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CBO

# The Depot-Level Maintenance of DoD's Combat Aircraft: Insights for the F-35

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# Notes

Unless otherwise indicated, the years referred to in this report are federal fiscal years, which run from October 1 to September 30 and are designated by the calendar year in which they end.

All dollar values are expressed in 2017 dollars.

The photograph on the cover shows an F-35A taking off from Hill Air Force Base, Utah (Alex R. Lloyd, courtesy of the U.S. Air Force).

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# The Depot-Level Maintenance of DoD's Combat Aircraft: Insights for the F-35


## Summary

Intended to replace older models of aircraft used by the U.S. Air Force, Navy, and Marine Corps, the F-35 is a fighter aircraft with stealth capabilities that reduce the chance of detection by radar and heat-seeking missiles. The Department of Defense (DoD) plans to spend almost $350 billion (in fiscal year 2017 dollars) from 1994 through 2044 to develop and procure F-35s. The department expects to spend almost twice as much to operate and support the aircraft over their lifetimes; a sizable portion of that spending will go toward the aircraft's depot-level maintenance. This report examines the depot-level maintenance experiences of aging combat aircraft currently in use by DoD and provides insights for the Congress and DoD to consider as the F-35 fleet enters service.

The depot-level maintenance of aircraft consists of in-depth maintenance that is beyond the capability of maintenance staff at aircraft's operating locations—for example, disassembly, inspection, repair, rebuilding, repainting, and flight testing. Whereas aircraft receive maintenance at their operating locations throughout their service lives, depot-level maintenance is provided only intermittently.

Depot-level maintenance can be costly and time-consuming, and aircraft are unavailable to operators while the maintenance occurs. Nevertheless, adequate depot-level maintenance is essential to ensuring an aircraft's safe operation and capability to perform missions. The extent of such maintenance can also influence whether an aircraft's life can be extended cost-effectively.

Funding for depot-level maintenance is provided by the Congress through operation and maintenance (O&M) appropriations, as well as through procurement appropriations for aircraft modification programs. Should the decision be made to replace, rather than continue to maintain, an existing system, the Congress would also provide appropriations for the replacement.

Different approaches to depot-level maintenance have been used for different combat aircraft, and outcomes have differed among those aircraft as they have aged. Those prior experiences can inform decisions about F-35s' depot-level maintenance, which will have long-term implications for the costs, availability, and longevity of the F-35 fleet. This report focuses on depot-level maintenance practices for the Air Force's F-15, F-16, and A-10 combat aircraft as well as the Navy's F/A-18 fighter aircraft as sources of insights for the F-35. Experience with those aircraft suggests that adequate depot-level maintenance throughout the F-35's life should enhance the aircraft's performance as it ages and make extending its service life more feasible.


### How Has DoD Provided Depot-Level Maintenance for Combat Aircraft?

DoD takes varying approaches to scheduling depot-level maintenance. Generally, such maintenance is calendar-based (for example, occurring once every six years) or modification-based (for example, accomplished in conjunction with the fleetwide installation of an upgrade).

The Air Force's F-15s receive a type of calendar-based maintenance called programmed depot maintenance (PDM). Under that system, the aircraft undergo depot-level maintenance on a regular basis, typically after each 61 to 72 months of operation. The Navy also uses a calendar-based system, called planned maintenance intervals, for its F/A-18 fighter aircraft.

Air Force F-16 fighter aircraft, by contrast, have received depot-level maintenance that is governed by orders for modifications or repairs. The F-16 program office coordinates with major commands to identify necessary modifications and repairs and plans the aircraft's visits to depots accordingly. F-16s' depot visits have been scheduled more irregularly, but also more frequently, than F-15s'.

The Air Force's A-10 aircraft do not receive calendar-based or modification-based maintenance. Instead, A-10s follow a system known as risk-based scheduling, under which they visit depots on the basis of flying hours, with adjustments to account for stress to the airframe incurred during their missions.

### How Have Different Combat Aircraft Performed As They Have Aged?

As the four types of combat aircraft have aged, they have all experienced declines in the percentage of their fleets that is available to operators and capable of performing missions. All four fleets have also experienced declines in annual flight hours per aircraft. Those declines have been particularly severe in recent years for older models (C/D variants) of the Navy's F/A-18.

The F/A-18C/D fleet's recent decreases in availability have resulted from lengthy depot-level maintenance on many of the aircraft. The Congressional Budget Office's analysis suggests that the increased maintenance currently required by the aircraft may be attributable to a relative lack of depot-level maintenance earlier in their service lives. In the 1990s, F/A-18C/Ds received less O&M funding per flying hour and spent fewer hours in depot-level maintenance per flying hour than did the A-10s, F-15C/Ds, or F-16C/Ds.

### What Are the Implications for the F-35's Depot-Level Maintenance?

In recent years, F-15C/Ds (using PDM) and F-16C/Ds (using modification-based maintenance) have had higher availability rates than F/A-18C/Ds. This suggests that either approach could be successful for the F-35.

How much depot-level maintenance aircraft receive may be more important than how that maintenance is scheduled. The F/A-18C/D appears to have been undermaintained, and the Navy has had difficulty extending its service life. By contrast, the Air Force has been able to extend the life spans of its F-15 and F-16 fleets with smaller declines in their availability. Those observations suggest that sufficient depot-level maintenance throughout the F-35's life should improve the aircraft's performance as it ages and make extending its life span easier—which could delay the need to procure a replacement aircraft, resulting in long-term cost savings. However, increased depot-level maintenance would require greater O&M funding throughout the F-35's life.

## Background on the F-35 Program and Its Estimated Costs

As DoD's newest fighter aircraft, the F-35 will replace several older aircraft used by the Air Force, Navy, and Marine Corps. The costs of operating the F-35 over the course of its service life are anticipated to be about twice the costs of acquiring it. The amount of resources that are devoted to the F-35's depot-level maintenance will have important long-term ramifications for the aircraft's life span and operating costs.

### The F-35 Program

The F-35 is termed a fifth-generation fighter aircraft because it has capabilities not found in fourth-generation fighter aircraft such as the Air Force's F-15 and F-16 and the Navy's F/A-18—most notably, stealth capabilities that reduce the chance of detection by radar and heat-seeking missiles. Lockheed Martin is the F-35's prime contractor, and Pratt & Whitney manufactures the F135 engine used on the aircraft.[1]

There are three F-35 variants:

- The F-35A, operated by the Air Force, will replace the Air Force's A-10 ground-attack aircraft and older models (the C/D variants) of the F-16. Like those aircraft, it flies from land-based airfields.
- The F-35B, operated by the Marine Corps, will replace the Marine Corps' AV-8B ground-attack aircraft. Like the AV-8B, it is designed to vertically take off from and land on the short decks of amphibious assault ships and locations on land without a runway.
- The F-35C, operated by the Navy, will replace the C/D variants of the Navy's F/A-18. Like the F/A-18, it has structural enhancements that allow it to take off from and land on aircraft carriers, including a retractable tailhook, which is designed to snag on cables to slow the plane during landing. The Marine Corps also plans to procure a limited number of F-35Cs.

