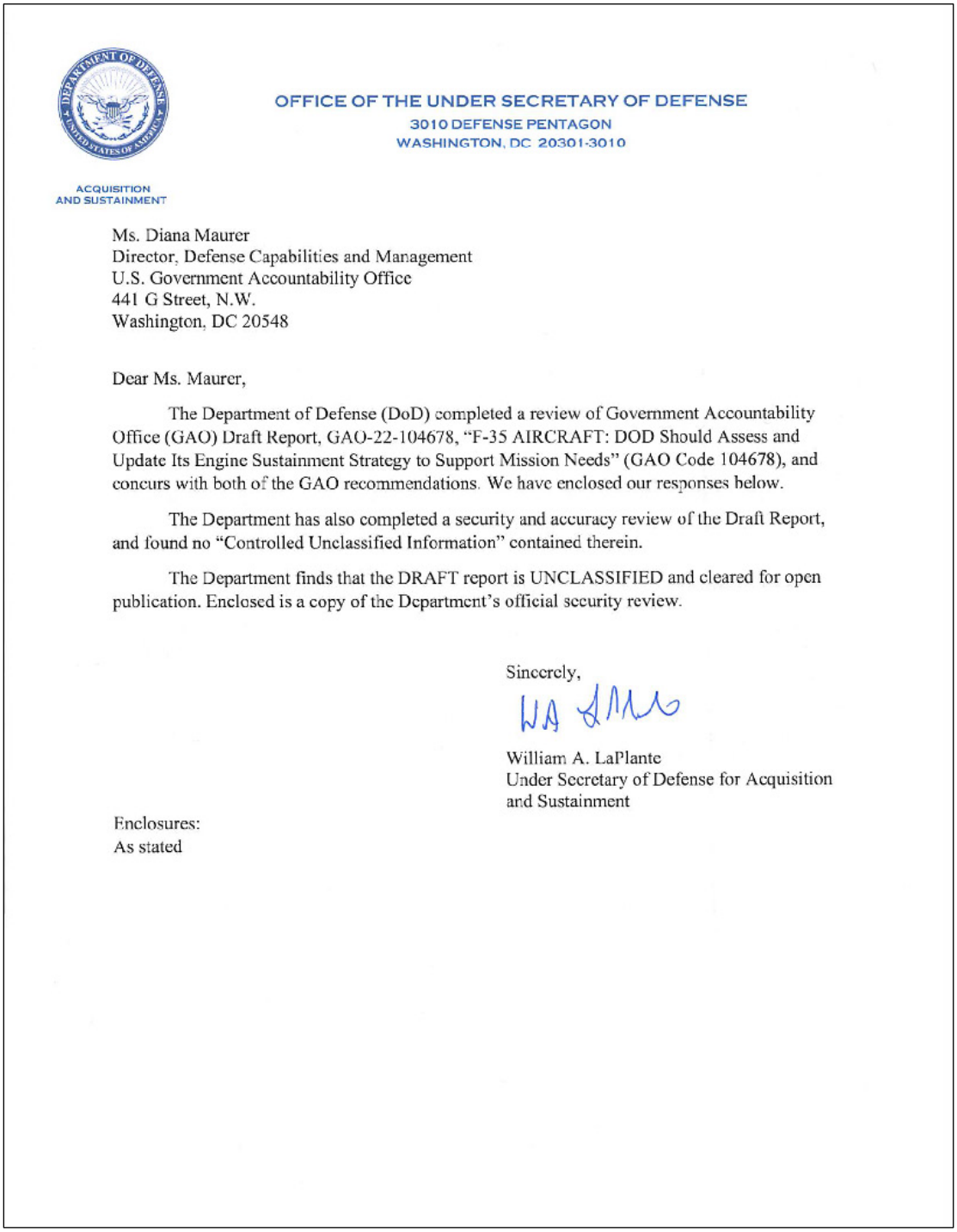
We provided a draft of this report to DOD for review and comment. In its written comments, reproduced in appendix I, DOD concurred with our recommendations. In addition, DOD provided technical comments, which we incorporated as appropriate.

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 F-35 Joint Program Office; the Secretaries of the Air Force and Navy; and the Commandant of the Marine Corps. In addition, the report is available at no charge on the GAO website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-9627 or maurerd@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Staff members making key contributions to this report are listed in appendix II.

