F-35 Joint Strike Fighter

Executive Summary

Test Strategy, Planning, Activity, and Assessment

- The Joint Strike Fighter (JSF) Program Office (JPO) acknowledged in 2016 that schedule pressure exists for completing System Development and Demonstration (SDD) and starting Initial Operational Test and Evaluation (IOT&E) by August 2017, the planned date in JPO's Integrated Master Schedule. In an effort to stay on schedule, JPO plans to reduce or truncate planned developmental testing (DT) in an effort to minimize delays and close out SDD as soon as possible. However, even with this risky, schedule-driven approach, multiple problems and delays make it clear that the program will not be able to start IOT&E with full combat capability until late CY18 or early CY19, at the soonest. These problems include:
  - Continued schedule delays in completing Block 3F mission systems development and flight testing, which DOT&E estimates will likely complete in July 2018
  - Delayed and incomplete Block 3F DT Weapons Delivery Accuracy (WDA) events and ongoing weapons integration issues
  - Continued delays in completing flight sciences test points, particularly those needed to clear the full F-35B Block 3F flight envelope, resulting in a phased release of Block 3F envelope across the variants, with the full Block 3F envelope for F-35B not being released until mid-CY18
  - Further delays in completing gun testing for all three variants and recently discovered gunsight deficiencies
  - Late availability of verified, validated and tested Block 3F Mission Data Loads (MDLs) for planned IOT&E and aircraft delivery dates; DOT&E estimates the first validated MDLs will not be available until June 2018
  - Continued shortfalls and delays with the Autonomic Logistics Information System (ALIS) and late delivery of ALIS version 3.0, the final planned version for SDD, at risk of slipping from early CY18 into mid-CY18
  - Significant, well-documented deficiencies; for hundreds of these, the program has no plan to adequately fix and verify with flight test within SDD; although it is common for programs to have unresolved deficiencies after development, the program must assess and mitigate the cumulative effects of these remaining deficiencies on F-35 effectiveness and suitability prior to finalizing and fielding Block 3F
  - Overall ineffective operational performance with multiple key Block 3F capabilities delivered to date, relative to planned IOT&E scenarios which are based on various fielded threat laydowns
  - Continued low aircraft availability and no indications of significant improvement, especially for the early production lot IOT&E aircraft
  - Insufficient progress in verification of Joint Technical Data, particularly those for troubleshooting aircraft fault codes and for support equipment
  - Delays in completing the required extensive and time-consuming modifications to the fleet of operational test aircraft which, if not mitigated with an executable plan and contract, could significantly delay the start of IOT&E
  - Insufficient progress in the following areas which are required for IOT&E:
    - Development, integration, and testing of the Air-to-Air Range Infrastructure instrumentation into the F-35 aircraft
    - Flight testing to certify the Data Acquisition, Recording, and Telemetry pod throughout the full flight envelope
    - Development of other models, including the Fusion Simulation Model, Virtual Threat Insertion table, and the Logistics Composite Model
  - Delays in providing training simulators in the Block 3F configuration to the initial training centers and operational locations
- Based on these ongoing problems and delays, and including the required time for IOT&E spin-up, the program will not be ready to start IOT&E until late CY18, at the soonest, or more likely early CY19. In fact, IOT&E could be delayed to as late as CY20, depending on the completion of required modifications to the IOT&E aircraft.

Progress in Developmental Testing

- Mission Systems Testing
  - The program continues to pursue a cost- and schedule-driven plan to delete planned mission systems DT points by using other test data for meeting test point objectives in order to accelerate SDD close-out. This plan, if not properly executed with applicable data,

sufficient analytical rigor and statistical confidence, would shift significant risk to operational test (OT), Follow-on Modernization (FoM) and the warfighter.

- This risky approach would also discard carefully planned build-up test content in the Test and Evaluation Master Plan (TEMP) and the Block 3F Joint Test Plan (JTP), content the program fully agreed was required when those documents were signed. The program plans to "quarantine" JTP build-up test points, which are planned to be flown by the test centers, and instead skip ahead to complex graduation-level Mission Effectiveness Risk Reduction test points, recently devised to quickly sample full Block 3F performance. Then, if any of the Block 3F functionality appears to work correctly during the complex test points, the program would delete the applicable underlying build-up test points for those capabilities and designate them as "no longer required." However, the program must ensure the substitute data are applicable and provide sufficient statistical confidence that the test point objectives had been met prior to deleting any underlying build-up test points. While this approach may provide a quick sampling assessment of Block 3F capabilities, there are substantial risks. The multiple recent software versions for flight test may prevent the program from using data from older versions of software to count for baseline test point deletions because it may no longer be representative of Block 3F. The limited availability and high cost of Western Test Range periods, combined with high re-fly rates for test missions completed on the range, make it difficult for the program to efficiently conduct this testing. Finally, the most complex capabilities in Block 3F have only recently reached the level of maturity to allow them to be tested, and they are also some of the most difficult test points to execute (i.e., full Block 3F capabilities and flight envelope).
- Historical experience indicates this approach, if not properly executed, may delay problem discoveries and increase the risk to completing SDD and increase the risk of failure in IOT&E (as well as, much more importantly, in combat). In fact, the program needs to allocate additional test points – which are not in its current plans – for characterization, root cause investigations, and correction of a large number of the open high-priority deficiencies and technical debt described later in this report. The completion of the planned baseline test points from the Block 3F JTP, along with correction or mitigation of significant deficiencies, is necessary to ensure full Block 3F capabilities are adequately tested and verified before IOT&E and, more importantly, before they are fielded for use in combat.
- Until recently, the Program Office estimated that mission systems flight testing will complete in October 2017. It now acknowledges the risk that this testing may extend into early CY18.
    - The October 2017 estimate was based on an inflated test point accomplishment rate and optimistically low regression and re-fly rates. The estimate also assumed that the Block 3FR6 software, delivered to flight test in December 2016, would have the maturity necessary to complete the remaining test points and meet specification requirements without requiring additional versions of software to address shortfalls in capability. However, this is highly unlikely, since several essential capabilities – including aimed gunshots and Air-to-Air Range Infrastructure – had not yet been flight tested or did not yet work properly when Block 3FR6 was released.
    - The Services have designated 276 deficiencies in combat performance as "critical to correct" in Block 3F, but less than half of the critical deficiencies were addressed with attempted corrections in 3FR6.
    - Independent estimates from other Pentagon staff agencies vary from March 2018 to July 2018 to complete mission systems testing – all based on the current number of test points remaining and actual historic regression and re-fly rates from the flight test program. Even these estimates are optimistic in that they account for only currently planned testing, which does not yet include the activities needed to correct the Services' remaining high-priority deficiencies.

- Flight sciences testing continues to be a source of significant discovery, another indication that the program is not nearing completion of development and readiness for IOT&E. For example:
    - Fatigue and migration of the attachment bushing in the joint between the vertical tail and the aircraft structure are occurring much earlier than planned in both the F-35A and F-35B, even with a newly designed joint developed to address shortfalls in the original design.
    - Excessive and premature wear on the hook point of the arresting gear on the F-35A, occuring as soon as after only one use, has caused the program to consider developing a more robust redesign.
    - Higher than predicted air flow temperatures were measured in the engine nacelle bay during flight testing in portions of the flight envelope under high dynamic pressure on both the F-35A and F-35C; thermal stress analyses are required to determine if airspeed restrictions will be needed in this portion of the flight envelope.
    - Overheating of the horizontal tail continued to cause damage, as was experienced on BF-3, one of the F-35B flight sciences test aircraft, while accelerating in afterburner to Mach 1.5 for a loads test point. The left horizontal inboard fairing surface reached temperatures that exceeded the design limit by a significant amount. Post-flight inspections revealed de-bonding due to heat damage on the trailing edge of the horizontal tail surface and on the horizontal tail rear spar.
    - Vertical oscillations during F-35C catapult launches were reported by pilots as excessive, violent, and therefore a safety concern during this critical phase of flight. The program is still investigating alternatives to address this

deficiency, which makes a solution in time for IOT&E and Navy fielding unlikely.

Mission Data Load Development and Testing

- Mission data files, which comprise MDLs, are essential to enable F-35 mission systems to function properly. Block 3F upgrades to the U.S. Reprogramming Laboratory (USRL) – where mission data files are developed, tested and validated for operational use – are late to meet the needs for Block 3F production aircraft and IOT&E. These upgrades to the Block 3F configuration, including the associated mission data file generation tools, are necessary to enable the USRL to begin Block 3F mission data file development. In spite of the importance of the mission data to both IOT&E and to combat, the Program Office and Lockheed Martin have failed to manage, contract, and deliver the necessary USRL upgrades to the point that fully validated Block 3F MDLs will not be ready for IOT&E until June 2018, at the earliest.
- Operational units are also affected by the capability shortfalls in the USRL to create, test and field MDLs. The complete set of Block 2B and Block 3i MDLs developed for overseas areas of responsibility (AORs) have yet to undergo the full set of lab and flight tests necessary to validate and verify these MDLs for operational use. Because of the delays in upgrading the USRL to the Block 3F configuration, the Services will likely not have Block 3F MDLs for overseas AORs until late 2018 or early 2019.
- In addition to the late Block 3F USRL upgrades, the required signal generators for the USRL – with more high-fidelity channels to simulate modern fielded threats – have not yet been placed on contract. As a result, the Block 3F MDLs will not be tested and optimized to ensure the F-35 will be capable of detecting, locating, and identifying modern fielded threats until 2020, per a recent program schedule. The program is developing multiple laboratories in order to produce MDLs tailored for partner nation-unique requirements, some of which will have more high-fidelity signal generator channels earlier than the USRL. The program is considering using one of these other laboratories for Block 3F MDL development and testing; however, the MDL that will be used for IOT&E must be developed, verified, validated, and tested using operationally representative procedures, like the MDLs that will be developed for the operational aircraft in the USRL.

Weapons Integration and Demonstration Events

- Block 3F weapons delivery accuracy (WDA) events are not complete. These events, required by the TEMP, are key developmental test activities necessary to ensure the full fire-control capabilities support the “find, fix, track, target, engage, assess” kill chain. As of the end of November, only 5 of the 26 events (excluding the gun events) had been completed and fully analyzed. Several WDAs have revealed deficiencies and limitations to weapons employment (e.g., AIM-9X seeker status tone problems and out-of-date launch zones for AIM-120 missiles). An additional 11 WDAs had occurred, but analyses were ongoing. Of the 10 remaining WDAs that had not been completed, 4 were still blocked due to open deficiencies that must be corrected before the WDA can be attempted. However, the program did not have time to fix the deficiencies, complete the remaining WDAs and analyze them before finalizing Block 3FR6 in late November for flight testing to begin in December 2016. For example, recent F-35C flight testing to prepare for a weapons event with the C-1 version of the Joint Stand-Off Weapon (JSOW-C1) discovered weapon integration, Pilot Vehicle Interface (PVI) and mission planning problems that will prevent full Block 3F combat capability from being delivered, if not corrected. These discoveries were made too late to be included in the Block 3FR6 software, the final planned increment of capability delivered to flight test for SDD. Also, multiple changes are being made late in Block 3F development to mission systems fire control software to correct problems with the British AIM-132 Advanced Short-Range Air-to-Air Missile (ASRAAM) missile and Paveway IV bomb, changes which could affect the U.S. AIM-9X air-to-air missile and GBU-31 laser-guided bomb capabilities, and may require regression testing of the U.S. weapons.
- Block 3F adds gun capability for all variants. The F-35A gun is internal; the F-35B and F-35C each use a gun pod. Ground firing tests have been completed on all variants; only on the F-35A has initial flight testing of the gun been accomplished. Early testing of the air-to-ground and air-to-air symbology have led to discovery of deficiencies in the gunsight and strafing symbology displayed in the pilot’s helmet – deficiencies which may need to be addressed before accuracy testing of the gun, aimed by the HMDS, can be completed. Because of the late testing of the gun and the likelihood of additional discoveries, the program’s ability to deliver gun capability with Block 3F before IOT&E is at risk, especially for the F-35B and F-35C.

Pilot Escape System

- The program completed pilot escape system qualification testing in September 2016, which included a set of modifications designed to reduce risk to pilots weighing less than 136 pounds.
  - Modifications include:
    - Reduction in the weight of the pilot’s Generation III Helmet Mounted Display System (HMDS), referred to as the Gen III Lite HMDS
    - Installation of a switch on the ejection seat which allows lighter-weight pilots to select a slight delay in the activation of the main parachute
    - Addition of a Head Support Panel (HSP) between the risers of the parachute.
  - These modifications to the pilot escape system were needed after testing in CY15 showed that the risk of serious injury or death is greater for lighter-weight pilots. Because of the risk, the Services decided to restrict pilots weighing less than 136 pounds from flying the F-35.