1. DoD originally planned to have General Electric develop a second, alternative engine to compete with the Pratt & Whitney F135 engine, but the department ultimately dropped those plans, citing concerns about costs. See, for instance, Government Accountability Office, *Joint Strike Fighter: Assessment of DOD's Funding Projection for the F136 Alternate Engine*, GAO-10-1020R (September 15, 2010), www.gao.gov/products/GAO-10-1020R.

### Projected Life-Cycle Costs for the F-35

DoD plans to eventually acquire 2,470 F-35 aircraft. The F-35 program's December 2016 Selected Acquisition Report (SAR)—a summary of projected development schedules, purchase quantities, and costs provided to the Congress—indicates that it will incur an estimated $64 billion in research, development, test, and evaluation (RDT&E) costs, $281 billion in procurement costs, and $4 billion in construction costs.[2] RDT&E funding commenced in 1994 and is projected to continue through 2022; procurement funding commenced in 2006 and is projected to continue through 2044.

Additionally, assuming that the aircraft will have a 30-year service life as planned, the SAR indicates that the program will incur $669 billion in life-cycle operating and support costs—nearly double the sum of the program's RDT&E and procurement costs. Experience with other combat aircraft suggests that depot-level maintenance costs will account for a sizable portion of the $669 billion total, which also includes the costs of other types of maintenance, consumable parts, and fuel.

There is a substantial literature discussing the F-35's acquisition and procurement.[3] This report focuses instead on issues related to depot-level maintenance for the aircraft over its stipulated 30-year life—or longer, if DoD chooses to extend its life.[4] That prospect seems likely, given that since the Second World War, the service lives of DoD aircraft have been extended for ever-longer periods.

### The Trade-Off in Depot-Level Maintenance

DoD's decisionmakers face a trade-off in setting the frequency and intensity of depot-level maintenance. Such maintenance is costly, not only because of its expense but also because aircraft in depots are not available to military commanders. But depot-level maintenance also provides a benefit: Aircraft that receive depot-level maintenance more regularly can be expected to operate safely and capably further into the future. Extending an aircraft's life span is more feasible and less costly if that aircraft has been better maintained.

In general, the longer DoD plans to continue using an aircraft, the more it invests in the aircraft's depot-level maintenance. If, for instance, an aircraft was scheduled to be replaced within the next year or two, DoD would be unlikely to incur the short-run costs of depot-level maintenance (beyond maintaining the aircraft to the extent required for it to be operated safely to the end of its life). By contrast, DoD would be more willing to invest in an aircraft that it anticipated operating for many years to come.

The amount of funding available for such maintenance is determined by the Congress. Depot-level maintenance is funded through O&M appropriations as well as through procurement appropriations for aircraft modification programs. The Congress must also provide RDT&E and procurement appropriations for a replacement system if the decision is made to replace, rather than continue to maintain, an existing system. Additionally, the Congress sets policies about what type of work is performed and how much of it is carried out by government-operated depots versus contractor-operated depots such as those overseas. As in other realms of defense policy, the Congress can request information from DoD and program office personnel about how F-35 maintenance plans are to be implemented over time.

2. The F-35 program's SAR presents costs in constant fiscal year 2012 dollars. CBO converted all dollar values in this report to fiscal year 2017 values using the Bureau of Economic Analysis's gross domestic product deflator.

3. See, for instance, Jeremiah Gertler, *F-35 Joint Strike Fighter (JSF) Program*, Congressional Research Service, RL 30563 (July 18, 2016); Government Accountability Office, *F-35 Joint Strike Fighter: Development of New Capabilities Requires Continued Oversight*, GAO-16-634T (April 26, 2016), www.gao.gov/products/GAO-16-634T; statement of Frank Kendall, Under Secretary of Defense, Acquisition, Technology, and Logistics, and Lt. General Christopher C. Bogdan, Program Executive Officer, F-35, before the Senate Armed Services Committee on F-35 Lightning II Program Review (April 26, 2016), https://go.usa.gov/xnpQ4 (PDF, 242 KB); statement by J. Michael Gilmore, Director, Operational Test and Evaluation, Office of the Secretary of Defense, before the Senate Armed Services Committee (April 26, 2016), https://go.usa.gov/xnpQY (PDF, 288 KB); and Government Accountability Office, *F-35 Joint Strike Fighter: Problems Completing Software Testing May Hinder Delivery of Expected Warfighting Capabilities*, GAO-14-322 (March 24, 2014), www.gao.gov/products/GAO-14-322.

4. Government Accountability Office, *Defense Management: DOD Needs to Monitor and Assess Corrective Actions Resulting from Its Corrosion Study of the F-35 Joint Strike Fighter*, GAO-11-171R (December 16, 2010), www.gao.gov/products/GAO-11-171R.

**Table 1.**

**Fighter Aircraft Depots**

| Name | Location | Role |
|---|---|---|
| | **U.S. Depots for F-35 Aircraft** | |
| Ogden ALC | Ogden, Utah | Lead depot for F-35As and F-35Cs (also lead Air Force depot for A-10s, F-16s, and F-22s) |
| FRC East | Cherry Point, North Carolina | Lead depot for F-35Bs |
| Oklahoma City ALC | Oklahoma City, Oklahoma | Lead depot for the F-35's F135 engine |
| | **International Depots for F-35 Aircraft** | |
| Cameri Air Base | Cameri, Italy | Depot for all three F-35 variants |
| Royal Australian Air Force Base Williamtown | Williamtown, Australia | Depot for all three F-35 variants |
| Nagoya Aerospace Systems Works Komaki Minami Plant | Nagoya, Japan | F-35A depot |
| Marine Corps Air Station Iwakuni | Iwakuni, Japan | F-35B and F-35C depot |
| | **U.S. Depots for Other Fighter Aircraft** | |
| Warner Robins ALC | Warner Robins, Georgia | Lead Air Force depot for F-15s |
| FRC Southeast | Jacksonville, Florida | Navy depot for F/A-18A–Ds |
| FRC West | San Diego, California | Navy depot for F/A-18A–Ds |
| | **International Depots for Other Fighter Aircraft** | |
| Kimhae Air Base | Kimhae, South Korea | Korean Air–operated depot for A-10s, F-15s, and F-16s based in Japan and South Korea |
| SABCA Charleroi | Charleroi, Belgium | Contractor-operated depot for F-16s based in Europe |

Source: Congressional Budget Office.