Diana Maurer
Director, Defense Capabilities and Management

Appendix I: Comments from the Department of Defense



OFFICE OF THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION
AND SUSTAINMENT

Ms. Diana Maurer
Director, Defense Capabilities and Management
U.S. Government Accountability Office
441 G Street, N.W.
Washington, DC 20548

Dear Ms. Maurer,

The Department of Defense (DoD) completed a review of Government Accountability Office (GAO) Draft Report, GAO-22-104678, "F-35 AIRCRAFT: DOD Should Assess and Update Its Engine Sustainment Strategy to Support Mission Needs" (GAO Code 104678), and concurs with both of the GAO recommendations. We have enclosed our responses below.

The Department has also completed a security and accuracy review of the Draft Report, and found no "Controlled Unclassified Information" contained therein.

The Department finds that the DRAFT report is UNCLASSIFIED and cleared for open publication. Enclosed is a copy of the Department's official security review.

Sincerely,

WA LaPlante

William A. LaPlante
Under Secretary of Defense for Acquisition and Sustainment

Enclosures:
As stated

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION
AND SUSTAINMENT

GAO-22-104678

"F-35 AIRCRAFT: DOD Should Assess and Update Its Engine Sustainment Strategy to Support Mission Needs"

Departmental Comments to the GAO Recommendations

RECOMMENDATION 1: The Secretary of Defense should ensure that the F-35 Joint Program Office, in collaboration with the military services, assesses and updates the F-35 engine sustainment strategy, including its goals and the necessary actions to achieve its goals—such as the required number of spare engines and modules and the levels of maintenance and capacity needed to repair the modules. The assessment and any corresponding decisions and actions should be documented and take into consideration engine sustainment costs and modernization plans.

DoD RESPONSE: Concur

The Department concurs and has already begun reviewing and revising a new propulsion sustainment strategy. The Department will continue to revise the strategy, as appropriate, as the program evolves.

RECOMMENDATION 2: The Secretary of Defense should ensure that the F-35 Joint Program Office collaborates with the military services and Pratt & Whitney on developing a shared model for spare part forecasts, reaches agreement with the military services and Pratt & Whitney on a model for spare parts forecasting, and documents that agreement to ensure common understanding of the model.

DoD RESPONSE: Concur

The Department concurs with GAO's recommendation to ensure that the F-35 Joint Program Office (JPO) collaborates with the military services and Pratt & Whitney on developing a shared model for spare parts forecasts.

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

Diana Maurer at (202) 512-9627 or maurerd@gao.gov.

Staff Acknowledgments

In addition to the contact listed above, John Bumgarner (Assistant Director), Leslie Bharadwaja, Vincent Buquicchio, Jeff Cirillo, Christopher Gezon, Richard Powelson, Michael Silver, and Tina Torabi made key contributions to this report.

Related GAO Products

F-35 Sustainment: DOD Faces Several Uncertainties and Has Not Met Key Objectives. GAO-22-105995. Washington, D.C.: April 28, 2022.

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.

F-35 Sustainment: DOD Needs to Cut Billions in Estimated Costs to Achieve Affordability. GAO-21-439. Washington, D.C.: July 7, 2021.

F-35 Sustainment: Enhanced Attention to and Oversight of F-35 Affordability Are Needed. GAO-21-505T. Washington, D.C.: April 22, 2021.

F-35 Joint Strike Fighter: DOD Needs to Update Modernization Schedule and Improve Data on Software Development. GAO-21-226. Washington, D.C.: March 18, 2021.

F-35 Sustainment: DOD Needs to Address Key Uncertainties as It Re-Designs the Aircraft's Logistics System. GAO-20-665T. Washington, D.C.: July 22, 2020.

Weapon System Sustainment: DOD Needs a Strategy for Re-Designing the F-35's Central Logistics System. GAO-20-316. Washington, D.C.: March 6, 2020.

*F-35 Aircraft Sustainment: DOD Faces Challenges in Sustaining a Growing Flee*t. GAO-20-234T. Washington, D.C.: November 13, 2019.

Space Command and Control: Comprehensive Planning and Oversight Could Help DOD Acquire Critical Capabilities and Address Challenges. GAO-20-146. Washington, D.C.: October 30, 2019.

F-35 Joint Strike Fighter: Action Needed to Improve Reliability and Prepare for Modernization Efforts. GAO-19-341. Washington, D.C.: April 29, 2019.

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Cloud Computing: Agencies Have Increased Usage and Realized Benefits, but Cost and Savings Data Need to Be Better Tracked. GAO-19-58. Washington, D.C.: April 4, 2019.

DOD Space Acquisitions: Including Users Early and Often in Software Development Could Benefit Programs. GAO-19-136. Washington, D.C.: March 18, 2019.

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F-35 Joint Strike Fighter: Assessment Needed to Address Affordability Challenges. GAO-15-364. Washington, D.C.: April 14, 2015.

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