- Twenty-two qualification test cases were completed between October 2015 and September 2016, with variations in manikin weight, speed, altitude, helmet size and configuration, and seat switch setting. Data from tests showed that the HSP significantly reduced neck loads under conditions that forced the head backwards, inducing a rearward neck rotation, during the ejection sequence. Data also showed that the seat switch reduced the "opening shock" by slightly delaying the main parachute for lighter-weight pilots at speeds greater than 160 knots. The extent to which the risk has been reduced for lighter-weight pilots (i.e., less than 136 pounds) by the modifications to the escape system and helmet is still to be determined by a safety analysis of the test data. If the Services accept the risk associated with the modifications to the escape system for the lighter-weight pilots, restrictions will likely remain in effect until aircraft have the modified seat and the HSPs, and until the lighter-weight Gen III Lite helmets are procured and delivered to the applicable pilots.
- Based on schedules for planned seat modifications, production cut-in of the modified seat, and the planned delivery of the Gen III Lite HMDS, the Air Force may be able to reopen F-35 pilot training to lighter-weight pilots (i.e., below 136 pounds) in early 2018. DOT&E is not aware of the plans for the Marine Corps and the U.S. Navy to open F-35 pilot training to the lighter-weight pilots.
- Part of the weight reduction to the Gen III Lite HMDS involved removing one of the two installed visors (one dark, one clear). As a result, pilots that will need to use both visors during a mission (e.g., during transitions from daytime to nighttime) will have to store the second visor in the cockpit. However, there currently is not enough storage space in the cockpit for the spare visor, so the program is working a solution to address this problem.
- The program has yet to complete the additional testing and analysis needed to determine the risk of pilots being harmed by the Transparency Removal System (which shatters the canopy first, allowing the seat and pilot to leave the aircraft) during off-nominal ejections in other than ideal, stable conditions (such as after battle damage or during out-of-control situations). Although the program completed an off-nominal rocket sled test with the Transparency Removal System in CY12, several aspects of the escape system have changed since then (including significant changes to the helmet) which warrant additional testing and analyses.

Joint Simulation Environment (JSE)

- JSE is a man-in-the-loop, F-35 mission systems software-in-the-loop simulation being developed to meet the operational test requirements for Block 3F IOT&E. However, multiple aspects of the JSE development effort continue to fall significantly behind schedule. The Program Office has been negotiating with the contractor to receive the F-35 aircraft and sensor models, referred to as "F-35 In A Box (IAB)," but very limited progress was made in CY16. Also, delays with security clearances for new personnel limited progress on several aspects of the development and validation effort. Although the Naval Air Systems Command (NAVAIR) government team has begun installing hardware on their planned timeline (facilities, cockpits, etc.), the team's progress in integrating the many different models (i.e., multi-spectral environment, threats, weapons) with F-35 IAB has been severely limited, and the verification, validation and accreditation of these models within JSE for use in IOT&E, have effectively stalled. The F-35 program's JSE schedule indicates that it plans to provide a fully accredited simulation for IOT&E use in May 2019; a schedule that carries high risk of further slips without resolving these issues, and is not credible. Without a high-fidelity simulation, the F-35 IOT&E will not be able to test the F-35's full capabilities against the full range of required threats and scenarios. However, for the reasons above, it is now clear that the JSE will not be available and accredited in time to support the Block 3F IOT&E. Therefore, the recently approved IOT&E detailed test design assumes only open-air flight testing will be possible and attempts to mitigate the lack of an adequate simulation environment as much as possible. In the unlikely event the JSE is ready and accredited in time for IOT&E, the test design has JSE scenarios that would be conducted.

Live Fire Test and Evaluation (LFT&E)

- The F-35 LFT&E program completed one major live fire test series using an F-35C variant full-scale structural test article (CG:0001). Preliminary test data analyses:
  - Demonstrated the tolerance of the vertical tail attachments to high-explosive incendiary (HEI) projectile threats
  - Confirmed the tolerance of the aft boom structures to Man-Portable Air Defense System (MANPADS) threats
  - Demonstrated vulnerabilities to MANPADS-generated fires in engine systems and aft fuel tanks. The data will support a detailed assessment in 2017 of these contributions to overall F-35 vulnerability.
- The test plan to assess chemical and biological decontamination of pilot protective equipment is not adequate; no plans have been made to test either the Gen II or the Gen III HMDS. The Program Office is on track to evaluate the chemical and biological agent protection and decontamination systems in the full-up system-level decontamination testing in FY17.
- The Navy conducted vulnerability testing of the F-35B electrical and mission systems to electromagnetic pulses (EMP).
- The 780th Test Squadron at Eglin AFB, Florida completed ground-based lethality tests of the PGU-47/U Armor Piercing High Explosive Incendiary with Tracer (APHEI-T) round, also known as the Armor Piercing with Explosive (APEX), against armored and technical vehicles, aircraft, and personnel-in-the-open targets.

Suitability

- The operational suitability of all variants continues to be less than desired by the Services. Operational and training units must rely on contractor support and workarounds that would be challenging to employ during combat operations. In the past year some metrics of suitability performance have shown improvement, while others have been flat or declined.

  - Most metrics still remain below interim goals to achieve acceptable suitability by the time the fleet accrues 200,000 flight hours, the benchmark set by the program and defined in the Operational Requirements Document (ORD) for the aircraft to meet reliability and maintainability requirements.
  - Reliability growth has stagnated and, as a result, it is highly unlikely that the program will achieve the ORD threshold requirements at maturity for the majority of reliability metrics, most notably Mean Flight Hours Between Critical Failures, without redesigning components of the aircraft.

Autonomic Logistics Information System

- The program failed to release any new ALIS capability in 2016, but did release two updates to the currently fielded ALIS 2.0.1 software to address deficiencies and usability shortfalls. The program planned to test and field ALIS 2.0.2, including integration of propulsion data management, in the summer of 2016, to support the Air Force declaration of Initial Operational Capability; however, delays in development and integration have pushed the testing and fielding into 2017.
- Because of the delays with ALIS 2.0.2, Lockheed Martin shifted personnel to support that product line development. This caused delays in the development schedule of ALIS 3.0, the last major SDD software release. The program acknowledged in August 2016 that it could not execute the ALIS 3.0 schedule and developed plans to restructure this ALIS release and the remaining planned ALIS capabilities into multiple releases, including some that will occur after SDD completion.
  - The program's restructuring of the ALIS capability delivery plan divided the planned capabilities and security updates for ALIS into four more versions: one version for SDD (ALIS 3.0), with what the Program Office considered to be needed for IOT&E, and three additional software releases intended to be fielded at 6-month intervals after SDD completion, with the remaining content originally planned for ALIS 3.0.
  - The program plans to release software maintenance updates midway between each of these four software releases to address deficiencies and usability problems, but these releases will not include new capabilities.
- The Air Force completed its first deployment of F-35A aircraft using the modularized version of the ALIS squadron hardware, called the Standard Operating Unit Version 2 (SOU v2), and software release 2.0.1 to Mountain Home AFB, Idaho in February 2016. Difficulties integrating the SOU v2 into the base network interfered with connectivity between the SOU v2 and the Mountain Home-provided workstations, but did not affect connectivity of the SOU v2 with the main Autonomic Logistics Operating Unit (ALOU) in Fort Worth, Texas.

Air-Ship Integration and Ship Suitability

- The program completed the last two ship integration DT periods in 2016 – both referred to as "DT-III" – one with the F-35B in November aboard the amphibious assault ship USS *America,* and one with the F-35C in August aboard the aircraft carrier USS *George Washington*. Test objectives included expanding the flight clearances for shipboard operations with carriage of external weapons, night operations, and Joint Precision Approach Landing System (JPALS) integration testing. For both periods, operational and test units accompanied the deployment to develop concepts of operations for at-sea periods.
- The specialized secure space set aside for F-35-specific mission planning and the required Offboard Mission Support (OMS) workstations is likely unsuitable for regular Air Combat Element (ACE) operations on the Landing Helicopter Dock (LHD) and Landing Helicopter Assault (LHA)-class assault ships with the standard complement of six F-35B aircraft, let alone F-35B Heavy ACE configurations with more aircraft. Similarly, for F-35C operations onboard CVN, adequate secure spaces will be needed to ensure planning and debriefing timelines support carrier operations.
- The F-35C DT-III included external stores, including bombs, but only pylons with no AIM-9X missiles on the outboard stations (stations 1 and 11) due to the F-35C wingtip structural deficiency. The U.S. Navy directed a proof-of-concept demonstration of an F-35C engine change while underway, a process that took several days to complete. ALIS was not installed on USS *George Washington*, so reach-back via satellite link to the shore-based ALIS unit was required, similar to previous F-35C test periods at sea, but connectivity proved troublesome.
- The F-35B DT-III deployment included an engine installation due to required maintenance, along with a lift fan change proof-of-concept demonstration. The Marine Corps deployed with an operational SOU v2 on USS *America*.

Cybersecurity Testing

- The JSF Operational Test Team (JOTT) continued to conduct cybersecurity testing on F-35 systems, in partnership with certified cybersecurity test organizations and personnel, and in accordance with the cybersecurity strategy approved by DOT&E in February 2015. In 2016, the JOTT conducted adversarial assessments (AA) of the ALIS 2.0.1 SOU, also known as the Squadron Kit, at Marine Corps Air Station (MCAS) Yuma, Arizona, and the Central Point of Entry (CPE) at Eglin AFB, Florida, completing testing that began in the Fall of 2015. They also completed cooperative vulnerability and penetration assessments (CVPA) of the mission systems ALOU at Edwards AFB, California, used to support developmental testing, and the operational ALOU in Fort Worth, Texas. The JOTT, with support from the

Air Force Research Laboratory (AFRL) also completed a limited cybersecurity assessment of the F-35 air vehicle in September 2016, on an F-35A aircraft assigned to the operational test squadron at Edwards AFB. These tests were not conducted concurrently as originally planned, so end-to-end testing of ALIS, from the ALOU to the air vehicle, has not yet been accomplished. An AA of the operational ALOU was scheduled for early December 2016, which would complete a full assessment (CVPA and AA) of each ALIS 2.0.1 component.

- The cybersecurity testing in 2016 showed that the program has addressed some of the vulnerabilities identified during earlier testing periods; however, much more testing is needed to assess the cybersecurity structure of the air vehicle and supporting logistics infrastructure system (i.e., ALOU, CPE, Squadron Kit) and to determine whether, and to what extent, vulnerabilities may have led to compromises of F-35 data. The scope of the cybersecurity testing must also expand to include other systems required to support the fielded aircraft, including the Multifunction Analyzer Transmitter Receiver Interface Exerciser (MATRIX) system which is used by contractor maintenance technicians, the USRL, avionics integration labs, the OMS and training simulators.

Follow-on Modernization

- The program continued making plans for Follow-on Modernization (FoM) for all variants, also referred to as Block 4, which is on DOT&E oversight. The program intends to award the contract for the modernization effort in 2QCY18 with developmental flight testing beginning in 3QCY19. Four increments of capability are planned, Blocks 4.1 through 4.4. Blocks 4.1 and 4.3 will provide software-only updates; Blocks 4.2 and 4.4 will include significant avionics hardware changes as well as software updates. Improved Technical Refresh 3 (TR3) processors with open architecture, designed to make adding, upgrading and replacing components easier, are planned to be added in Block 4.2.
- The program's plans for FoM are not executable for a number of reasons including, but not limited to the following:
  - Too much technical content for the production-schedule-driven developmental timeline
  - Overlapping increments without enough time for corrections to deficiencies from OT to be included in the next increment
  - High risk due to excessive technical debt and deficiencies from the balance of SDD and IOT&E being carried forward into FoM because the program does not have a plan or funding to resolve key deficiencies from SDD prior to attempting to add the planned Block 4.1 capabilities
  - Inadequate test infrastructure (aircraft, laboratories, personnel) to meet the testing demands of the capabilities planned and the multiple configurations (i.e., TR2, TR3, and Foreign Military Sales)
  - Insufficient resources for conducting realistic operational testing of each increment

System

- The F-35 Joint Strike Fighter (JSF) program is a tri-Service, multi-national, single-seat, single-engine family of strike aircraft consisting of three variants:
  - F-35A Conventional Take-Off and Landing (CTOL)
  - F-35B Short Take-Off/Vertical-Landing (STOVL)
  - F-35C Aircraft Carrier Variant (CV).
- The F-35 is designed to survive in an advanced threat environment (year 2015 and beyond) using numerous advanced capabilities. It is also designed to have improved lethality in this environment compared to legacy multi-role aircraft.
- Using an active electronically scanned array (AESA) radar and other sensors, the F-35 with Block 3F is intended to employ precision-guided weapons, such as the GBU-12 Laser-Guided Bomb (LGB), GBU-31/32 Joint Direct Attack Munition (JDAM), GBU-39 Small Diameter Bomb (SDB), Navy Joint Stand-Off Weapon (JSOW)-C1, and air-to-air missiles such as AIM-120C Advanced Medium-Range Air-to-Air Missile (AMRAAM), and AIM-9X infrared guided short-range air-to-air missile.
- The SDD program was designed to provide mission capability in three increments:
  - Block 1 (initial training; two increments were fielded: Blocks 1A and 1B)
  - Block 2 (advanced training in Block 2A and limited combat capability in Block 2B)
  - Block 3 (limited combat capability in Block 3i and full SDD warfighting capability in Block 3F)
- The F-35 is under development by a partnership of countries: the United States, Great Britain, Italy, the Netherlands, Turkey, Canada, Australia, Denmark, and Norway.

Mission

- The Combatant Commander will employ units equipped with F-35 aircraft in joint operations to attack targets during day or night, in all weather conditions, and in heavily defended areas.
- The F-35 will be used to attack fixed and mobile land targets, surface units at sea, and air threats, including advanced aircraft and cruise missiles.

