Depot-level maintenance is essential to keeping aircraft flying safely. As the Department of Defense (DoD) begins operating F-35 fighter aircraft, earlier generation fighter aircraft (Air Force A-10s, F-15C/Ds, F-16C/Ds, and Navy legacy Hornet F/A-18C/Ds) provide insights on aircraft depot maintenance practices. All four earlier fighter programs had declining availability and annual flying hours per tail as they aged. Declines have been particularly marked for legacy Hornets. A variety of explanations for legacy Hornet challenges is proposed, including more hours flown than similarly aged Air Force combat aircraft, operating in challenging maritime environments, and a lower level of depot-level maintenance performed per flying hour than other Air Force aircraft. DoD decision makers face a trade-off in F-35 depot-level maintenance. More maintenance on the aircraft would cost more in the near-term, but may result in a better maintained aircraft that the DoD could operate further into the future.

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The F-35 program is the Department of Defense (DoD)'s newest fighter aircraft acquisition program. Like all aircraft, the F-35 will require extensive maintenance during its life, including trips to depots for significant maintenance and upgrades.

Background

The F-35 is termed a “fifth generation” fighter aircraft in that it contains capabilities—most notably stealthiness (the ability to reduce the chances of being detected by radar and heat-seeking missiles)—not found in “fourth generation” fighter aircraft like the U.S. Air Force’s F-15 and F-16 fighters and the U.S. Navy’s F/A-18 fighters.

Production of the F-35 occurs in three variants:

- The F-35A, operated by the Air Force, flies from the type of land-based airfields that other Air Force fighter aircraft use, i.e., the F-15 and F-16.
- The F-35B, operated by the Marine Corps, has a lift fan and other systems that enable it to take off and land vertically on the short decks of amphibious assault ships and on locations on land without a runway.
- The F-35C, operated by the Navy, has a tail hook and other structural enhancements that allow the aircraft to take off from, and land on, aircraft carriers. The Marine Corps also plans to procure a limited number of F-35Cs.

This article focuses on how the F-35 will receive depot-level maintenance support over its stipulated 30-year design life (or longer if DoD chooses to extend its life cycle).

The Role of Depots in Aircraft Maintenance

When aircraft are operated, they experience stresses that can weaken or break parts and structural components on the aircraft. Even aircraft that are not flown will eventually need maintenance as seals dry and metal corrodes.

Maintenance can occur at different locations or levels. Clearly, it would be most convenient to undertake maintenance at the flight line directly where the aircraft operates. The flight line is the location either at an air base or on a ship where military personnel undertake routine maintenance on the aircraft. Maintenance personnel at flight lines often remove inoperative parts from aircraft and replace them with operating parts (either new or repaired parts).

Some maintenance, however, cannot be undertaken on the flight line. Flight-line maintenance personnel may lack the training or skills required or the flight line may lack the requisite equipment or space. If, for instance, an aircraft needs large-scale disassembly to address a problem, that disassembly must be done away from the flight line.

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

The military services have used different approaches to maintenance behind the flight line. The Navy uses three levels of maintenance. The Navy’s flight-line maintenance is termed organizational maintenance, which is performed by the squadron where the aircraft operates, including on aircraft carriers. The second level, termed intermediate maintenance, is performed by military personnel on aircraft carriers and at shore-based air stations. Intermediate maintenance tasks include calibration, repair, or replacement of damaged or unserviceable parts, components, or assemblies; emergency manufacture of nonavailable parts; and provision of technical assistance to flight-line maintainers (Office of the Assistant Secretary
of Defense for Logistics & Materiel Readiness, 2016). If tasks cannot be accomplished in intermediate maintenance, the aircraft is sent to a central Navy depot with yet additional capabilities and equipment. The two Navy depots that have done the most work on F/A-18 A–D variants (termed legacy Hornets) are Fleet Readiness Center (FRC) Southwest at North Island in San Diego, California, and FRC Southeast at Jacksonville, Florida.