ALC = air logistics complex; FRC = fleet readiness center; SABCA = Société Anonyme Belge de Constructions Aéronautiques.

## Approaches to Aircraft Depot-Level Maintenance

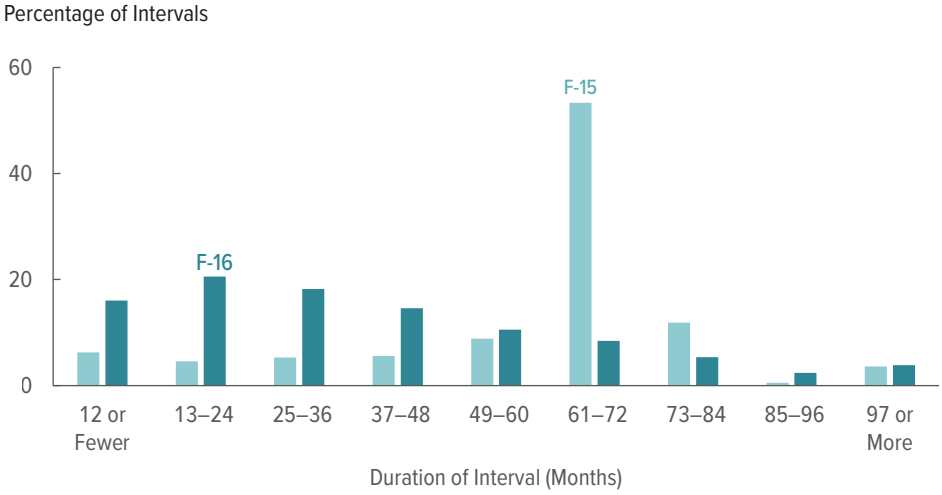
All aircraft require maintenance. Some maintenance occurs at the flight line where the aircraft operate, including on ships. Maintenance personnel at flight lines remove inoperative parts and replace them with new or repaired parts. But when more in-depth maintenance is needed—for instance, when an aircraft must be disassembled—flight-line maintenance personnel may lack the training or skills required to carry it out, or the flight line may lack the requisite equipment or space. In such cases, aircraft receive maintenance at depots—large, technologically advanced industrial facilities staffed predominately by civilians.[5] (Table 1 lists depots that work on the F-35 and other aircraft discussed in this report.)

For different types of aircraft, DoD employs different approaches to depot-level maintenance, each of which might inform the department's decisions about depot-level maintenance for the F-35. Those approaches vary on a number of dimensions—including how depot visits are scheduled, what role manufacturers play in aircraft's depot-level maintenance, and whether aircraft are maintained at foreign depots.

5. Depots also repair parts that are removed and replaced by maintenance personnel at the flight line. This report focuses on aircraft and engine depot-level maintenance, not depot-level parts repair.

Figure 1.

**Intervals Between Depot Visits for Air Force F-15s and F-16s, 1990 to 2017**




Intervals between F-16s' depot visits have varied widely; by contrast, the majority of F-15s have returned to depots after 61 to 72 months of operation.

Source: Congressional Budget Office, using data from the Department of Defense.

### Schedules for Maintenance Visits

Maintenance can occur on a scheduled or an unscheduled basis. Surprises can affect the timeline of scheduled maintenance—for instance, an unanticipated problem discovered in the course of a planned inspection might require a repair—but the timing of the aircraft's arrival at the depot is planned in advance. Unscheduled depot-level maintenance, by contrast, is required when an aircraft is damaged or shows abnormal wear and tear. Because unscheduled repairs fall outside of depots' regular, more routinized processes (and are comparatively infrequent), this report focuses on scheduled maintenance.

For DoD's aircraft, there are two primary types of scheduled depot-level maintenance: calendar-based PDM and modification-based depot-level maintenance. Aircraft that undergo calendar-based PDM are scheduled to return to a depot at regular intervals—for example, once every six years in the case of F-15s. PDM can also be based on flying hours, such that aircraft are scheduled to return to a depot after they hit specific flying-hour thresholds. If all of the aircraft in a fleet fly the same number of hours each month, this approach is equivalent to calendar-based PDM.

By contrast, modification-based maintenance occurs when a military service orders a modification or identifies a necessary repair. In either instance, the operators coordinate with the program office to schedule depot visits for the aircraft. Fleetwide modification programs are established irregularly, on the basis of technical innovation, military necessity, and available funding. For example, in the mid-2000s, F-16s underwent modifications as part of the Falcon Structural Augmentation Roadmap (Falcon STAR) program, in which 13 of the F-16s' structural components were replaced or repaired to compensate for stress-related damage to the airframe and extend the aircraft's life.[6] Individual aircraft can be scheduled to receive modifications on the basis of factors such as deployment schedules and the aircraft's availability and condition—a different approach from the "furthest from last visit" algorithm associated with calendar-based PDM.

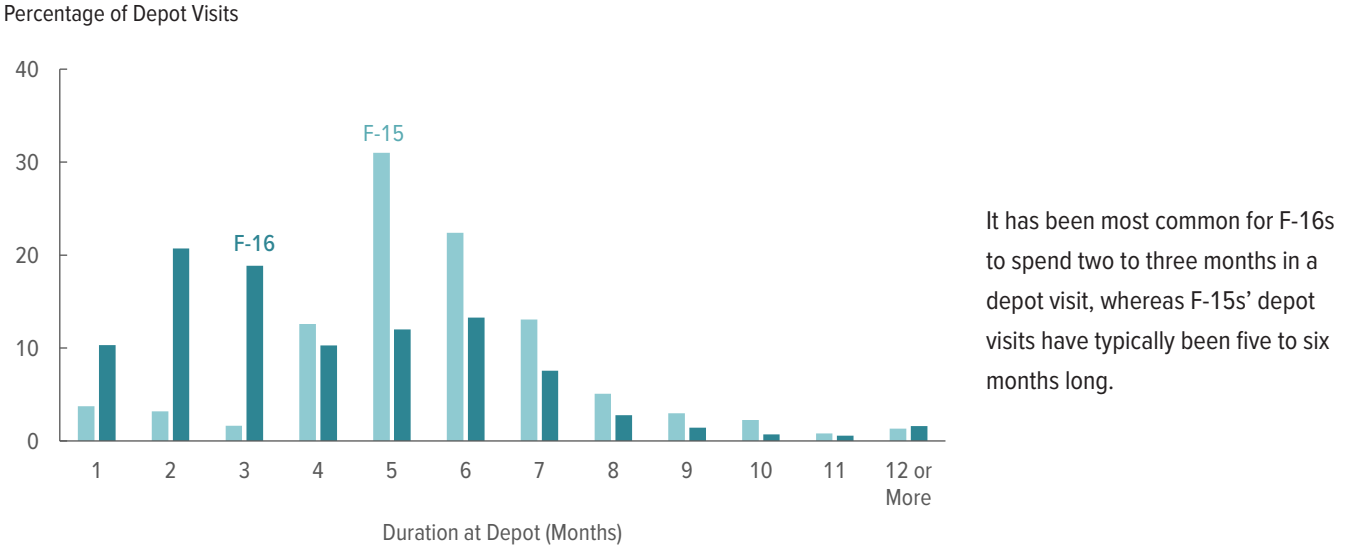
Regardless of how a fleet's depot-level maintenance is scheduled, engineers continually reevaluate depot scheduling plans on the basis of a given aircraft's condition, both at the flight line and upon its arrival at a depot. They determine the feasibility of extending or reducing maintenance and inspection intervals without sacrificing safety or reliability.[7]