Major Contractor

Lockheed Martin, Aeronautics Division – Fort Worth, Texas

Test Strategy, Planning, and Resourcing

- Preparations for IOT&E. In 2016, the JPO acknowledged schedule pressure for starting IOT&E in August 2017, as planned in the Integrated Master Schedule created in 2012. Due to multiple problems and further delays, the program will not be able to start IOT&E until late CY18, at the earliest, and more likely early CY19, but it could be as late as CY20 before required modifications are completed to IOT&E aircraft. The issues that will not allow IOT&E to start as planned include:
  - Continued schedule delays in completing Block 3F mission systems development and flight testing
    - The program's plan to deliver the "Full SDD Warfighting Capability" version of Block 3F software – now referred to as version 3FR6 – was significantly delayed. It was planned for release to flight test in February 2016, according to the program's latest mission systems software and capability release schedule, but did not begin flight test until early December 2016 (10 months late). However, during this time, the program released several "Quick Reaction Cycle" (QRC) versions of software to quickly resolve deficiencies that were preventing the completion of key test points, like weapons deliveries. Due to these delays, along with the recently acknowledged SDD funding shortfall, software versions 3FR7 and 3FR8 have fallen off the program's schedule. However, ongoing delays in maturing some of the capabilities and new problem discoveries continue to prevent testing of some planned Block 3F capabilities and will almost certainly require additional unplanned releases of Block 3F software.
    - DOT&E estimates that mission systems flight testing will not complete prior to July 2018, based on the number of Block 3F baseline mission systems test points to go, the monthly average mission systems test point completion rate observed for CY16 to date, and the average regression, discovery and developmental test point rate of 63 percent experienced so far in CY16. This estimate also includes a decrement of 11 percent for test points to be designated "no longer required," the percentage used by the Program Office to account for efficiency in CY16 planning of test point accomplishment objectives.
  - Delayed and incomplete Block 3F developmental testing Weapons Delivery Accuracy (WDA) events and ongoing weapons integration issues
    - WDA events – key developmental test activities necessary to ensure the full fire-control capabilities work together to properly support the "find, fix, track, target, engage, assess" kill chain – are not complete. As of the end of November, only 5 of the 26 WDA events (excluding gun events) had been completed and fully analyzed.
    - Several WDAs have revealed deficiencies and limitations to weapons employment (e.g., AIM-9X seeker status tone problems and out-of-date launch zones for AIM-120 missiles). An additional 11 WDAs had occurred, but analyses are ongoing. Of the 10 remaining WDAs, 4 were still blocked due to open deficiencies that must be corrected before the WDA can be attempted, but the program did not have time to complete and analyze them before finalizing Block 3FR6.
  - Continued delays in completing flight sciences test points, particularly those needed to provide the F-35B Block 3F flight envelope for operational use
    - Through the end of November, flight sciences testing on all variants was behind the plan for the year. Although the program planned to complete Block 3F testing on the F-35A in October, testing continued into December, with weapons separations and regression testing of new software to be completed.
    - Flight sciences test point completion for CY16 was 5 percent behind for the F-35B and 23 percent behind for the F-35C as of the end of November. The program plans to complete Block 3F flight sciences testing in August 2017 with the F-35C and by the end of October 2017 with the F-35B, the latter being 10 months later than planned in the program's Integrated Master Schedule.
    - Due to the delays with completing flight sciences testing, the program plans a phased release of the Block 3F envelope across all three variants, with the full Block 3F envelope for the F-35B not being released until mid-CY18.
  - Further delays in completing gun testing for all three variants and recently discovered gunsight deficiencies
    - Block 3F adds gun capability for all three variants. The F-35A gun is internal; the F-35B and F-35C each use a gun pod. Differences in mounting make the gun pods unique to a specific variant, i.e., a gun pod designated for an F-35B cannot be mounted on an F-35C aircraft. Flight sciences testing of the gun has occurred with the F-35A; discoveries required control law changes to the flight control software and delayed the start of mission systems gun testing on the F-35A from September 2016 to December 2016. Although the F-35B and F-35C have completed ground firings of their gun pods, airborne flight sciences gun testing (i.e., airborne firing) for the F-35B and F-35C has yet to be accomplished.
    - Besides the ongoing delays with software and gun modifications, both DT and OT pilots have reported concerns from preliminary test flights that the air-to-ground gun strafing symbology, displayed in the helmet, is currently operationally unusable and potentially unsafe to complete the planned testing due to a combination of symbol clutter obscuring the target, difficulty reading key information, and pipper stability. Also, for air-to-air employment, the pipper symbology is very unstable while tracking a target aircraft; however, the funnel version of the air-to-air gunsight appears to be more stable in early testing.
    - Fixing these deficiencies may require changes to the mission systems software that controls symbology

    to the helmet, or the radar software, even though the program recently released the final planned version of flight test software, Block 3FR6. Plans to begin flight testing of aimed gunshots, integrated with mission systems, which requires aiming with the helmet, on the F-35A were planned for fall of 2016, but had slipped to December 2016, at the soonest, before this new problem with the gun symbology was discovered.
  - F-35B ground test firing of its gun pod was accomplished in July 2016 and flight testing is planned to begin in January 2017; the F-35C conducted first ground firing in November 2016; flight testing is planned to begin in March 2017.
- Late availability of verified, validated and tested Block 3F MDLs
  - Failure by the program to plan for, procure, and provide the necessary Block 3F upgrades and the associated Mission Data File Generation (MDFG) tools to the USRL has caused delays in developing, testing, and verifying mission data loads for IOT&E.
  - If Block 3F MDFG tools are delivered in early CY17, verified, validated and tested MDLs will not be available for IOT&E until June 2018 (15 months later) at the soonest, which is late to need for both IOT&E and fielding of Block 3F.
  - In collaboration with partner nations, the program is developing multiple laboratories to produce MDLs tailored for country-unique requirements. Although these other laboratories may provide additional capacity for developing and testing MDLs, the MDL that will be used for IOT&E must be developed, verified, validated, and tested using operationally representative procedures involving the USRL.
- Continued shortfalls and delays with ALIS and late delivery of ALIS software version 3.0, the final planned version for SDD, which is at risk of slipping from early-CY18 into mid-CY18
  - The program has failed to deliver increments of ALIS capability as planned. No new capability has completed testing in 2016, although the program had planned to field ALIS 2.0.2, with the propulsion integration module included, by August 2016 to support the Air Force IOC declaration, but continued problems caused this to slip into early CY17.
  - The program restructured the ALIS capabilities delivery plan in 2016 and moved content planned for ALIS 3.0 – the last version to be developed during SDD – to post-SDD ALIS development and fielding. Despite the delays and deferred content, IOT&E will still evaluate the suitability of the F-35 with ALIS in operationally realistic conditions.
- Significant, well-documented deficiencies resulting in overall ineffective operational performance of Block 3F, hundreds of which will not be adequately addressed with fixes and corrections verified with flight testing within SDD
  - The program, Services, JOTT, and DT and OT pilots recently conducted a review of the status and priority of open deficiency reports (DRs). This review was a follow-on from a review in the spring of 2016, where the stakeholders reviewed all the open DRs and created a rank-ordered list of 263 priority deficiencies to be addressed by the program. The review team later pared the list down to 176 priority DRs, with 12 being brought forward to the JPO's Configuration Steering Board (CSB); 7 for decision and 5 for CSB awareness. In the review in the fall of 2016, the stakeholders reviewed the approximately 1,200 open deficiencies, including the original 176 priority DRs, plus 231 new DRs since Feb 2016, minus 55 that had been corrected, to create an updated DR list. This time, however, the team prioritized the open DRs into one of 4 priorities: priority 1 DRs are "service critical," and the Services will not field the aircraft unless these DRs are fixed; priority 2 have significant impact that may, when combined with other DRs, lead to mission failure; priority 3 carry medium impact and should be addressed by the program, but maybe not within SDD; and priority 4 have low impact. The review team identified 72 DRs as priority 1 and 204 DRs as priority 2, for a total of 276 DRs to address within SDD or risk fielding deficiencies that could lead to operational mission failures during IOT&E or combat.
  - While these deficiencies must be addressed to some degree during the remaining time in development, the final planned software load, Block 3FR6, which started flight test in December 2016, only included attempted fixes for less than half of the 276 priority 1 and 2 DRs. Corrections to these deficiencies will need to be developed, tested in the labs (if possible) and then flight tested, since the labs have proven to not be an adequate test venue for verifying corrections to deficiencies identified during flight testing. However, the current schedule-driven program plans to close out SDD testing in 2017 do not include enough time to fix these key deficiencies, nor time to verify corrections in flight test. There is risk in attempting to verify DR fixes only in the lab because the labs proved to not always be representative of the actual aircraft for detecting problems or verifying fixes for stability problems. The labs are also not able to adequately replicate the demands on the mission systems like open air testing does, such as infrared and radar background clutter and terrain-driven multipath reflections of radio-frequency emissions from threat emitters, so most fixes to deficiencies will require flight testing.
- Overall ineffective operational performance with multiple key Block 3F capabilities to date
  - Three independent assessments conducted during the past 6 months rate the F-35 as red or unacceptable (not all assessments used the same scoring criteria) in most critical combat mission areas: The Air Force's IOC Readiness Assessment (IRA) of Block 3i, an OT

community assessment of Block 3FR5.03 based on observing develomental testing, and an assessment by the JOTT of the capability of Block 3FR5.05 to perform the planned mission trials in the IOT&E, based on observing and assisting with DT.

- ▪ In July, the Air Force completed their IRA report. The assessment was based on a limited series of events conducted with six Block 3i-configured aircraft, including test missions in Close Air Support (CAS), Air Interdiction (AI), and Suppression/Destruction of Enemy Air Defenses (SEAD/DEAD). The assessment noted unacceptable problems in fusion and electronic warfare and, concerning the CAS mission, determined that the Block 3i F-35A does not yet demonstrate equivalent CAS capabilities to those of fourth generation aircraft.
- ▪ In August, an F-35 OT pilot from Edwards AFB, California, briefed the results of an OT community assessment of F-35 mission capability with Block 3FR5.03, based on observing developmental flight test missions and results to date. This OT assessment rated all IOT&E mission areas as “red,” including CAS, SEAD/DEAD, Offensive Counter Air (OCA) and Defensive Counter Air (DCA), AI, and Surface Warfare (SuW). Several DT Integrated Product Team representatives also briefed the status of different F-35 mission systems capabilities, most of which were rated “red,” and not meeting the entrance criteria to enter the “graduation level” mission effectiveness testing. Trend items from both the OT and IPT briefings were limitations and problems with multiple Block 3F system modes and capabilities, including Electro-Optical Targeting System (EOTS), Distributed Aperture System (DAS), radar, electronic warfare, avionics fusion, identification capabilities, navigation accuracy, GPS, datalinks, weapons integration and mission planning.
- ▪ In November 2016, the JOTT provided an assessment of a later version of Block 3F software – version 3FR5.05 – based on observing and assisting with F-35 DT flight operations and maintenance. The JOTT assessment made top-level, initial predictions of expected IOT&E results of the F-35 with Block 3FR5.05 against planned scenarios and realistic threats. For mission effectiveness, the assessment predicted severe or substantial operational impacts across all the planned IOT&E missions (similar to the list of missions above) due to observed shortfalls in capabilities, with the exception of the Reconnaissance mission area, which predicted minimal operational impact. Unlike the other assessments, the JOTT also assessed suitability, predicting mixed operational impacts due to shortfalls for deployability (from minimal to severe), severe impacts for mission generation, and substantial impacts for training and logistics support.

- Continued low aircraft availability, especially for the early production lot IOT&E aircraft. The program has still not been able to improve aircraft availability, in spite of reliability and maintainability initiatives, to the goal of 60 percent, which is well short of the 80 percent necessary to conduct an efficient IOT&E and to support sustained combat operations. As a result, IOT&E will likely take longer than currently planned and suitability, along with fielded operations, will be adversely affected.
- Late delivery of the JSE, a man-in-the-loop simulator expected for IOT&E, which required the test team to create a test design that attempts to mitigate the high likelihood that it will not be available. Some IOT&E measures of effectiveness will not be fully resolved without a verified, validated and accredited simulator to evaluate the F-35 in an operationally realistic, dense threat environment.
- Progress in verification of Joint Technical Data (JTD) is behind plans to complete within SDD, particularly those for troubleshooting aircraft fault codes and for support equipment. As of September 2016, the program had verified approximately 83 percent of all JTD modules, but just over 50 percent of those associated with support equipment. While symptomatic of an immature system, the lack of verified JTD makes the completion of aircraft maintenance more difficult and forces maintainers to rely more heavily on submitting electronic requests to the contractor for help or to seek assistance from contractor representatives at field locations.
  - ▪ The program has made significant progress in verifying JTD for sustaining the aircraft’s low observable signature, primarily by completing verifications on an F-35A damaged in 2014 by an engine fire
  - ▪ All Block 3F JTD must be written and verified prior to the start of IOT&E
- Delays in completing the extensive and time-consuming modifications required to the fleet of operational test aircraft which, if not mitigated with an executable plan and contract, could significantly delay the start of IOT&E.
  - ▪ The program is developing and working plans with Lockheed Martin and the Services to provide production-representative operational test aircraft, with the necessary instrumentation, to start IOT&E. Although it was part of the agreed-to entrance criteria for IOT&E, the program currently does not have an adequate plan to provide test aircraft that meet the TEMP criteria for entering IOT&E until late-2018, at the earliest, and possibly as late as 2020. Extensive modifications are required on all of the TEMP-designated OT aircraft; 155 different modifications (known to date) are necessary between all variants and all lots of aircraft (Lots 3 through 5) to bring the IOT&E aircraft to the required production-representative configuration, although no single aircraft requires all 155 modifications. Additional discoveries and modifications are likely as the program finishes SDD.
  - ▪ The Program Office and the Services are considering using later lot aircraft with an alternate instrumentation package. However, to date, no analyses of the adequacy of the alternate instrumentation has been completed; nor is there a contract to design, build and test alternative packages.
- Insufficient progress in the development and testing of modeling, simulations, and instrumentation required for IOT&E.