The Air Force relies on two levels of maintenance: flight lines and depots. Most F-15 depot-level maintenance occurs at the Warner Robins Air Logistics Center (ALC) at Robins Air Force Base in central Georgia. Most A-10 and F-16 depot-level maintenance occurs at the Ogden ALC at Hill Air Force Base in Utah.

The workers at both Navy and Air Force depots are almost all civilians.

Different Approaches to Aircraft Depot-Level Maintenance

Different types of aircraft use different approaches to aircraft depot-level maintenance. Approaches vary across a number of dimensions including how visits are scheduled, how much work takes place during depot visits, the role of aircraft original equipment manufacturers (OEM) in depot-level maintenance, and whether foreign depots are used.

A depot develops a standard package—a list of tasks like inspections and repairs that the depot is to perform during an aircraft’s visit. Upon induction, an aircraft is disassembled to the degree appropriate for the tasks in the standard package. For example, the engine(s) and the wings may be removed. Depot workers then inspect the aircraft. To the extent that unexpected problems are found, the depot proposes additional tasks (termed “over-and-above” work) to the program office to address these problems. Issues that could affect flight safety are always addressed; other over-and-above tasks are undertaken at the discretion of the program office, which must pay for over-and-above work. (Typically, a buffer is budgeted for some anticipated level of over-and-above work, but an unusually large number of adverse surprises will require additional funds.)

The depot’s workers then undertake the tasks (both from the standard package and the agreed-upon over-and-above list). For instance, workers could replace worn parts with new parts or insert upgraded equipment onto the aircraft. The aircraft is then rebuilt, repainted, and flight-tested before it is flown back to its home base or to a different base. (After depot-level inspections or repairs, aircraft are sometimes sent to different units than the ones from which they came.)

Standard packages evolve (typically increase) over time. In particular, if an over-and-above problem is found across a number of inducted aircraft, addressing that problem often becomes part of the standard package for subsequent aircraft. (Tasks could also be removed from the standard package if, for instance, a replacement part is installed fleet-wide that permanently rectifies a problem.)

Depot-Level Maintenance Practices for Combat Aircraft

The Air Force’s F-15s, F-16s, A-10s, and the Navy’s F/A-18s have different depot-level maintenance practices. F-15s and A-10s use different forms of calendar-driven maintenance with aircraft entering depots on a schedule. The F-15’s approach is termed programmed depot maintenance (PDM), with each aircraft returning to the depot every 6 years. F-16s use modification-driven maintenance, with aircraft entering depots based on the vicissitudes of when modification programs are implemented.

The Navy’s legacy Hornets use a calendar-driven system called Planned Maintenance Intervals (PMI). A given legacy Hornet cycles between two different types of maintenance activities, labeled PMI-1 and PMI-2, on a calendar basis—every 6 years for shore-based legacy Hornets and every 4 years for carrier-based legacy Hornets (Department of the Navy, 2013). PMI-1 is an extensive set of disassembly, inspection, and repair tasks done at
a maintenance depot. PMI-2 is a more targeted, selective set of repairs that may be done at a maintenance depot or in the field. In recent years, some legacy Hornets have additionally received much more extensive depot-level maintenance including center barrel replacements and high flight hour (HFH) inspections. Center barrel replacements replace the center portion of the aircraft where the wings and the main landing gear attach to the fuselage (Fleet Readiness Center Southwest, 2011). HFH inspections (and repairs to address problems identified in those inspections) are intended to extend the safe operating life of legacy Hornets beyond their originally stipulated flying hour limit. The Navy has noted considerable challenges in legacy Hornet HFH inspections (McGarry, 2015; Myers, 2015; Versprille, 2015).