6. U.S. Air Force, "Ogden Center Delivers First Falcon STAR F-16" (press release, February 10, 2004), https://tinyurl.com/yb3nomvl.

7. See Secretary of the Air Force, *Depot Maintenance of Aerospace Vehicles and Training Equipment*, Technical Manual TO 00-25-4 (April 30, 2016), pp. 1–7, https://tinyurl.com/y969uarc (PDF, 788 KB).

Figure 2.

**Durations of Completed Depot Visits for Air Force F-15s and F-16s, 1990 to 2017**




Source: Congressional Budget Office, using data from the Department of Defense.

### The Role of the Original Equipment Manufacturer

The role of the aircraft's (or engine's) manufacturer in depot-level maintenance varies, but every aircraft manufacturer (or its successor corporation, if the original one is no longer in business) has some ongoing role in that aircraft's depot-level maintenance. At a minimum, manufacturers serve as repositories of detailed knowledge about the aircraft. For instance, Boeing and Lockheed Martin are contracted to serve as sources of technical expertise on the F-15 and F/A-18 and on the F-16, respectively.

For the F-22, Lockheed Martin advises the federal civilians who perform depot-level maintenance at the Ogden Air Logistics Complex (ALC) and manages the procurement of parts for the aircraft.[8] The manufacturer bills the Air Force for its work in that role and compensates the depot for labor. Lockheed Martin is responsible for ensuring that the number of F-22s required by DoD is available.

By contrast, the A-10's manufacturer, the Fairchild Republic Company, has been out of business since the 1980s. Northrop Grumman bought the rights to data, such as repair instructions, from the company and continues to support the maintenance of the A-10 through the Air Force's Structural Integrity Program, which establishes requirements for and evaluates the structural integrity of aircraft and provides information on the aircraft's development, maintenance, and costs.[9]

A manufacturer's role in maintenance may extend beyond an aircraft's physical structure to its embedded software. For example, Lockheed Martin maintains and updates the software used on the F-22. By contrast, the software on the F-16 is maintained by federal civilians at the Ogden ALC.

### The Use of Overseas Depots

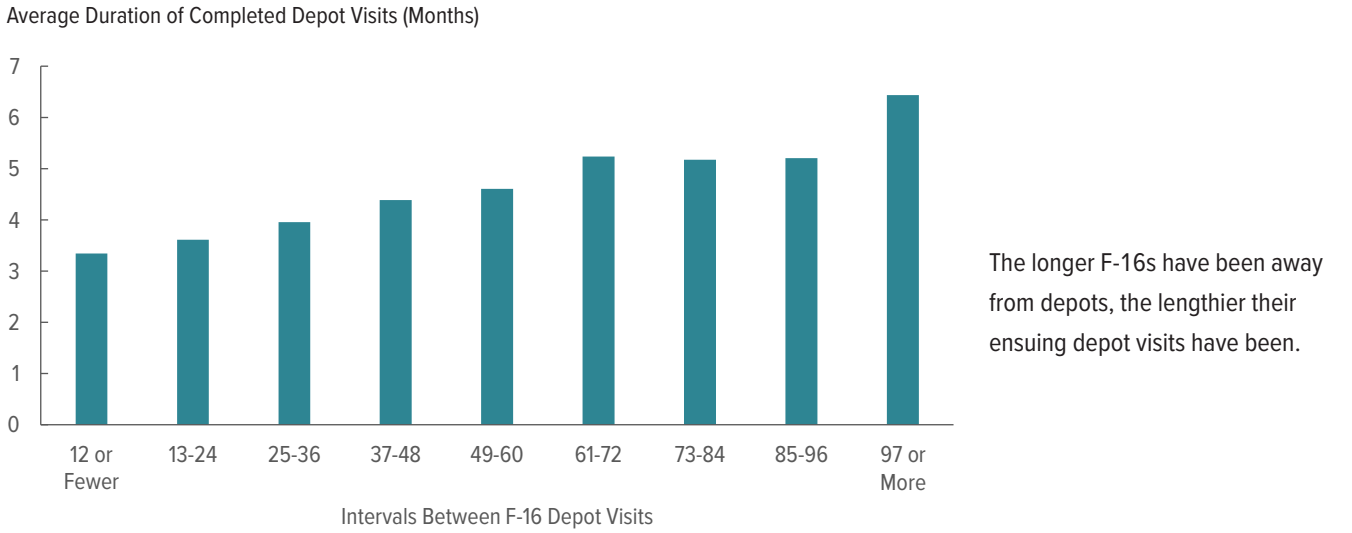
The use of overseas, foreign-operated depots also varies among DoD's combat aircraft. The Korean Air–operated Kimhae depot provides maintenance for A-10s, F-15s, and F-16s based in Japan and Korea, and the contractor-operated Charleroi depot maintains Europe-based F-16s. By using those depots, DoD can avoid costly and time-consuming transoceanic flights for depot-level maintenance. The F-22, by contrast, has received depot-level maintenance only in the United States (initially at a Lockheed Martin facility in Palmdale, California, and then

8. For more details on the responsibilities of companies such as Lockheed Martin in what is termed a product support integrator role, see Department of Defense, *Product Support Manager Guidebook* (April 2016), https://go.usa.gov/xndWY.

9. See Northrop Grumman, "A-10 Thunderbolt II" (accessed January 12, 2018), https://tinyurl.com/ybtwgvuz.

Figure 3.

**The Relationship Between F-16s' Depot Visit Intervals and Depot Visit Durations, 1990 to 2017**




Source: Congressional Budget Office, using data from the Department of Defense.

at the Ogden ALC after that depot upgraded its facilities and trained its workers to maintain the aircraft).