    - Flight testing to allow the Data Acquisition Recording and Telemetry (DART) pod to be used throughout the full Block 3F flight envelope during IOT&E, including during simulated weapons releases when the weapons bay doors will cycle open, has not yet been planned, put on contract or completed. The DART pod is required for collecting data during IOT&E.
    - Flight testing of the Air-to-Air Range Infrastructure (AARI) – as integrated with the F-35 and required for adequacy of the open air flight test trials – has not yet been completed. AARI is used to support battle-shaping of air-to-air engagements by modeling weapon fly-outs and accounting for endgame effects to remove aircraft "shot down" by another aircraft or ground threat. The program must begin testing AARI and allow for corrections of deficiencies during flight testing, to ensure AARI is adequate for IOT&E.
    - Integration of AARI and associated range simulators with the F-35 to indicate inbound missiles on cockpit displays is required for an adequate evaluation of open air missions. Within the aircraft, the Embedded Training (ET) function is intended to support live/virtual/constructive training using a mixture of real and virtual entities (e.g., missiles, ground systems, and aircraft). To avoid intermingling data from real and virtual entities, as it may cause issues within the F-35, the contractor developed a separate model, the Fusion Simulation Model (FSM), to emulate fusion functionality for virtual entities within ET. The current FSM implementation has significant deficiencies that make the model so inaccurate that some required capabilities may not be usable for IOT&E. Although a properly functioning FSM is required for IOT&E, the program had not yet completed contract actions for fixes to correct the FSM deficiencies within SDD and prior to IOT&E, but was apparently developing plans and intended to award contract actions for at least some of the work on FSM by the end of January 2017.
    - Virtual Threat Insertion (VTI) is a function inside of FSM that correlates virtual threat parametric data supplied by AARI with data from tables embedded within the FSM to provide cockpit display indications to the pilot for threat activity (i.e., a surface-to-air missile launched). The reference tables for VTI are incomplete and do not include all threats planned for use in IOT&E. The program was also apparently planning to update the VTI tables, but this was also not yet on contract.
    - The Logistics Composite Model (LCOM), which will be used to support assessments of suitability measures including sortie generation rate and logistics footprint – two key performance parameters in the ORD – is still under development. Seven versions of the model will be needed to cover the three variants as well as partner-unique and shipborne operations.
  - The program is behind in developing and fielding training simulators, referred to as F-35 Full Mission Simulators (FMS), to train pilots, both at the integrated training centers for initial F-35 pilot training and at the operational locations. The FMS is a multi-ship, man-in-the-loop, F-35 mission systems software-in-the-loop simulation using virtual threats, it is used to train both U.S. and partner pilots.
    - In 2014, the program moved simulator development from Akron, Ohio to Orlando, Florida. As a result of the move, the program lost experienced personnel, suffered from shortfalls in required staffing, and fell behind in meeting the hardware and software demands of the rapidly growing pilot training requirements.
    - In March 2016, following an inspection of the Block 2B FMS, evaluators reported 203 test discrepancies; 173 remained open, 4 were canceled, 2 were pending corrections, and 24 had been closed and corrections included in the next build of FMS for Block 3i.
    - The Block 3i FMS is behind the planned schedule for fielding. The first Block 3i FMS is scheduled for delivery to Marine Corps Air Station Iwakuni, Japan, in December 2016, followed by two more FMS delivered to partner countries.
    - Because of delays in delivering the Block 3i FMS, the Block 3F FMS is even further behind schedule. Although earlier plans included delivering the Block 3F FMS in CY17, the program is now replanning the schedule.
    - Since the FMS runs F-35 mission systems software, it requires Block 3F mission data files, integrated with virtual threats, to build the threat environment simulation (TES). It currently takes up to 20 months for the program to build the TES after new mission data files are available, hence pilots will not have Block 3F FMS, with the USRL-produced mission data files, available for training prior to IOT&E. Alternatively, the program may elect to use the contractor-developed DT mission data files for the Block 3F FMS. However, doing so would make the training in the FMS not operationally representative, as those mission data files do not accurately portray the TES to the pilot. Without an adequate Block 3F FMS, the OT pilots will have to rely on the available Block 3F OT aircraft for training.
- The JOTT completed detailed test designs for accomplishing IOT&E. DOT&E approved the designs in August 2016. The test designs include comparisons of the F-35 with the A-10 in the Close Air Support role, the F-16C (Block 50) in the Suppression/Destruction of Enemy Air Defenses (SEAD/DEAD) mission area, and the F-18E/F in the air-to-surface strike mission area. The JOTT has begun detailed test planning based on these designs, and will provide these plans to DOT&E for approval, prior to the start of IOT&E.
- Block Buy. The program and Services continue to pursue a "Block Buy" for production lots 12 through 14. This multi-year procurement scheme is based on a partial group of the partner nations, designated as "Full Participants," funding a 2 percent Economic Order Quantity (EOQ) in FY17 and another 2 percent EOQ in FY18. Other partner nations,

designated "Partial Participants," would procure Lot 12 as a single year lot procurement, then commit to procuring Lots 13 and 14 as a part of the Block Buy and provide funding of 4 percent EOQ in FY18. Similar to the Partial Participants, the Services would procure Lot 12 as a single year procurement and fund 4 percent EOQ in FY18, but maintain the options for single year procurements in Lots 13 and 14. Altogether, 452 F-35 aircraft would be procured under the Block Buy scheme, on top of the 490 aircraft (346 for the U.S. Services) previously procured in lots 1-11, all purchased without the informed results of an IOT&E. As reported in the FY15 DOT&E Annual Report, many questions remain on the prudence of committing to the multi-year procurement of a Block Buy scheme prior to the completion of IOT&E:

  - Is the F-35 program sufficiently mature to commit to the Block Buy with the ongoing rate of discovery while in development?
  - Is it appropriate to commit to a Block Buy given that essentially all the aircraft procured thus far require modifications to be used in combat? The Services will have accepted delivery of 346 aircraft through Lot 11, before the additional aircraft are purchased via the Block Buy scheme.
  - Would committing to a Block Buy prior to the completion of IOT&E provide the contractor with needed incentives to fix the problems already discovered, as well as those certain to be discovered during IOT&E?
  - Would the Block Buy be consistent with the "fly before you buy" approach to acquisition advocated by the Administration, as well as with the rationale for the operational testing requirements specified in title 10, U.S. Code, or would it be considered a "full rate" decision before IOT&E is completed and reported to Congress, not consistent with the law?

- Follow-on Modernization (FoM). The program continued making plans for all variants for FoM, also referred to as Block 4, which is on DOT&E oversight. The program intends to award the contract for the modernization effort in 2QCY18 with developmental flight testing beginning 3QCY19. Four increments of capability are planned, Blocks 4.1 through 4.4. Blocks 4.1 and 4.3 will provide software-only updates, Blocks 4.2 and 4.4 will add hardware as well as software updates. Improved Technical Refresh 3 (TR3) processors are planned to be added in Block 4.2. However, the plans for FoM are not executable for a number of reasons including, but not limited to, the following:
  - Too much technical content for the allocated developmental timeline. Experience with the F-22 modernization program indicates the planned 18- to 24-month cycle for FoM is insufficient for the large number of planned additional capabilities; the F-22 increments had less content plus software maintenance releases between new capability releases.
  - High risk of carrying excessive technical debt and deficiencies from Block 3F and the balance of SDD into FoM. The planned 4-year gap between the planned final release of Blocks 3F in 2017 and Block 4.1 in 2021 lacks resources (i.e., funding and time) for a bridge software maintenance release to reduce technical debt and verify Block 3F IOT&E corrections of deficiencies. Although the unresolved technical debt is an SDD shortfall, it sets up FoM to fail due to unrealistic planning and inadequate resourcing.
  - Insufficient time for conducting adequate operational testing for each increment.
    - The current plan for F-35 Block 4.2 only has 18 months for DT flight test and 6 months for OT&E, despite containing substantially more new capabilities and weapons than F-22 Block 3.2B.
    - For comparison, the F-22 Block 3.2B program planned approximately two years for DT flight test and one year of OT&E spin-up and flight test; F-22 Blocks 3.1, 3.2A and 3.2B have suffered delays and problems accomplishing testing due to inadequate test resources and schedule.
  - Inadequate test infrastructure (aircraft, laboratories, personnel) to meet the testing demands of the capabilities planned.
    - The current end-of-SDD developmental test aircraft drawdown plan is still being developed. However, any plan that significantly reduces the F-35 test force in 2017 and 2018 – precisely when the program needs this test force to finish the delayed SDD Block 3F Joint Test Plan (JTP) and correct remaining deficiencies with additional Block 3F updates in preparation for IOT&E – would result in shortfalls of the necessary resources to provide full Block 3F capability.
    - A robust test force will also be required to be available through 2020 to correct the inevitable new discoveries from IOT&E and produce a final Block 3F software release that provides a stable foundation for adding the new Block 4.1 capabilities.
    - The program plans to award contracts to start simultaneous development of Blocks 4.1 and 4.2 in 2018, well prior to completion of IOT&E and having a full understanding of the deficiencies that will emerge from IOT&E; without any budget or time to fix deficiencies from earlier development.
    - The requirement to integrate and test multiple configurations simultaneously (TR2 and TR3) will require additional time, test aircraft, and lab resources; a problem that must be addressed as the program considers plans for the fleet of test aircraft for FoM.
    - As of the writing of this report, the program's published FoM plan would have reduced test infrastructure from 18 DT aircraft and 1,768 personnel, which are still heavily tasked to complete ongoing Block 3F development, to just 9 aircraft and approximately 600 personnel to support FoM. Clearly, this plan is grossly inadequate. However, the program and Services were in the process of replanning the test infrastructure for FoM and had not yet provided the results.

  - Both the Air Force and the Navy conducted independent studies in 2016 to determine what infrastructure and test periods for FoM would be adequate. Neither report had been released as of the time of this report. DOT&E has requested to see the preliminary results of the Air Force study, but the Air Force has refused to provide them, citing the fact that the results are not final and the report is in draft.
- Significant technical and schedule risk due to Block 4.1 adding new capabilities to the already-stretched TR2 avionics hardware, along with Block 4.2 attempting to simultaneously migrate to a new open-architecture TR3 processor while adding many significant new capabilities.
  - For Block 4.1, the program plans to add multiple new capabilities to the TR2 avionics hardware, even though this architecture already has memory and processing limitations running the full Block 3F capabilities, resulting in avionics stability issues and capability limitations.
  - For Block 4.2, the program plans to simultaneously add multiple significant new software capabilities while migrating to a new avionics hardware configuration, including a new open-architecture TR3 processor and new electronic warfare (EW) hardware. This will be far more challenging than the program's problematic re-hosting of Block 2B software, designed to run on TR1 processors, on to TR2 processors to create Block 3i. Although no new capabilities were added in Block 3i, significant avionics stability issues were manifested due to technical debt and differences with the new architecture.
  - The program claims the new F-35 Block 4.2 software, which will be designed to run on new TR3 processors, will also be backward-compatible to run in the hundreds of early production aircraft with TR2 processors, but has not yet presented a plan to demonstrate this. Based on the current TR2 architecture capacity limitations with Block 3F, this claim is unlikely to be realized.
  - Instead of adding lab capacity to support testing of processor loads with the additional mission systems capabilities, the program plans to reduce the lab infrastructure supporting development. The program has already retired the Cooperative Avionics Test Bed aircraft – a decision that has increased the burden on flight testing with F-35 aircraft.
  - Current JPO projections for modifying aircraft with TR2 processors to the TR3 processor configuration extend into the 2030s. As a result, up to three configurations of test aircraft and labs may be needed if the program requires more advanced processors than the TR3 planned for Block 4 (i.e., the next Block upgrade requiring even more processing capacity driving the need for new processors).
  - The program also does not yet have an executable plan to provide a mission data reprogramming lab in the TR3 configuration in time to support Block 4.2 OT and fielding.
- Attempting to proceed with the current unrealistic plans for FoM would be to completely ignore the costly lessons learned from Block 2B, 3i and 3F development, as well as those from the F-22 program. As learned from the F-22 Blocks 3.1, 3.2A and 3.2B, an overly aggressive plan with inadequate resources ultimately takes longer, costs more and delays needed capabilities for the warfighter.