Different Outcomes in Combat Aircraft Availability

Different combat aircraft have gone through different trends over their service lives in their availability to fly and hours flown. This study examined those trends for four programs: the Air Force’s A-10, F-15, and F-16; and the Navy’s F/A-18, focusing on the C/D variants of the F-15, F-16, and F/A-18. The legacy Hornet fleet has not fared well compared to the three Air Force systems. However, what remains unclear is what fraction of the outcome differences has been driven by differences in depot maintenance practices. The aircraft are intrinsically different and have been used differently.

Patterns in Aircraft Availability

One metric by which to assess a fleet’s performance over time is its operator-possessed and mission-capable rate. This is the percentage of aircraft in the fleet that are both (a) possessed by operators, that is, not assigned a depot maintenance status, and (b) mission-capable.

This metric is the percentage of the total fleet available to operators and capable of performing missions.

All four programs (A-10, F-15C/D, F-16C/D, and F/A-18C/D) have had marked declines in this rate since the early 1990s (Figure 1). Problems have been especially marked for the F/A-18C/D, which has recently experienced rates below 30 percent. A large number of legacy Hornets have been tied up in lengthy HFH inspections. The F-15C/D operator-possessed and mission-capable rate, while exceeding that of the F/A-18C/D, has been below the rates for the A-10 and the F-16C/D since Fiscal Year 2015.

Flying hours per tail is a complementary metric describing aircraft availability. Between 1995 and 2005, all four programs averaged 200–400 flying hours per tail per year (Figure 2). Across all four fleets, this metric has trended downward since then. The decline has been especially marked for the F/A-18C/D, which declined from over 400 annual flying hours in the early 1990s to fewer than 150 annual flying hours in recent years.
Possible Explanations for Legacy Hornet Challenges

One explanation for legacy Hornet challenges is that the aircraft have flown more hours than the similarly aged Air Force combat aircraft. The F/A-18C/D averaged more hours per tail than the other aircraft in the 1990s and early 2000s, implying that a greater percentage of its estimated service life was consumed as of 2008 (Congressional Budget Office, 2009, Figures 1–2 & 1–4).

A second explanation for the marked declines in F/A-18C/D aircraft availability and flying hours is the more challenging environment in which legacy Hornets operate. Operating on and off aircraft carriers creates both structural stresses (from catapult launches and tailhook landings) and corrosion challenges (from exposure to salt water) not experienced by land-based aircraft. Increased structural stresses and corrosion figure to lessen aircraft availability and increase the maintenance challenges associated with keeping aircraft flying safely.

A third explanation is that the level of depot-level maintenance on F/A-18 C/Ds may have been inadequate. In the 1990s, notwithstanding its challenging operating environment, legacy Hornets spent fewer hours in depot-coded status per flying hour than the three Air Force combat programs (Figure 3). The ground attack A-10 received many more depot-coded hours per flying hour than the F-15C/D and F-16C/D fighters. All four systems have undergone increases in depot-coded hours per flying hour in recent years, with the F-15C/D and F/A-18C/D having the most dramatic increases (Figure 4). The F-15C/D was put into a rewiring program starting in November 2009 that increased the duration of aircraft PDM visits. In 2008, A-10s started a Scheduled Structural Inspection program that increased depot hours on that aircraft.
Upcoming F-35 Depot-Level Maintenance Decisions

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

The Timing and Intensity of Depot-Level Maintenance

The F-35 could be put on calendar-driven, depot-level maintenance like F/A-18 PMI or F-15 PDM. Alternatively, it could receive modification-driven maintenance like F-16s. The F-35 program of record is to follow the latter, modification-driven approach, but that is a choice that can be revisited before, or even after, the F-35 fleet begins depot-level maintenance in earnest.

Modification-driven depot-level maintenance may be more flexible for aircraft operators; they are not committed to sending specific tails to depots on specific dates. But calendar-driven maintenance may be preferred by depots because it may be easier to plan their workloads and maintain a stable workforce.