## Depot-Level Maintenance Practices for Selected Combat Aircraft

CBO examined the approaches to scheduling maintenance for the Air Force's F-15s, F-16s, and A-10s and the Navy's F/A-18 A–D variants, known as legacy Hornets.[10] Each approach represents a possible paradigm for the F-35's depot-level maintenance.

### F-15s' Calendar-Based Programmed Depot Maintenance

The Air Force's F-15s are intended to be on a six-year PDM cycle—that is, individual aircraft are scheduled to return to either the Warner Robins ALC or Kimhae Air Base for maintenance every six years. The Air Force has largely kept to that schedule (see Figure 1 on page 5). Since 1990, the most common interval between depot visits has been between 61 and 72 months. F-15s have sometimes returned to a depot earlier, presumably because of unanticipated events outside of the PDM schedule.

From 1990 through 2017, F-15s' visits to depots have most often been five to six months long (see Figure 2). However, the F-15C/D was put into a rewiring program from 2009 through 2016 that lengthened its PDM visits.

### F-16s' Modification-Based Depot-Level Maintenance

Air Force F-16s receive depot-level maintenance during scheduled modifications, and the intervals between their visits to Ogden, Kimhae, and Charleroi have varied considerably (see Figure 1 on page 5). Most frequently, individual F-16 aircraft have returned to a depot approximately every two years, but it has not been uncommon for specific aircraft to go five or six years without visiting a depot, similar to F-15s under the PDM system.

Although the duration of depot-level maintenance for specific F-16 aircraft can vary widely, depending on the modifications and repairs that are scheduled, from 1990 through 2017, F-16s spent less time per visit at depots (typically two to three months) than F-15s did (see Figure 2). In general, because F-16s receive depot-level maintenance more often than F-15s, they need less work during each depot visit, and their visits are consequently shorter. Depot stays have been longer for F-16s with longer intervals between visits (see Figure 3).

### A-10s' Risk-Based Scheduled Depot-Level Maintenance

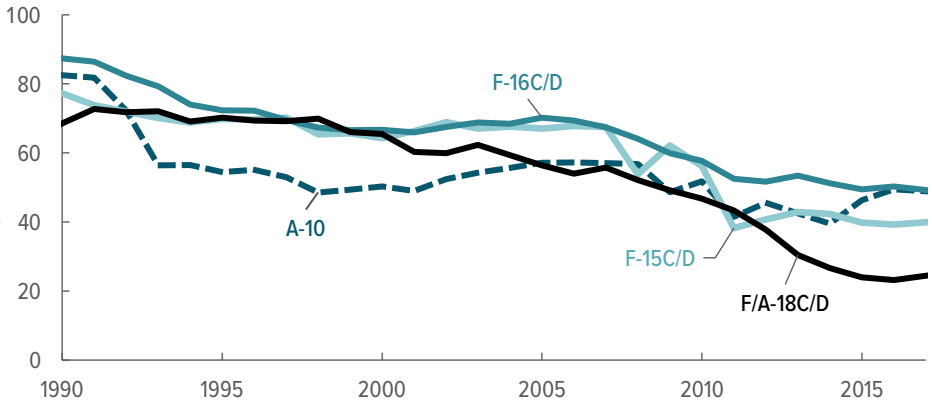
The Air Force's A-10s follow what is known as risk-based scheduling, visiting Ogden or Kimhae on the basis of flying hours and a severity factor (a metric used to quantify

10. The newer F/A-18E/F variant aircraft, not discussed here, are referred to as Super Hornets.

Figure 4.

**Annual Operator-Possessed and Mission-Capable Rate for Selected Combat Aircraft, 1990 to 2017**

Percentage of Aircraft Available




The availability of aircraft in all four fleets has declined, but that decline has been most acute for F/A-18C/Ds in recent years.

Source: Congressional Budget Office, using data from the Department of Defense.

stress to the airframe incurred during an aircraft's missions). Under that system, intervals between depot visits range from approximately 1,500 to 3,000 flying hours. On average, A-10s receive depot-level maintenance every 2,750 flying hours, although A-10s with more annual flying hours, including active-duty A-10s, typically undergo depot-level maintenance more frequently.

In the 1990s, A-10s did not receive regularly scheduled depot-level maintenance. Instead, depot-level maintenance for the aircraft was driven by intermittent orders for modifications and maintenance. In the late 1990s, A-10 maintenance personnel started to see damage in the wings, but formally scheduled depot inspections and repairs did not start until the early 2000s. That maintenance increased beginning in 2008, when the Air Force implemented a program requiring regular structural inspections.

### Legacy Hornets' Planned Maintenance Intervals

Under the planned maintenance interval system, the Navy's legacy Hornets undergo two alternating sets of maintenance activities, labeled PMI-1 and PMI-2, on a recurring calendar basis (every six years for shore-based legacy Hornets and every four years for aircraft carrier–based legacy Hornets).[11] PMI-1 depot visits are similar to F-15s' depot visits under the PDM system, consisting of an extensive set of disassembly, inspection, and repair tasks conducted at a maintenance depot. PMI-2 visits involve a more targeted, selective set of repairs that may be carried out at a maintenance depot or in the field.

In recent years, more than 100 legacy Hornets have also received much more extensive depot-level maintenance through what are termed high flight hour inspections, which are aimed at extending the aircraft's operating lives beyond originally stipulated flying-hour limits. Those inspections, and repairs to address problems that they have identified, have significantly lengthened depot visits for many legacy Hornets.[12]

## Different Outcomes in the Availability of Combat Aircraft

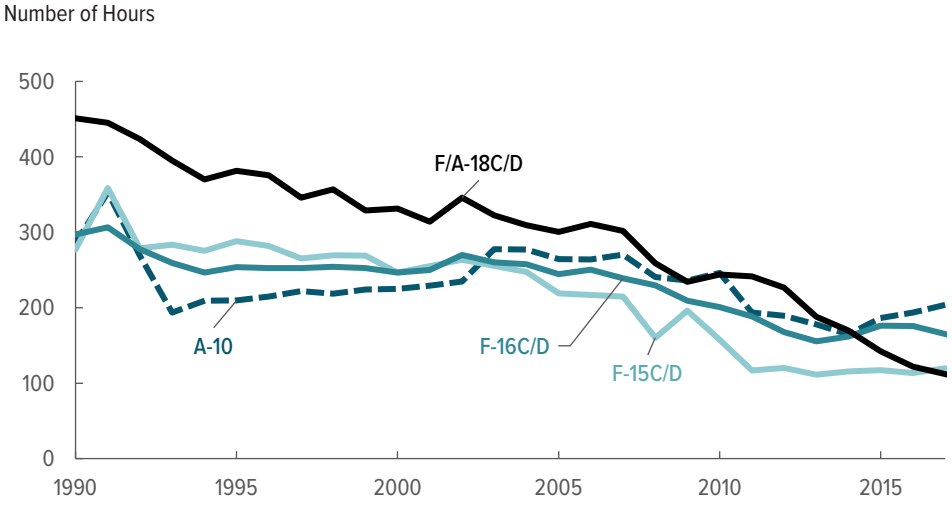
In addition to their different maintenance experiences, DoD's combat aircraft have had different outcomes in their availability—that is, the fraction of each fleet that is available to operating commands and capable of performing missions. In assessing availability, CBO focused

11. Department of the Navy, Office of the Chief of Naval Operations, "Policies and Peacetime Planning Factors Governing the Use of Naval Aircraft," OPNAVINST 3110.11U (May 29, 2013), https://tinyurl.com/y89hnefh (PDF, 259 KB).