- This report includes assessments of the progress of testing to date, including developmental and operational testing intended to verify performance prior to the start of IOT&E. Test flights and test points are summarized in two tables on the next page.
  - For developmental flight testing, the program creates test plans by identifying specific test points (discrete measurements of performance under specific flight test conditions) for accomplishment, in order to assess the compliance of delivered capabilities with contract specifications.
    - Baseline test points refer to points in the test plans that must be accomplished in order to evaluate if performance meets contract specifications.
    - Non-baseline test points are accomplished for various reasons. Program plans include a budget for some of these points within the capacity of flight test execution. The following describes non-baseline test points.
      - Development points are test points required to "build up" to, or prepare for, the conditions needed for assessing specification compliance (included in non-baseline budgeted planning in CY16).
      - Regression points are test points flown to ensure that new software does not introduce shortfalls in performance for requirements that had previously been verified using previous software (included in non-baseline budgeted planning in CY16).
      - Discovery points are test points flown to investigate root causes of newly discovered deficiencies or to characterize deficiencies so that the program can design fixes for them (not included in planning in CY16).
    - As the program developed plans for allocating test resources against test points in CY16, the program included a larger budget for non-baseline test points (development and regression points) for mission systems testing, as the plans for the year included multiple versions of software, requiring regression and developmental test points be completed. For CY16 mission systems testing, planners budgeted an additional 69 percent of the number of planned baseline test points for non-baseline test purposes (e.g., development and regression points), the largest margin planned for a CY to date. This large margin was planned because the program anticipated the test centers would need points for building up to the baseline points that would be flown for specification compliance as well as for completing regression of multiple versions of Block 3F software. In this report, growth in test points refers to points flown over and above the planned amount of baseline and budgeted non-baseline points (e.g., discovery points and any other added testing not originally included in the formal test plan).

- The continued need to budget for non-baseline test points in the CY16 plan is a result of the limited maturity of capabilities in the early versions of mission systems software. Although the program planned to complete developmental flight testing in January 2017, according to their Integrated Master Schedule, developed after the program was restructured in 2010, delays in issuing mature software to flight test made it clear that regression and development test points would still be needed throughout CY16.
- Cumulative SDD test point data in this report refer to the total progress towards completing development at the end of SDD.

- Limited operational testing was also conducted throughout the year to support assessments of weapon capability, deployment demonstrations, shipborne testing, and the Air Force's IOC declaration; results of these limited tests are used to support assessments throughout this report.

TEST FLIGHTS (AS OF NOVEMBER 30, 2016)

	All Testing	Flight Sciences			Mission Systems
	All Variants	F-35A	F-35B	F-35C	
2016 Planned	1,221	151	359	237	474
2016 Actual	1,362	226	386	271	479
Difference from Planned	+11.5%	+49.7%	+7.5%	+14.3%	+1.1%
Cumulative Planned	7,624	1,587	2,242	1,469	2,326
Cumulative Actual	7,853	1,697	2,318	1,479	2,359
Difference from Planned	+3.0%	+6.9%	+3.4%	+0.7%	+1.4%
Prior to CY16 Planned	6,403	1,436	1,883	1,232	1,852
Prior to CY16 Actual	6,492	1,471	1,932	1,209	1,880

TEST POINTS (AS OF NOVEMBER 30, 2016)

	All Testing	Flight Sciences						Mission Systems[1]		
		F-35A		F-35B		F-35C				
	All Variants	Block 3F Baseline	Budgeted Non-Baseline[2]	Block 3F Baseline	Budgeted Non-Baseline[2]	Block 3F Baseline	Budgeted Non-Baseline[2]	Block 3F	Budgeted Non-Baseline[2]	Other[3]
2016 Test Points Planned (by type)	8,774	1,205	159	1,876	115	1,695	146	1,189	1,534	855
2016 Test Points Accomplished (by type)	7,838	1,303	156	1,783	115	1,304	136	975	1,534	532
Difference from Planned	-10.7%	+8.1%	-1.9%	-5.0%	0.0%	-23.1%	-6.8%	-18.0%	0.0%	-37.8%
Points Added Beyond Budgeted Non-Baseline (Growth Points)	304	0		54		0		250		
Test Point Growth Percentage (Growth Points/Test Points Accomplished)	3.9%	0.0%		3.0%		0.0%		25.6%		
Total Points (by type) Accomplished in 2016[4]	8,142	1,459		1,952		1,440		3,291		
Cumulative Data										
Cumulative System Design and Development (SDD) Planned Baseline	51,060	12,225		15,994		12,604		10,237		
Cumulative SDD Actual Baseline	50,278	12,327		15,970		12,279		9,702		
Difference from Planned	-1.5%	+0.8%		-0.2%		-2.6%		-5.2%		
Est. Baseline Test Points Remaining	6,649	100		1,726		1,178		3,645		
Est. Non-Baseline Test Points Remaining	2,502	12		136		73		2,281		

1. Mission Systems Test Points for CY16 are shown only for Block 3F. Testing conducted to support Block 2B and Block 3i Mission Systems are discussed separately in the text. Cumulative numbers include all previous Mission Systems activity.
2. These points account for planned development and regression test points built into the 2016 plan; additional points are considered "growth." The total number of regression, development and discovery points completed is the sum of budgeted non-baseline test points accomplished plus points added beyond budgeted non-baseline.
3. Represents mission systems activity not directly associated with Block capability (e.g., radar cross section characterization testing, test points to validate simulator).
4. Total Points Accomplished = 2016 Baseline Accomplished + Added Points

Developmental Testing: F-35A Flight Sciences

Flight Test Activity with AF-1, AF-2, and AF-4 Test Aircraft

- F-35A flight sciences testing focused on:
  - Clearing the F-35A Block 3F flight envelope (i.e., to Mach 1.6, 700 knots, and 9.0 g) for loads, flutter, and weapons environment
  - Testing of the internal gun
  - Flight envelope clearance for external weapons required for full Block 3F weapons capability
  - Weapons separation testing of the AIM-9X missile (external only), GBU-12 bomb (external carriage added for Block 3F)
  - High energy braking, high sink rate landings, and arresting gear engagements
  - AF-4 completed all flight testing for which it had been slated, in July, and transitioned to chemical and biological testing in August

F-35A Flight Sciences Assessment

- The program planned to complete F-35A flight sciences testing by the end of October 2016; however, additional testing for weapons environment and regression of new software forced testing to continue into at least December 2016. The program was able to complete baseline test points to clear the aircraft structure for Block 3F envelope (up to 9 g, 1.6M and 700 knots), completing flutter testing on AF-2 on September 29 and loads testing on AF-1 on November 4, 2016. Through the end of November, the test team flew 50 percent more flights than planned (226 flown versus 151 planned) and accomplished 8 percent more baseline test points than planned for the year (1,303 test points accomplished versus 1,205 planned). These additional baseline test points were added by the program throughout the year and represent testing not originally budgeted for when the CY16 plans were made. The test team also flew an additional 156 test points for regression of new air vehicle software, all of which were within the budgeted non-baseline test points allocated for the year. As of the end of November the program had approximately 100 baseline test points remaining to complete F-35A flight sciences testing for Block 3F.
- The following discoveries were made during F-35A flight sciences testing:
  - Failure of the attachment joint, as indicated by the migration of the bushing in the joint, between the vertical tail and the airframe structure is occurring much earlier than planned, even with a newly designed joint developed to address shortfalls in the original design. In October 2010, the F-35A full scale durability test article, AJ-1, showed wear in the bushing of this joint after 1,784 test hours, which indicated that the joint will fall short of the 8,000 hours of service life required by the JSF contract specification. The program developed a redesigned joint and began installing them on the production line with Lot 6 aircraft, which began delivery in October 2014. Subsequently, in July 2015, when inspections showed bushing migrations and significant damage to the right and left side attachment joints in BF-3, one of the F-35B flight sciences developmental test aircraft, the joint was repaired and the bushing replaced to replicate the redesigned joint. In August, 2016, inspections of the joints in AF-2, one of the F-35A flight sciences developmental test aircraft, showed similar bushing migration requiring repair and bushing replacement in accordance with the redesign. On September 1, 2016, inspections of the vertical tail on BF-3 showed that the newly designed joint had failed, after only 250 hours of flight testing since the new joint had been installed, requiring another repair and replacement. BF-3 completed repairs and returned to flight on November 10, 2016.
  - Vibrations induced by the gun during firing are excessive and caused the 270 volts DC battery to fail. The program began qualification testing of a redesigned battery in 2015, but cracks in the casing discovered after the first series of testing required additional redesigning of the battery. Requalification of a newly designed battery has not yet occurred as of the writing of this report.
  - Limitations to the carriage and employment envelope of the AIM-120 missile above 550 knots may be required due to excessive vibrations on the missiles and bombs in the weapons bay. Analyses of flight test data and ground vibration test data are ongoing (this applies to all variants).
  - Excessive and premature wear on the hook point of the arresting gear has caused the program to consider a more robust redesign. In fact, the hook point has required replacement after only one engagement in some instances; the longest a hook point has lasted to date is five arrestments. This fails to meet the minimum service life of 15 arrestments. Additionally, failure of the hook point of the arresting gear on AF-4 occurred in July during testing of high speed engagements. However, this appears to be due to a malfunction of the Mobile Aircraft Arresting System (MAAS), which holds the arresting cable in place on both sides of the runway. The MAAS is designed to allow the arresting cable to slide across the hook upon engagement until the right and left sides are in equilibrium before the braking action to slow the aircraft takes place (this helps steer the aircraft toward the center of the runway during the engagement). For unknown reasons, only one side of the MAAS released the cable, resulting in the hook point becoming abraded by the arresting cable and failing 1.5 seconds after engagement.
  - Block 3F envelope testing required an inflight structural temperature assessment, which yielded higher than predicted air flow temperatures in the engine nacelle bay in high-speed portions of the flight envelope under high dynamic pressures. This resulted in higher than expected nacelle structural temperatures on both the F-35A and F-35C aircraft. Thermal stress analyses of the affected parts are necessary before the program can provide the full

Block 3F flight envelope for fleet release. The outcome may result in restricting fielded operational aircraft to 600 knots airspeed below 5,000 feet altitude or a structural change; this will be determined when the Services review the analyses and issue the military flight release, which certifies the operational flight envelope.

- All F-35 variants display objectionable or unacceptable flying qualities at transonic speeds, where aerodynamic forces on the aircraft are rapidly changing. Particularly, under elevated "g" conditions, when wing loading causes the effects to be more pronounced, pilots have reported the flying qualities as "unacceptable." The program adjusted control laws that govern flight control responses in an updated version of software released to flight test in March 2016. Results from flight testing of the software changes have not yet been released. Although the elevated g "dig-in" apparently affects all three variants, the program does not plan to develop any additional control law changes to mitigate these responses to aerodynamic effects in the transonic region. In operational fleet aircraft, g limit exceedances are annunciated to the pilot and, in peacetime, result in subsequent restricted maneuvering, mission termination, and a straight-in approach and landing to recover the aircraft. The aircraft is then down for some time for maintenance inspections and potential repairs. Also, the probability and long-term structural effects of the g exceedances should be assessed by the program and mitigated, if necessary.
- Foam insulation around the polyalphaolefin (PAO) coolant tubes that pass through wing and main body fuel tanks in F-35A aircraft was found to be failing after exposure to fuel. The discovery was made on a fielded production F-35A aircraft (AF-101) as it was undergoing depot-level modifications for fuel valves in August 2016. The program determined the cause was a failure of the manufacturing process with the sealant coating on the insulation designed to protect the insulation from being exposed to fuel. Instead, the sealant was permeable to fuel, permitting the insulation to absorb fuel and expand, forcing cracking and failure of the sealant coatings and eventual breakdown and flaking of the insulation. This affected a total of 57 F-35A aircraft; 42 in the production process and 15 fielded aircraft. The Air Force temporarily grounded the 15 fielded aircraft, 10 of which were designated as Initial Operational Capability aircraft. The program quickly developed inspections and implemented procedures to mitigate the insulation problems for fielded aircraft and those too far in the production line to have the fuel lines replaced with proper insulation. The procedures vary depending on whether fuel has entered the tank with the PAO lines. For aircraft in which the fuel tanks have contained fuel, the procedures involve accessing the affected fuel tanks, removing the defective insulation, installing blocking screens to prevent debris from leaving the tank (and possibly contaminating other tanks, clogging valves or affecting fuel pump operation). For the aircraft in the production line that have not yet had fuel in the tanks, the insulation will be removed from the PAO tubes, but screens will not be added to the tank. The program does not plan to re-insulate the PAO tubes, as the Block 3F avionics – which are cooled by the PAO – apparently have adequate thermal margin to tolerate the loss of insulation on the tubes. The program must ensure that deployed operating locations with high ambient temperatures – such as those in Southwest Asia – are able to provide the cooling effect necessary to prevent avionics overheat conditions, especially for heat-soaked aircraft with hot fuel tanks and during extended ground operations. The program will need to conduct another assessment for Block 4 avionics, and any new processors, to ensure the thermal margin with that hardware configuration is still adequate.
- An Air Force F-35A aircraft assigned to Luke AFB, Arizona, experienced a tailpipe fire during engine start while deployed to Mountain Home AFB, Idaho in September 2016, causing significant damage to the aircraft. The incident is under investigation.
- The program designed and fielded an electrical Engine Ice Protection System (EIPS) to protect the engine from ice damage when exposed to icing conditions during ground operations and in flight. Although it was qualified during SDD engine ground tests, no SDD aircraft have the system installed in the engine. The program fielded the system with later-lot production aircraft, but deficiencies in the system caused electrical shorting and damage to the composite blades (referred to as the Fan Inlet Variable Vanes) on the front of several engines. To prevent further damage to engines in the field, the program has disabled EIPS and is changing the technical orders to require pilots to shut down the aircraft if icing conditions are encountered on the ground. DOT&E is not aware of any corrections to the EIPS planned during SDD.
- The program completed the final weight assessment of the F-35A air vehicle for contract specification compliance in April 2015 with the weighing of AF-72, a Lot 7 aircraft. The actual empty aircraft weight was 28,999 pounds, 372 pounds below the planned not-to-exceed weight of 29,371 pounds. The actual weights of production aircraft since then have been stable, with no significant weight growth observed. Weight estimates for production Lots 10 and later indicate an expected weight growth of between 120 and 140 pounds, primarily due to new electronic warfare (EW) avionics. Weight management of the F-35A is important for meeting performance requirements and structural life expectations. The program will need to continue disciplined management of the actual aircraft weight beyond the contract specification as further discoveries during the remainder of SDD may add weight and result in performance degradation that would adversely affect operational capability.