Whether the F-35 is maintained using a calendar-driven approach or a modification-driven schedule, an important question is the level of effort that the military services devote to depot-level maintenance. A lengthier depot-level task list would cost more in the near-term and keep aircraft in the depot system longer at each visit, but may result in a better-maintained aircraft that the DoD could operate at lower fleet-wide cost and further into the future. Many of DoD’s aircraft, including the A-10, F-15, F-16, and F/A-18 are being operated longer than originally envisioned, especially as replacement aircraft like the F-35 have been delayed. Other things being equal, the longer an aircraft is expected to be operated, the more cost-effective are earlier-in-life maintenance activities.

The F-35B and F-35C variants may require more maintenance because both will operate in corrosive maritime environments; and the F-35C will use structurally demanding catapults and tailhook-arrested landings when operating from aircraft carriers.

DoD will also need to decide whether to treat each of the F-35 variants differently, perhaps varying maintenance frequency and intensity. The F-35B and F-35C variants may require more maintenance because both will operate in corrosive maritime environments; and the F-35C will use structurally demanding catapults and tailhook-arrested landings when operating from aircraft carriers.

The low observability (LO) materials used on F-35s pose a particular maintenance challenge. The materials are expensive and difficult to handle. They also provide incentive to accomplish as much work as possible in depots every time those materials are removed on part of an aircraft, given the costs and time associated with removal and reinstallation. LO materials may therefore suggest a preference for fewer, but longer, more intensive depot-level maintenance events, more characteristic of a PDM approach.

Who Participates in F-35 Depot-Level Maintenance and What They Do

The F-35’s tri-Service status makes it different than most DoD aircraft. Traditionally, the military services’ depots have maintained their own equipment. A controversy erupted between the Air Force and the Navy in which the Navy argued that its Jacksonville depot was not afforded a fair opportunity to compete with the Oklahoma City ALC to perform work on the Air Force’s F-22 F119 engine (Cook et al., 2011). Heretofore, the F-35 has departed from that paradigm: The Air Force’s Ogden ALC is the lead depot for both the Air Force’s F-35As and the Navy’s F-35Cs. The Navy’s FRC East Depot at Cherry Point, North Carolina, is the lead depot for F-35Bs. The Air Force’s Oklahoma City ALC will handle F135 engine depot-level maintenance for all variants.
Approaches to F-35 Depot-Level Maintenance: Insights from Other Systems

Because the F-35 is an international program, there will also be depots at Cameri, Italy (all variants); Williamtown, Australia (all variants); Nagoya, Japan (F-35A); and Iwakuni, Japan (F-35B and F-35C). U.S. F-35s will be able to access those depots on an emergency, unscheduled basis, as well as use them as sources of supply of F-35 components that depots repair. One or more foreign depots could be used for depot-level maintenance events, avoiding transoceanic flights to and from depots in the United States for U.S. F-35s based overseas.

Conclusions

Depot maintenance practices have both short- and long-term effects on availability and flying hour rates. In the short run, an aircraft that is in depot maintenance is not available to operators and does not fly (except for test flights). In the long run, however, depot-level maintenance is necessary to keep a fleet flying. Too little depot-level maintenance can result in diminished availability and flying hours later in a fleet’s life. DoD decision makers need to balance the short-run costs (both financial and in aircraft availability) associated with depot-level maintenance against the long-run benefits of such maintenance (a better-maintained fleet that would be easier to continue operating for more years if so desired).

References


Endnotes

1 Not all depot-level maintenance occurs at depots. For some types of actions, such as installation of modification kits, a field service team might be sent from a depot to an operating location with the work actually being accomplished at the operating location. However, irrespective of its location, this would still be considered “depot-level” maintenance in that it requires the skills and expertise of depot maintenance personnel.

2 The values of this metric for fiscal year 2017 are annualized using data through April 2017.

3 This metric tallies hours spent by specific tails in a depot-coded status. If an aircraft spends a week in a depot-coded status, it would record 168 (24*7) hours in this status. An aircraft may be depot-coded without being physically located in a depot. This metric does not consider the number of labor hours depot employees work on aircraft.
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