12. There have been considerable delays in the successful completion of high flight hour inspections. See, for instance, Allyson Versprille, "Super Hornet Service Life Extension to Commence As Early As 2017," *National Defense* (August 12, 2015), https://tinyurl.com/y9c7cvyv; Brendan McGarry, "Admiral: Corrosion Damage on F/A-18 Hornets 'Caught Us by Surprise,'" *Military.com* (June 5, 2015), https://tinyurl.com/y9sczch7; and Meghann Myers, "Officials Extend F/A-18 Hornet Service Lives," *Navy Times* (March 7, 2015), https://tinyurl.com/pdeesm5.

Figure 5.

**Annual Flying Hours per Tail for Selected Combat Aircraft, 1990 to 2017**




F/A-18C/Ds had the most flying hours per aircraft in the 1990s and early 2000s, but their annual flying hours have declined precipitously.

Source: Congressional Budget Office, using data from the Department of Defense.

on the C/D variants of the Air Force's F-15 and F-16, along with the A-10 and the C/D variants of the Navy's F/A-18. The Navy's F/A-18C/Ds have been less available than the Air Force's A-10s, F-15C/Ds, and F-16C/Ds in recent years. There are several possible explanations for that difference, but maintenance appears to be a critical factor. The total amount of maintenance an aircraft receives may be more important than whether that maintenance is calendar- or modification-based—a possibility that has implications for the F-35.

### Patterns in Aircraft Availability

One metric for assessing a fleet's availability is its operator-possessed and mission-capable rate, the percentage of aircraft in the fleet that are both possessed by operators—that is, not currently undergoing depot-level maintenance—and capable of performing missions.[13] CBO's analysis shows that the operator-possessed and mission-capable rate of all four selected combat aircraft (A-10s, F-15C/Ds, F-16C/Ds, and F/A-18C/Ds) has markedly declined since the early 1990s (see Figure 4). But availability has declined most severely for legacy Hornets, falling below 30 percent in recent years. Since 2015, the F-15C/D's operator-possessed and mission-capable rate has also fallen below the rates for the A-10 and the F-16C/D, although it has exceeded the rate for the F/A-18C/D.

A complementary metric for a fleet's availability is its number of flying hours per tail (that is, flying hours per individual aircraft). Between 1995 and 2005, all four programs averaged between 200 and 400 flying hours per tail per year (see Figure 5). For all four fleets, that metric has trended downward since then. The decline has been especially marked for the F/A-18C/D, whose annual flying hours per tail fell from over 400 in the early 1990s to fewer than 150 in recent years.[14]

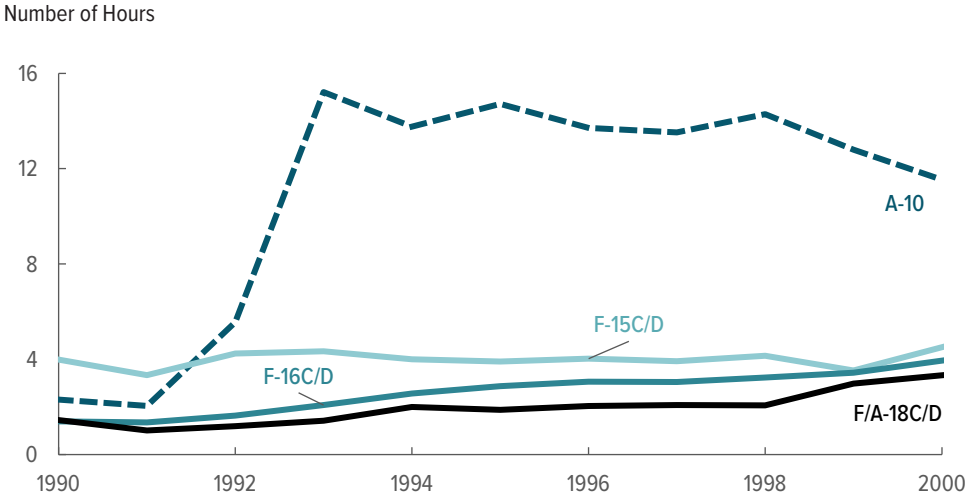
By either measure, availability has declined among all four combat aircraft as they have aged. When a fleet is less frequently available and flies fewer hours, military capability is reduced unless another system bears a heavier burden. Although flying hours can decrease for other reasons (such as reductions in flying-hour budgets, transitions of aircraft from active-duty units to National Guard and Reserve units, and changes in the weapon systems used in missions), and one should expect an aircraft's availability to decline as the aircraft ages, the amount of depot-level maintenance it receives will influence the rate of that decline.

13. Certain types of depot-level maintenance can sometimes be performed by depot employees dispatched to an aircraft's operating location. Hence, the amount of time an aircraft spends in depot-level maintenance can exceed the amount of time the aircraft spends in a depot.

14. The values of this metric for fiscal year 2017 are projected on the basis of data that extend through April 2017.

Figure 6.

**Annual Depot-Coded Hours per Flying Hour for Selected Combat Aircraft, 1990 to 2000**




In the 1990s, F/A-18C/Ds spent less time undergoing depot-level maintenance per flying hour than the other selected aircraft.

Source: Congressional Budget Office, using data from the Department of Defense.

Depot-coded hours reflect the amount of time that aircraft are considered to be under depot-level maintenance and unavailable to military commanders. An aircraft can be in depot-coded status without being physically located in a depot.

### Possible Explanations for Legacy Hornets' Declines in Availability

There are several possible explanations for legacy Hornets' considerable declines in availability. First, the aircraft have flown more hours than similarly aged Air Force combat aircraft. The F/A-18C/D averaged more flying hours per tail than the other aircraft in the 1990s and early 2000s, which implies that a greater percentage of its estimated service life (measured in lifetime flying hours) was consumed as of 2008, the last year examined in CBO's most recent analysis of DoD's fighter aircraft.[15] Second, legacy Hornets have operated in more challenging environments. Operating from aircraft carriers leads to both structural stresses (from catapult launches and tailhook landings) and corrosion (from exposure to salt water) not experienced by land-based aircraft. Structural stresses and corrosion increase the maintenance needed to keep the aircraft flying safely.