Developmental Testing: F-35B Flight Sciences

Flight Test Activity with BF-1, BF-2, BF-3, BF-4, and BF-5 Test Aircraft

- F-35B flight sciences focused on:
  - Clearing the F-35B Block 3F flight envelope (i.e., to Mach 1.6, 630 knots, and 7.0 g)
  - High angle-of-attack testing with external stores
  - Air refueling with the British KC-30A Voyager and Air Force KC-10 aircraft
  - Mode 4 (i.e., flight with the lift fan engaged to support short takeoff and vertical landing operations) envelope expansion
  - Weapons separation testing of the AIM-9X missile (external only), GBU-12 bomb (external carriage added for Block 3F); Paveway IV bomb (internal and external) for the United Kingdom, AIM-132 missile (external only) for the United Kingdom
  - Ground gun fire testing with the F-35B gun pod; accomplished on BF-1 in July

F-35B Flight Sciences Assessment

- Through the end of November, the test team flew 8 percent more flights than planned (386 flown versus 359 planned), yet accomplished 5 percent less than the planned Block 3F baseline test points (1,783 points accomplished versus 1,876 planned). The team flew an additional 169 test points for regression of new air vehicle software, 115 of which were the budgeted non-baseline points planned for CY16 and 54 points representing growth.
- The following details discoveries in F-35B flight sciences testing:
  - Limitations to the carriage and employment envelope of the AIM-120 missile above 550 knots may be required due to excessive vibrations induced on the missiles and bombs in the weapons bay. Analyses of flight test data and ground vibration test data are ongoing (this applies to all variants).
  - All F-35 variants display objectionable or unacceptable flying qualities at transonic speeds, where aerodynamic forces on the aircraft are rapidly changing. Particularly, under elevated "g" conditions, when wing loading causes the effects to be more pronounced, pilots have reported the flying qualities as "unacceptable." The program adjusted control laws that govern flight control responses in an updated version of software released to flight test in March 2016. In the F-35B, an uncommanded aircraft g "dig-in" that exceeds design limits has been observed while performing elevated-g maneuvers in the transonic region between 0.9M and 1.05M. Significant g exceedances (up to 7.7 g; a 0.7 g exceedance) have occurred when pilots were attempting to sustain 6.5 g or greater in this region. Based on flight test data, the F-35B responses to transonic aerodynamic effects between 0.9M and 1.05M during rolling or elevated-g maneuvering cause uncommanded excursions that exceed the designed g limit as well. Although the elevated g "dig-in" apparently affects all three variants, the program does not plan to develop any additional control law changes to mitigate these responses to aerodynamic effects in the transonic region. In operational fleet aircraft, g limit exceedances are annunciated to the pilot, and in peacetime, result in subsequent restricted maneuvering, mission termination, and a straight-in approach and landing to recover the aircraft. The aircraft is then down for some time for maintenance inspections and potential repairs. Also, the probability and long-term structural effects of the g exceedances should be assessed by the program and mitigated, if necessary.
  - Horizontal tail overheating was experienced on BF-3 during loads testing while accelerating to 1.5M for a loads test point. The left horizontal inboard fairing surface reached temperatures that exceeded the design limit by a significant amount. Post-flight inspections revealed de-bonding on the trailing edge of the horizontal tail surface and heat damage was noted on the horizontal tail rear spar. Hardness checks on the rear spar were performed and were determined to be within the acceptable range. It is not yet known whether the program or the Services will impose airspeed or afterburner time restrictions in the Block 3F envelope due to horizontal tail overheating.
  - Failure of the attachment joint, as indicated by the migration of the bushing in the joint, between the vertical tail and the airframe structure, is occurring much earlier than planned, even with a newly designed joint developed to address shortfalls in the original design. In October 2010, the F-35A full scale durability test article, AJ-1, showed wear in the bushing of this joint after 1,784 test hours, which indicated that the joint will fall short of the 8,000 hours of service life required by the JSF contract specification. The program developed a redesigned joint and began installing them on the production line with Lot 6 aircraft, which began delivery in October 2014. Subsequently, in July 2015, when inspections showed bushing migrations and significant damage to the right and left side attachment joints in BF-3, one of the F-35B flight sciences developmental test aircraft, the joint was repaired and the bushing replaced, to replicate the redesigned joint. In August 2016, inspections of the joints in AF-2, one of the F-35A flight sciences developmental test aircraft, showed similar bushing migration requiring repair and bushing replacement in accordance with the redesign. On September 1, 2016, inspections of the vertical tail on BF-3 showed that the newly designed joint had failed, after only 250 hours of flight testing since the new joint had been installed, requiring another repair and replacement. BF-3 completed repairs and returned to flight on November 10, 2016.
  - An F-35B assigned to Marine Corps Air Station Beaufort, South Carolina, experienced a fire within the weapons bay during a training mission in late October 2016. The

incident, although still under investigation, resulted in a Class A mishap (involves loss of life or damage of more than $2 Million). The Marine Corps did not ground any of the training fleet as a result of the incident.

- The program designed and fielded an electrical Engine Ice Protection System (EIPS) to protect the engine and lift fan from ice damage when exposed to icing conditions during ground operations and in flight. Although it was qualified during SDD engine ground tests, no SDD aircraft have the system installed in the engine. The program fielded the system with later-lot production aircraft, but deficiencies in the system caused electrical shorting and damage to the composite blades (referred to as the Fan Inlet Variable Vanes) on the front of the several engines. To prevent further damage to engines in the field, the program has disabled EIPS and is changing the technical orders to require pilots to shut down the aircraft if icing conditions are encountered on the ground. DOT&E is not aware of any corrections to the EIPS planned during SDD.
- Weight management of the F-35B aircraft is critical to meeting the Key Performance Parameters (KPPs) in the Operational Requirements Document (ORD), including the Vertical Landing Bring-Back (VLBB) requirement, which will be evaluated during IOT&E. This KPP requires the F-35B to be able to fly an operationally representative profile and recover to the ship with the necessary fuel and balance of unexpended weapons (two 1,000-pound bombs and two AIM-120 missiles) to safely conduct a vertical landing.
  - The program completed the final weight assessment of the F-35B air vehicle for contract specification compliance in May 2015 with the weighing of BF-44, a Lot 7 production aircraft. Actual empty aircraft weight was 32,442 pounds, only 135 pounds below the planned not-to-exceed weight of 32,577 pounds and 307 pounds (less than 1 percent) below the objective VLBB not-to-exceed weight of 32,749 pounds.
  - The actual weights of production aircraft through Lot 8 have increased slightly, with the latest Lot 8 aircraft weighing approximately 30 pounds heavier than BF-44. Weight estimates for Lot 10 aircraft and later project weight growth of an additional 90 pounds, primarily due to additional EW equipment.
  - Known modifications to the 14 Lot 2 through 4 F-35B aircraft, required to bring those aircraft to the Block 3F configuration, are expected to potentially add an additional 350 pounds, which will push their weight above the objective not-to-exceed weight to meet the VLBB KPP. This KPP will be evaluated during IOT&E with an F-35B OT aircraft.
  - Estimates for FoM weight growth include an additional 250 pounds, which will exceed the vertical landing structural limit not-to-exceed weight of 33,029 pounds for the Lot 2 through Lot 4 aircraft. This additional weight may prevent these aircraft from being upgraded to the Block 4 configuration.

Developmental Testing: F-35C Flight Sciences

Flight Test Activity with CF-1, CF-2, CF-3, and CF-5 Test Aircraft

- F-35C flight sciences focused on:
  - Clearing the F-35C Block 3F flight envelope (i.e., to Mach 1.6, 700 knots, and 7.5 g)
  - Air refueling with F/A-18, KC-10, and KC-135 aircraft
  - Weapons separation testing of the AIM-9X missile (external only), Joint Standoff Weapon (JSOW, internal only), GBU-12 bomb (external carriage added for Block 3F)
  - Shore-based ship suitability testing with external stores, in preparation for shipborne trials that were conducted in August
  - High angle-of-attack testing with external stores
  - Testing of the Joint Precision Approach and Landing System (JPALS)
  - Ground gun fire testing with the F-35C gun pod; accomplished on CF-3 in November

F-35C Flight Sciences Assessment

- Through the end of November, the test team flew 14 percent more than planned flights (271 flown versus 237 planned), but accomplished 23 percent less than the planned Block 3F baseline test points (1,304 points accomplished versus 1,695 planned). The team flew an additional 136 test points for regression of new software, all of which were accounted for in the budgeted non-baseline points planned for the year.
- The following details discoveries in F-35C flight sciences testing:
  - Flight testing of structural loads with the AIM-9X air-to-air missile, which will be carried on external pylons outboard of the wing fold in the F-35C, shows exceedances above the wing structural design limit during flight in regions of aircraft buffet (increased angle-of-attack) and during landings. To address these deficiencies, the program is developing a more robust outer wing design, which is scheduled for flight testing in early CY17. Without the redesigned outer wing structure, the F-35C will have a restricted flight envelope for missile carriage and employment, which will be detrimental to maneuvering, close-in engagements.
  - Limitations to the carriage and employment envelope of the AIM-120 missile above 550 knots may be required due to excessive vibrations induced on the missiles and bombs due to the acoustics in the weapons bay. Analyses of flight test data and ground vibration test data are ongoing (this applies to all variants).
  - All F-35 variants display objectionable or unacceptable flying qualities at transonic speeds, where aerodynamic forces on the aircraft are rapidly changing. Particularly, under elevated "g" conditions, when wing loading causes the effects to be more pronounced, pilots have reported the flying qualities as "unacceptable." The program adjusted control laws that govern flight control responses in an updated version of software released to flight test in March 2016. In the F-35C, like the other variants, an

uncommanded aircraft g "dig-in" that exceeds design limits has been observed while performing testing of elevated-g maneuvers in the transonic region of the flight envelope. While attempting to sustain a maximum g (7.5g) turn, an F-35C test aircraft experienced 8.2 g – an exceedance of 0.7 g. The program does not plan to develop any additional control law changes to address the flying quality. Similar to the other variants, an over-g condition requires the pilot to terminate the mission (in peacetime) and recover the aircraft with a straight-in approach and landing with minimal maneuvering. The aircraft is then down for some time for maintenance inspections and potential repairs. Also, the probability and long-term structural effects of the g exceedances should be assessed by the program and mitigated, if necessary.

- Weapons environment testing showed that the aircraft experienced transient rolling conditions while asymmetrically opening and closing the weapon bay doors (WBD). The flight control laws were designed to compensate for the doors opening and closing asymmetrically. The program corrected the on-board aerodynamic models in two vehicle systems software updates (versions R31.1 and R35.1) to reduce the roll transients. These corrections resolved the transients for the subsonic and transonic flight regimes, but not for supersonic regimes. The operational impact of these transients will be assessed during IOT&E.
- Block 3F envelope testing required an inflight structural temperature assessment, which yielded higher than predicted air flow temperatures in the engine nacelle bay in high-speed portions of the flight envelope under high dynamic pressures. This resulted in higher nacelle structural temperatures on both the F-35A and F-35C aircraft. Thermal stress analyses of the affected parts are necessary before the program can provide the full Block 3F flight envelope for fleet release. The outcome may result in restricting fielded operational aircraft to 600 knots airspeed below 5,000 feet altitude, or a structural change; this will be determined when the Services review the analyses and issue the military flight releases, which will certify the operational flight envelope.
- As reported in previous DOT&E Annual Reports, the F-35C experiences buffet and transonic roll off (TRO), an uncommanded roll, at transonic Mach numbers and elevated angles of attack. It is caused by the impact of airflow separating from the leading edge of the wing that "buffets" aft areas of the wing and aircraft during basic fighter maneuvering. The TRO and buffet occur in areas of the maneuvering envelope that cannot be sustained for long periods of time, as energy depletes quickly and airspeed transitions out of the flight region where these conditions manifest. However fleeting, these areas of the envelope are used for critical maneuvers. Operational testing of the F-35C during IOT&E will assess the effect of TRO and buffet on overall mission effectiveness.
- Due to the stiffness of the landing gear struts, particularly the nose gear, taxiing in the F-35C results in excessive jarring of the aircraft and often requires pilots to stop taxiing if they need to make changes using the touchscreens on the cockpit displays or to write information on their kneeboard. Currently, the program has no plans to correct the deficiency of excessive jarring during F-35C taxi operations.
- Excessive vertical oscillations during catapult launches make the F-35C operationally unsuitable for carrier operations, according to fleet pilots who conducted training onboard USS *George Washington* during the latest set of ship trials. Although numerous deficiencies have been written against the F-35C catapult launch – starting with the initial set of F-35C ship trials (DT-I) in November 2014 – the deficiencies were considered acceptable for continuing developmental testing. Fleet pilots reported that the oscillations were so severe that they could not read flight critical data, an unacceptable and unsafe situation during a critical phase of flight. Most of the pilots locked their harness during the catapult shot which made emergency switches hard to reach, again creating, in their opinion, an unacceptable and unsafe situation. The U.S. Navy has informed the Program Office that it considers this deficiency to be a "must fix" deficiency. The program should address the deficiency of excessive vertical oscillations during catapult launches within SDD to ensure catapult operations can be conducted safely during IOT&E and during operational carrier deployments.
- Overheating of the Electro-Hydraulic Actuator System (EHAS) occurs under normal maneuvering in the F-35C. The EHAS actuators move the flight surfaces and are cooled by airflow across the control surfaces. Pilots are alerted in the cockpit of an overheat condition and must then minimize maneuvering and attempt to cool the EHAS by climbing, if practical, to an altitude with lower temperatures to enhance cooling. Recovery and landing must be completed as soon as possible, terminating the mission.
- The program designed and fielded an electrical Engine Ice Protection System (EIPS) to protect the engine from ice damage when exposed to icing conditions during ground operations and in flight. Although it was qualified during SDD engine ground tests, no SDD aircraft have the system installed in the engine. The program fielded the system with later-lot production aircraft, but deficiencies in the system have caused electrical shorting and damage to the composite blades (referred to as the Fan Inlet Variable Vanes) on the front of the engine. To prevent further damage to engines in the field, the program has disabled EIPS and is changing the technical orders to require pilots to shut down the aircraft if icing conditions are encountered on the ground. DOT&E is not aware of any corrections to the EIPS planned during SDD.

  - Weight management of the F-35C is important for meeting air vehicle performance requirements, including the KPP for recovery approach speed to the aircraft carrier, and structural life expectations. The program completed the final weight assessment of the F-35C air vehicle for contract specification compliance in May 2016 with the weighing of CF-28, a Lot 8 aircraft. The actual empty aircraft weight was 34,581 pounds, 287 pounds below the planned not-to-exceed weight of 34,868 pounds. The weights of the other three Lot 8 production aircraft have been consistent with that of CF-28. Weight estimates for production Lots 11 and later indicate an expected weight growth of approximately 160 pounds. The program will need to continue rigorous management of the actual aircraft weight through the balance of SDD to avoid performance degradation that would affect operational capability.

Developmental Testing: Mission Systems

- Mission systems are developed, tested, and fielded in incremental blocks of capability.
  - Block 1. The program designated Block 1 for initial training capability in two increments: Block 1A for Lot 2 (12 aircraft) and Block 1B for Lot 3 aircraft (17 aircraft). No combat capability was available in either Block 1 increment. The Services have upgraded all of these aircraft to the Block 2B configuration through a series of modifications and retrofits. Additional modifications will be required to configure these aircraft in the Block 3F configuration.
  - Block 2A. The program designated Block 2A for advanced training capability and delivered aircraft in production Lots 4 and 5 in this configuration. No combat capability was available in Block 2A. The Services accepted 62 aircraft in the Block 2A configuration (32 F-35A aircraft in the Air Force, 19 F-35B aircraft in the Marine Corps, and 11 F-35C aircraft in the Navy). Similar to the Block 1A and Block 1B aircraft, the Services have upgraded all of the Block 2A aircraft to the Block 2B configuration with modifications and retrofits, although fewer modifications were required. Additional modifications will be required to fully configure these aircraft in the Block 3F configuration.
  - Block 2B. The program designated Block 2B for initial, limited combat capability with selected internal weapons (AIM-120C, GBU-31/32 JDAM, and GBU-12). This block is not associated with the delivery of any lot of production aircraft, but with an upgrade of mission systems software capability for aircraft delivered through Lot 5 in earlier Block configurations. Block 2B is the software that the Marine Corps accepted for the F-35B IOC configuration. Corrections to some deficiencies identified during Block 2B and Block 3i mission systems testing have been included in the latest production release of Block 2B software – version 2BR5.3 – fielded in May 2016 after airworthiness testing in April. The Services began converting aircraft from these earlier production lots to the Block 3i configuration by replacing the older Technical Refresh 1 (TR1) integrated core processor with newer Technical Refresh 2 (TR2) processors this year. As of the end of November, 1 F-35A (AF-31) and 1 F-35B (BF-19) had completed the TR2 modifications, both of which are instrumented operational test aircraft. The Marine Corps declared IOC with Block 2B-capable aircraft in July 2015.
  - Block 3i. The program designated Block 3i for delivery of aircraft in production Lots 6 through 8, as these aircraft include a set of upgraded TR2 integrated core processors. The program delivered Lot 6 aircraft with a Block 3i version that included capabilities equivalent to Block 2A in Lot 5. Lot 7 aircraft were delivered with capabilities equivalent to Block 2B, as are Lot 8 aircraft currently. Block 3i software began flight testing in May 2014 and completed baseline testing in October 2015, eight months later than planned in the Integrated Master Schedule (IMS). Because of software immaturity and instability during startup and in flight, the program paused flight testing of Block 3F software in February 2016 (software version 3FR5) and returned to Block 3i development and flight testing to address poor mission systems stability. After completing flight testing in April of another build of Block 3i software, version 3iR6.21, that version was fielded to the operational units with improved stability performance, which was similar to that seen in the latest build of Block 2B software. By the end of November, the program had delivered 51 F-35A aircraft to the Air Force, 17 F-35B aircraft to the Marine Corps, and 13 F-35C to the Navy in the Block 3i configuration in Lots 6, 7 and 8. The Air Force declared IOC with Block 3i-capable aircraft in August 2016.
  - Block 3F. The program designated Block 3F as the full SDD warfighting capability for production Lot 9 and later. Block 3F expands the flight envelope for all variants and includes additional weapons, external carriage of weapons, and the gun. Flight testing with Block 3F software on the F-35 test aircraft first began in March 2015. Flight testing of Block 3F mission systems software, version 3FR5, was paused in February 2016 when the program discovered that it was too unstable for productive flight testing. The program elected to reload a previous version of Block 3F software – version 3FR4 – on the mission systems flight test aircraft, to allow limited testing to proceed. After improving the flight stability of the Block 3i software, the program applied the corrections to deficiencies causing instabilities to the Block 3FR5 software and delivered another version to flight test – version 3FR5.02 – in March, to continue Block 3F testing. The program restarted Block 3F testing in earnest in May with Block 3FR5.03 and released several more Quick Reaction Cycle (QRC) versions, Blocks 3FR5.04 through 3FR5.07, through November 2016 in attempts to quickly address key deficiencies that were blocking test points. The program delivered the final planned version of Block 3F software –

3FR6 – to flight testing in December 2016. The program will then determine, with testing in early 2017, if additional QRC patches will be adequate to meet specifications, or if another full release of Block 3F software (e.g., 3FR7) will be required. Of note, all of the aircraft from earlier production lots, i.e., Lots 2 through 5 will need to be modified, including structural modifications and the installation of TR2 processors, to have full Block 3F capabilities. The program plans to begin delivering Lot 9 aircraft in early CY17. The Program Office has agreed to allow the initial Lot 9 aircraft to be delivered with Block 3i software. These provisional acceptances may continue until August 2017, when the program plans to have Block 3FP8 – the first version of Block 3F production software – for delivery of the remainder of Lot 9 and later aircraft.

- Block 4. The program has designated the first release of added capabilities following completion of SDD as Block 4, with four distinct increments (Blocks 4.1, 4.2, 4.3, and 4.4). Current program schedules plan for testing of Block 4.1 to begin at the end of CY19 with subsequent increments following at 2-year intervals. Hardware upgrades are planned in Blocks 4.2 and 4.4, and will include the next upgrade in processors with open-architecture Technical Refresh 3 (TR3) processors. Production cut-in for initial Block 4.1 capabilities is planned with Lot 13, beginning delivery in 2021, and Lot 15 for Block 4.2. The post-SDD development program is referred to as Follow-on Modernization (FoM). However, for reasons discussed elsewhere in this report, the program's initial FoM plan is not executable and is being re-planned by the program and stakeholders.

Flight Test Activity with AF-3, AF-6, AF-7, BF-4, BF-5, BF-17, BF-18, CF-3, CF-5, and CF-8 Flight Test Aircraft and Software Development Progress

- Mission systems testing focused on:
  - Attempting to resolve software stability problems with Block 2B and Block 3i mission systems
  - Block 3F mission systems development and testing
  - Initial integration testing of the U.S. Navy Joint Standoff Weapon, version C1 (JSOW-C1)
  - Completing weapons separation testing for the Small Diameter Bomb (SDB) version I (SDB-I), which requires mission systems-capable aircraft for interfacing with the SDB
  - Weapons integration and testing of the United Kingdom Paveway IV bomb and Advanced Short-Range Air-to-Air Missile (ASRAAM); determining root cause and options to fix ASRAAM integration deficiencies
  - On-Board Inert Gas Generation System (OBIGGS) testing on CF-8, the only F-35C test aircraft modified with the necessary hardware to complete testing
  - Regression testing of Block 2B software on operational test aircraft (AF-21, AF-23, BF-16 and BF-20), since the developmental test aircraft had all already been converted to the Block 3i or Block 3F configuration
  - Joint Precision Approach and Landing System (JPALS) testing with CF-5
  - Testing of the Gen III Helmet Mounted Display System (HMDS) illumination settings during the third F-35C developmental test period at sea, designed to correct excessive "green glow" during night operations onboard the carrier
  - The six mission systems developmental flight test aircraft assigned to the Edwards AFB test center flew an average rate of 6.9 flights per aircraft, per month in CY16 through November, slightly above the planned rate of 6.7 for the year, and flew slightly more than the planned number of flights (479 flights accomplished versus 474 planned).

Mission Systems Assessment

- Block 2B
  - Although the program completed Block 2B mission systems testing in 2015 and provided a fleet release version of the software to the fielded units, deficiencies remained and were carried forward into Block 3i. This schedule-driven decision to pass deficiencies forward had consequences. The many deficiencies, including instabilities in both Block 3i and Block 3F mission systems software, led the program to return to Block 3i development to make corrections. When the revised Block 3i software, Block 3iR6.21, demonstrated improved inflight stability, the program developed and tested another version of Block 2B software – version 2BS5.3 – with the corrections to the stability deficiencies included. This version was released to fielded units in May 2016 for the F-35A and F-35B, and in August 2016 for the F-35C; the program expects to complete retrofit of all fielded aircraft in the Block 2B configuration with the Block 2BS5.3 software by the end of January 2017.
  - Because the test center aircraft had all been upgraded to the Block 3i/3F configuration (i.e., with the newer TR2 processors), flight testing of the Block 2BS5.3 software occurred on OT aircraft assigned to the OT squadron at Edwards AFB, California.
- Block 3i
  - Block 3i began with the schedule-driven decision to rehost the immature Block 2B software and capabilities into new TR2 avionics processors. Because of the extreme overlap of development and production, combined with delays in software development, the program was forced to create a Block 3i capability to support delivery of Lot 6 and later aircraft, as they were being delivered with the new processors. Although the program originally intended that Block 3i would not inherit technical problems from earlier blocks, this is what occurred, resulting in severe problems with Blocks 3i and 3F software that needed to be addressed, affecting both Block 2B and Block 3i fielded aircraft, and stalling the progress of mission systems testing early in CY16.
  - When Block 3i developmental flight testing began in May 2014, six months later than planned in the program's

Integrated Master Schedule (IMS), the combination of rehosted, immature software and new processors resulted in severe avionics stability problems that were significantly worse than those in Block 2B. Continued delays in completing Block 2B software development and testing in support of the Marine Corps IOC, which was a priority over Block 3i development for the program and the test centers, combined with the severe stability problems with the early versions of Block 3i software, caused several pauses in early Block 3i flight testing. Block 3i flight testing resumed again in March 2015 and was considered to be complete in October 2015, eight months later than planned in the IMS. Despite the continued problems with avionics stability, sensor fusion, and other inherited issues from Block 2B, the program terminated Block 3i developmental flight testing in October 2015, and released Block 3i software to the fielded units. This decision was made in an attempt to meet the program's unrealistic schedule for completing development and flight testing of Block 3F mission systems.

  - The program created an initial version of Block 3F software by adding the final required capabilities and weapons to the problematic Block 3i software. However, productive and efficient flight testing was not possible due to inherited instabilities and other deficiencies. The Air Force insisted on fixes for seven (five identified in 2014 and two more in 2015) of the most severe deficiencies inherited from Block 2B as a prerequisite to use the final Block 3i capability in the Air Force IOC aircraft. Consequently, in February 2016, the program decided to return to Block 3i development and testing in another attempt to fix key unresolved software deficiencies, including the avionics instabilities troubling both Block 3i and Block 3F. A new version of mission systems software, Block 3iR6.21, was quickly developed and tested, and showed improvement to several of the "must fix" deficiencies identified by the Air Force and the inflight stability problems, so it was released to the fielded aircraft in late May 2016. Data collected on start-up and inflight stability of the Block 3iR6.21 mission systems software showed that both have improved over earlier versions of Block 3i, and are approximately equivalent to the final version of Block 2B software. Based on flights conducted with the production software through the end of October 2016, the Air Force reported that, of the seven "must fix" deficiencies, five had been corrected, one was partially corrected, but needed full Block 3F set of capabilities to ensure full implementation, and one – associated with extended post-mission download times from the aircraft's portable memory device (PMD) – was awaiting fielding of an upgraded ground data receptacle (see more detail in the ALIS section below).