The aircraft's heavy use in demanding environments for much of its service life suggests a third reason for its low availability rates: an inadequate amount of depot-level maintenance. In the 1990s, legacy Hornets underwent fewer hours of depot-level maintenance per flying hour than any of the three Air Force combat aircraft (see Figure 6).[16] Between 1990 and 2000, F/A-18C/Ds averaged 2.05 hours of depot-level maintenance per flying hour—22 percent less than F-16C/Ds (2.64 hours), 48 percent less than F-15C/Ds (3.97 hours), and 79 percent less than A-10s (9.77 hours). In recent years, all four aircraft have spent more time in depot-level maintenance per flying hour, but those increases have been the most dramatic for F-15C/Ds and F/A-18C/Ds (see Figure 7). High flight hour inspections have been a major contributor to the F/A-18C/Ds' increase.

Maintenance for DoD's aircraft depends on O&M funding, and beginning in the early 1990s, F/A-18s consistently received less O&M funding per flying hour than F-16s and much less than F-15A-Ds (see Figure 8 on page 12).[17] Although the total amount of O&M

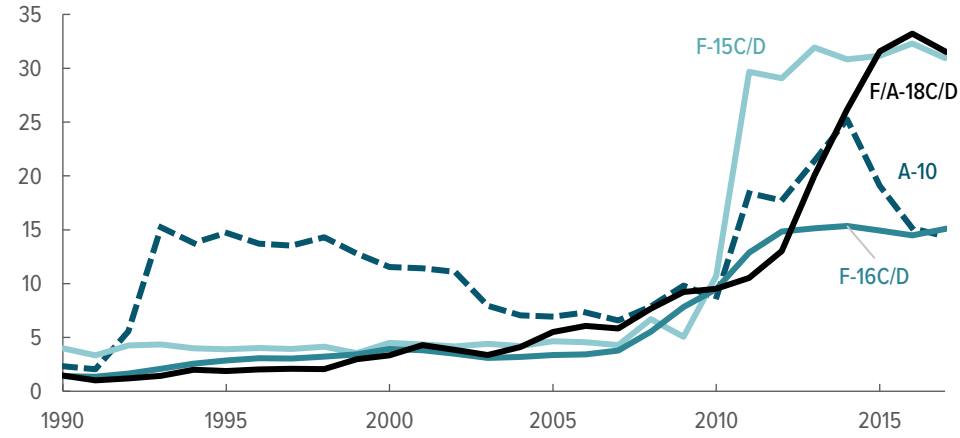
15. See Congressional Budget Office, *Alternatives for Modernizing U.S. Fighter Forces* (May 2009), Figures 1-2 and 1-4, www.cbo.gov/publication/41181.

16. This metric tallies hours spent by aircraft in what is termed *depot-coded* status. An aircraft can be in depot-coded status without being physically located in a depot—if, for instance, depot employees perform work on an aircraft at its operating location. This metric does not consider the number of hours depot employees work on aircraft.

17. In DoD's Future Years Defense Program, a five-year plan for normal peacetime activities associated with DoD's budget, data on funding for legacy Hornets and for Super Hornets (F/A-18E/F variants) are merged. By contrast, data on funding for F-15A–D variants and for F-15E variants are reported separately.

Figure 7.

**Annual Depot-Coded Hours per Flying Hour for Selected Combat Aircraft, 1990 to 2017**




F/A-18C/Ds and F-15C/Ds had the largest increases in depot-coded hours per flying hour since 2010.

Source: Congressional Budget Office, using data from the Department of Defense.

Depot-coded hours reflect the amount of time that aircraft are considered to be under depot-level maintenance and unavailable to military commanders. An aircraft can be in depot-coded status without being physically located in a depot.

funding reflects spending on more than just maintenance (on fuel, for example), the fact that the F/A-18s received less O&M funding than other aircraft suggests that funding for the fleet's maintenance may have been insufficient.[18] Navy experts have noted that changes in funding affect the availability of aircraft two to three years later; that would imply, for instance, that lower O&M funding for the F/A-18 in 2014 led to decreases in the aircraft's mission-capable rate in 2017.[19] In addition, depot-level maintenance personnel who work on older fleets have suggested that if those aircraft had received more depot-level maintenance earlier, they would require less depot-level maintenance today.[20]

### Implications for the F-35

Although availability has declined among all four combat aircraft as they have aged, recent declines have been much more marked for the Navy's legacy Hornets than for any of the three Air Force combat aircraft. The Navy's recent struggle to extend the F/A-18C/D's life span suggests that the aircraft has been undermaintained.

Both the F-15C/Ds (using PDM) and the F-16C/Ds (using modification-based maintenance) have fared better than the F/A-18C/Ds. How much depot-level maintenance aircraft receive thus appears to have a greater influence on their availability and longevity than how that maintenance is scheduled. Adequate depot-level maintenance throughout the F-35's life, whether PDM or modification-based maintenance, should improve the aircraft's performance as it ages and make extending its service life more feasible.

## Upcoming Decisions About Depot-Level Maintenance for the F-35

The F-35 program office will confront a number of issues as it implements depot-level maintenance on the aircraft. Decisions it makes in upcoming years will have long-term implications for the availability and longevity of the F-35 fleet and the costs of maintaining it.

### What Approach to Scheduling Depot-Level Maintenance Should the F-35 Program Follow?

The F-35 could receive calendar-based depot-level maintenance similar to the F-15's PDM or the F/A-18's planned maintenance intervals. Alternatively, it could

18. During the 1990s, the F/A-18 received more O&M funding per tail than the F-16 received per tail (though less than the F-15A–D received per tail). However, as shown in Figure 5, during that period, F/A-18C/Ds flew considerably more hours per tail than the three Air Force combat aircraft.

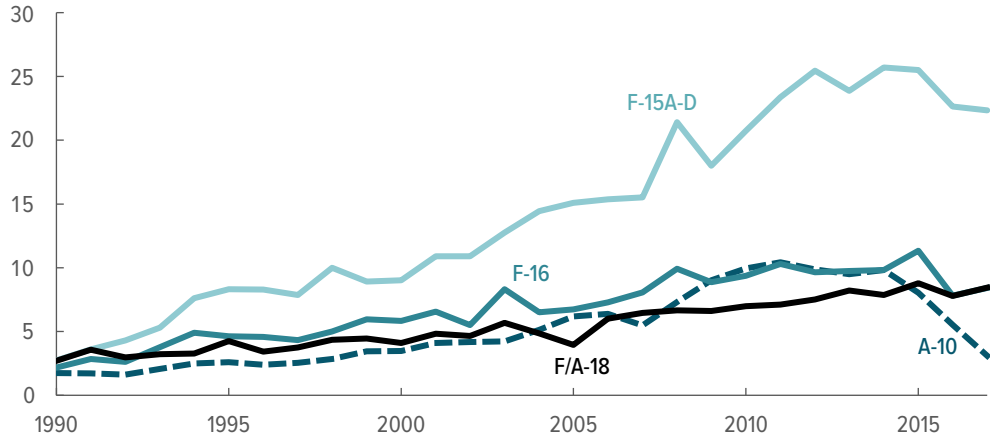
19. Staff of Patuxent River Naval Air Station, briefing to CBO staff (August 22, 2017).

20. Staff of Ogden ALC, remarks to CBO staff (May 3, 2017).

Figure 8.

**Operation and Maintenance Funding per Flying Hour for Selected Combat Aircraft, 1990 to 2017**

Thousands of 2017 Dollars




F/A-18s received less operation and maintenance funding per flying hour than did F-15s and F-16s.

Source: Congressional Budget Office, using data from the Department of Defense.

receive modification-based maintenance like the F-16's. The F-35 program office currently plans to follow a modification-based approach, but that is a choice that can be revisited before or even after a large number of the aircraft begin receiving depot-level maintenance. Modification-based depot-level maintenance is more flexible for aircraft operators because it does not require them to commit to sending specific planes to depots on specific dates. However, depot personnel might prefer PDM if it makes planning their workloads and maintaining a stable workforce easier. In discussions with CBO, some F-16 experts noted that depot-level maintenance for the aircraft had become increasingly demanding and suggested that more regular maintenance under a PDM system might solve that problem.[21] An expert suggested that the F-16 already has "de facto PDM," in the sense that the duration of F-16s' depot visits has become comparable to that of other aircraft under a PDM system.[22]

### How Frequent and Intensive Should the F-35's Depot-Level Maintenance Be?

Regardless of DoD's ultimate approach to scheduling depot maintenance for the F-35, an important question is what level of effort the military services should devote to that maintenance. Performing more maintenance on the aircraft would cost more in the near term and lengthen the aircraft's depot visits, but it would result in better-maintained aircraft that DoD might be able to operate at a lower cost further into the future. The longer an aircraft is expected to be operated, the more cost-effective its early-in-life maintenance is, other things being equal.

Three factors will further affect decisions about the frequency and intensity of the F-35's maintenance. First, F-35s are constructed with what are termed low-observability materials. Those materials are expensive and difficult for maintenance workers to handle, which provides an incentive to accomplish as many tasks as possible when the materials are removed during a depot visit. It might therefore be advantageous for the F-35's depot visits to be less frequent but longer, similar to the F-15's depot visits under the PDM approach.

Second, the F-35 includes a diagnostic system called the Autonomic Logistics Information System (ALIS), which is designed to monitor and predict when systems or parts require maintenance. ALIS could streamline depot-level maintenance on the aircraft by, for example, reducing the number of surprises depot-level maintenance personnel encounter when they begin work on an aircraft.

21. Staff of Ogden ALC, remarks to CBO staff (May 3, 2017).

22. Meeting with CBO staff at RAND Arlington (April 28, 2017).

However, ALIS has experienced software problems and delays in its development, so the value of its contribution to future depot-level maintenance is unclear.[23]

Third, DoD will need to decide whether to maintain the F-35 variants differently, perhaps by varying the frequency and intensity of their depot-level maintenance. The F-35B and F-35C variants may require more maintenance because both will operate in corrosive maritime environments. The F-35C variant will face particularly high levels of stress from the structurally demanding tailhook landings it must make on aircraft carriers.

### Who Will Participate in the F-35's Depot-Level Maintenance and How?

Traditionally, the depots for each military branch have maintained only that branch's aircraft and engines.[24] Unlike most DoD aircraft, however, the F-35 is used by three branches of the military, and it has consequently departed from that paradigm. The Air Force's Ogden ALC is the lead depot for both F-35As and F-35Cs, but it has also performed work on F-35Bs. The Navy's Fleet Readiness Center East depot is the lead depot for F-35Bs, but it has also performed work on F-35As and F-35Cs. The Air Force's Oklahoma City ALC will handle depot-level engine maintenance for all variants.

As of June 2017, Lockheed Martin planned to manufacture not only the 2,470 F-35 aircraft that will be acquired by DoD but an additional 741 aircraft to be purchased by foreign nations.[25] Those nations will have their own depots, which U.S. F-35s can access in an emergency and use as sources of spare parts. Those depots are in Cameri, Italy; Williamtown, Australia; Nagoya, Japan (F-35A variants only); and Iwakuni, Japan (F-35B and F-35C variants only). It is also possible that one or more foreign depots could play a role akin to Kimhae Air Base's role for A-10s, F-15s, and F-16s, working on U.S. F-35s overseas so that they can avoid transoceanic flights to and from depots in the United States.

Lockheed Martin and Pratt & Whitney will participate in F-35 depot-level maintenance, but the specifics of their roles are likely to evolve. DoD currently plans to have the government and contractors collaborate in managing F-35 product support.[26] Although their roles can change over time, manufacturers are contracted to serve as sources of knowledge for decades after an aircraft begins operation.

23. See Government Accountability Office, *F-35 Sustainment: DOD Needs a Plan to Address Risks Related to Its Central Logistics System*, GAO-16-439 (April 14, 2016), www.gao.gov/products/GAO-16-439.

24. The Navy attempted to have its Jacksonville depot perform work on the Air Force F-22's F119 engine, but the Air Force ultimately decided to have that work carried out at one of its own depots, the Oklahoma City ALC. See Cynthia R. Cook and others, *A Methodology for Comparing Costs and Benefits of Management Alternatives for F-22 Sustainment*, TR-763-AF (RAND Corporation, 2011), www.rand.org/pubs/technical_reports/TR763.html.

25. See Lockheed Martin, "F-35 Lightning II Program Status and Fast Facts" (February 5, 2018), www.f35.com/media-kit.

26. Government Accountability Office, *F-35 Aircraft Sustainment: DOD Needs to Address Challenges Affecting Readiness and Cost Transparency*, GAO-18-75 (October 2017), www.gao.gov/products/GAO-18-75.

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# About This Document

This Congressional Budget Office report was prepared at the request of the Chairman and Ranking Member of the Subcommittee on Readiness of the House Armed Services Committee. In keeping with CBO's mandate to provide objective, impartial analysis, the report makes no recommendations.

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Director
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