- Block 3F
  - Block 3F flight testing began in March 2015, six months later than the date planned in the IMS.
  - The emphasis on, and return to, Block 3i testing in March and April 2016 contributed in part to the program's inability to progress with Block 3F flight testing at the planned rate. As of the end of November, a total of 975 Block 3F baseline test points had been completed in CY16, compared to 1,189 planned (82 percent of planned). An additional 1,784 development and regression points were flown, 1,534 of which were accounted for in the budgeted non-baseline points for the year and 250 representing growth.
  - The lag in completing baseline test points – which are used to verify capability – is also due to the program delivering Block 3F software to flight test that was not mature enough to meet specification compliance, or because deficiencies prevent the specification from being met. In an attempt to address the deficiencies and the lack of maturity in the software, the program began developing and delivering QRC versions of software to flight test. These software versions are built, lab tested, and delivered to flight test on a shorter timeline than the originally planned series of software versions for Block 3F.
  - Delays in starting Block 3F testing, pausing to redo Block 3i work, and the immaturity of the Block 3F software delivered to flight test have all contributed to the program being well behind the plan to complete Block 3F flight testing by the end of July 2017, the forecasted completion date according to the program's most recent Mission Systems Software and Capability Release Schedule. Instead, DOT&E estimates the program will likely not finish Block 3F development and flight testing prior to July 2018, based on the following:
    - Continuing a 6.5 test point per flight accomplishment rate, which is the CY16 rate observed through the end of November.
    - Continuing a flight rate of 6.9 flights per aircraft per month, as was achieved through the end of November.
    - Completing all of the baseline test points (3,645 remaining as of the end of November) and experiencing a regression, development and discovery test point work load of 63 percent (historical average, but well below the rate of 83 percent experienced in CY16 through November).
  - The program plans to truncate the planned testing by eliminating test points, instead using alternative test points or old data, in order to meet schedule deadlines with the expectation of finishing SDD, getting to IOT&E, and starting full-rate production. While this approach may provide a quick sampling assessment of Block 3F capabilities, there are substantial risks. The multiple recent software versions for flight test may prevent the program from using data from older versions of software to count for baseline test point deletions because it may no longer be representative of Block 3F. Limited availability and high cost of range periods, combined with high re-fly rates for test missions completed on the Western Test

Range, make it difficult for the program to efficiently conduct this testing. Finally, the most complex capabilities in Block 3F have only recently reached the level of maturity to allow them to be tested, and they are also some of the most difficult test points to execute (i.e., full Block 3F capabilities and flight envelope). Such a risky course of action, if not properly executed with applicable data, sufficient analytical rigor and statistical confidence, would likely result in failures in IOT&E causing the need for additional follow-on operational testing, and, most importantly, deliver Block 3F to the field with severe shortfalls in capability – capability that the Department must have if the F-35 is ever needed in combat against current threats. In fact, the plan to eliminate or replace test points is at a point in the development program where the most difficult, yet some of the most important capabilities, have just started to reach maturity to begin flight testing. The program should complete testing of all necessary Block 3F baseline test points, as defined in the Joint Test Plans; if the program attempts to use test data from previous testing or added complex test points to sign off some of these test points, the program must ensure the data are applicable and provide sufficient statistical confidence prior to deleting any underlying build-up test points. Additionally, the program should consider adding another full version of Block 3F software to develop and deliver to flight test in order to address more deficiencies.

- Deficiencies in performance and significant operational shortfalls must be resolved if the program is to deliver the expected full Block 3F capability by the end of SDD. Based on operational test pilot observations of developmental test missions flown in June and July 2016, an assessment of the operational utility of Block 3FR5.03 software to support planned IOT&E missions, including Close Air Support, Suppression/Destruction of Enemy Air Defenses, Offensive and Defense Counter-Air, Air Interdiction, and Surface Warfare, rated each of the mission areas "red" and unacceptable overall. Additionally, the JOTT provided an assessment of the Block 3F capabilities, based on observing and assisting with F-35 developmental testing with Block 3FR5.05 software, which began flight testing in August. The team's assessment made top-level, initial predictions of expected IOT&E results of the F-35 for each of the mission areas. The team predicted severe or substantial operational impacts across all the planned IOT&E missions, similar to the list of missions above, due to shortfalls and deficiencies, with the exception of the Reconnaissance mission area, which predicted minimal operational impact. The program should ensure adequate resources remain available (personnel, labs, flight test aircraft) through the completion of IOT&E to develop, test and verify corrections to deficiencies identified during flight testing that may cause operational mission failures during IOT&E or in combat.
- The program plans to provide full Block 3F capability, as defined in the TEMP, with the first Lot 10 aircraft delivery in January 2018. In fact, as required by the National Defense Authorization Act (NDAA) for FY16, the Secretary of the Air Force certified to Congress in September 2016 that these aircraft will have full combat capability, as determined as of the date of the enactment of the NDAA, with Block 3F hardware, software, and weapons carriage. However, for many reasons, it is clear that the Lot 10 aircraft will not initially have full Block 3F capability. These reasons include, but are not limited to, the following:
  - Envelope limitations will likely restrict carriage and employment of the AIM-120 missile and bombs well into 2018, if not later.
  - The full set of geographically specific area of responsibility MDLs will not be complete, i.e., developed, tested and verified, until 2019, at the soonest, due to the program's failure to provide the necessary equipment and software tools for the USRL.
  - Even after they are delivered, the initial set of MDLs will not be tested and optimized to deal with the full set of threats present in operational test, let alone in actual combat, which is part of full combat capability.
  - The program currently has more than 270 Block 3F unresolved high-priority (Priority 1 and Priority 2, out of a 4-priority categorization) performance deficiencies, the majority of which cannot be addressed and verified prior to the Lot 10 aircraft deliveries; less than half of these deficiencies were being actively worked in Block 3F.
  - The program currently has 17 known and acknowledged failures to meet the contract specification requirements, all of which the program is reportedly planning to get relief from the SDD contract due to lack of time and funding.
  - Dozens of contract specification requirements are projected to be open into FY18; these shortfalls in meeting the contract specifications will translate into limitations or reductions to full Block 3F capability.
  - Estimates to complete Block 3F mission systems that extend into the summer of 2018 have been put forth not just from DOT&E, but also from other independent Department agencies (e.g., CAPE), affirming that delivery of full capability in January 2018 will be nearly impossible to achieve, unless testing is prematurely terminated, which would increase the likelihood that the full Block 3F capabilities will not be adequately tested and priority deficiencies fixed.
  - Deficiencies continue to be discovered at a rate of about 20 per month, and many more will undoubtedly be discovered before and during IOT&E.
  - ALIS version 3.0, which is necessary to provide full combat capability, will not be fielded until mid-2018, and a number of capabilities that had previously been designated as required for ALIS 3.0 are now being

deferred to later versions of ALIS (i.e., after summer of 2018).

  - The Department has chosen to not fund the program to the CAPE estimate that the completion of Block 3F mission systems testing will last until mid-2018, a time span which is much later than, and at a cost that is at least double, the Program Office's latest unrealistic estimate to complete SDD. This guarantees the program will attempt a premature resource- and schedule-driven shutdown of mission systems testing which will increase the risk of mission failures during IOT&E and, more importantly, if the F-35 is used in combat.
  - Finally, rigorous operational testing in IOT&E, which provides the most credible means to predict combat performance in advance of actual combat, will not be completed until at best the end of 2019 – and more likely later.

Assessment of Block 2B and 3i "Initial Warfighting" Fielded Capability

- Using aircraft in the Block 2B configuration, both the Air Force, with the F-35A, and the Marine Corps, with the F-35B, have flown simulated combat missions during training or in support of training exercises. These training missions have highlighted numerous shortfalls in Block 2B capability.
  - Unlike legacy aircraft, Block 2B aircraft will need to make substantial use of voice communications to receive targeting information and clearance to conduct an attack during Close Air Support (CAS) missions due to the combined effects of digital data communications deficiencies, lack of infrared pointer capability, limited ability to detect infrared pointer indications from a controller (which may be improved in the Generation III Helmet Mounted Display System (Gen III HDMS)), and inability to confirm coordinates loaded to GPS-aided weapons. Each of these shortfalls limit effectiveness and increase the risk of fratricide in combat.
  - Many pilots assess and report that the Electro-Optical Targeting System (EOTS) on the F-35 is inferior to those currently on legacy systems, in terms of providing the pilot with an ability to discern target features and identify targets at tactically useful ranges, along with maintaining target identification and laser designation throughout the attack. Environmental effects, such as high humidity, often forced pilots to fly closer to the target than desired in order to discern target features and then engage for weapon employment, much closer than needed with legacy systems, potentially alerting the enemy, exposing the F-35 to threats around the target area or requiring delays to regain adequate spacing to set up an attack. However, due to design limitations, there are no significant improvements to EOTS planned for Block 3F.
  - When F-35 aircraft are employed at night in combat, pilots are restricted from using the current limited night vision camera in the Generation II helmet with Block 2B aircraft. This restriction does not apply to pilots equipped with the Generation III helmet, which is fielded with the Block 3i aircraft. In general, if used in combat, pilots flying Block 2B aircraft would operate much like early fourth generation aircraft using cockpit panel displays, with the Distributed Aperture System providing limited situational awareness of the horizon, and heads-up display symbology projected on the helmet.
- Because Block 3i is an interim capability based on Block 2B, it inherited numerous limitations that will reduce operational effectiveness and require workarounds if F-35 in the Block 3i configuration are used in combat. The Air Force conducted an IOC Readiness Assessment (IRA), using F-35A aircraft with four different versions of Block 3i mission systems software. Based on observations from fielded units and from the Air Force's IRA, the following mission areas will be affected by limitations, which may affect overall effectiveness:
  - Close Air Support (CAS). In many ways, the F-35 in the Block 3i configuration does not yet demonstrate CAS capabilities equivalent to those of fourth generation aircraft. The F-35A in the Block 3i configuration has numerous limitations that make it less effective overall in the CAS mission role than most currently fielded fighter aircraft like the F-15E, F-16, F-18 and A-10 in a permissive or low-threat environment, which is where CAS is normally conducted. These limitations, consistent with observations made by the Air Force in its IRA report, include:
    - The limited weapons load of two bombs (along with two missiles for self-defense) constrains the effectiveness of the Block 3i F-35 for many CAS missions. Compared to a legacy fighter with multiple weapons on racks, and multiple weapons types per aircraft, the limited Block 3i load means that only a limited number and type of targets can be effectively attacked.
    - No gun capability. An aircraft-mounted gun is a key weapon for some CAS scenarios when a bomb cannot be used due to collateral damage concerns or when the enemy is "dangerously close" to friendly troops. The gun can also be an effective weapon for attacking moving targets. However, even though an internal gun is installed in the Block 3i F-35A, it cannot be used until significant modifications to both the gun system and aircraft are completed, and a version of Block 3F software is tested and delivered to fielded aircraft. Gun weapons delivery accuracy (WDA) testing, aimed by the HMDS, with the required modifications and software, has slipped from September 2016 to early 2017. Initial build-up testing for the gun WDA was being planned for December 2016 at the time of writing this report.
    - Limited capability to engage moving targets. Even though the Block 3i F-35A does not have a functioning gun, it can carry the GBU-12 laser guided bomb which has limited moving target capability. However, Block 3i (and Block 3F because it is currently not planned to be addressed) does not have an automated targeting

function with lead-laser guidance (i.e., automatically computing and positioning the laser spot proportionately in front of the moving target to increase the likelihood of hitting the target) to engage moving targets with the GBU-12, like most legacy aircraft have that currently fly CAS missions. Instead, F-35 pilots can only use basic rules-of-thumb when attempting to engage moving targets with the GBU-12, resulting in very limited effectiveness. Also, limitations with cockpit controls and displays have caused the pilots to primarily use two-ship "buddy lasing" for GBU-12 employment, which is not always possible during extended CAS engagements when one of the aircraft has to leave to refuel on a tanker. To meet the ORD requirement for engaging moving targets, the Air Force is considering integrating the GBU-49, a fielded weapon that has similar size, weight and interfaces as the GBU-12, or a similar weapon that does not require lead-laser guidance, in Block 3F. Otherwise, the program plans to develop and field lead-laser guidance in Block 4.2, which would be delivered in CY22, at the earliest. However, because of the similarities, the GBU-49 could be quickly integrated with Block 3F to provide a robust moving target capability for the F-35 much earlier.

  - ▪ Voice communications are sometimes required to validate digital communications. Problems with Variable Message Format (VMF) and Link-16 datalink messaging – including dropped or hidden information or incorrect formats – sometimes require pilots to use workarounds by validating or "reading back" information over the radio that prevent them from conducting digital (only) CAS, a capability that is common in most legacy CAS aircraft. Recent use of VMF digital communications during weapons demonstration events by the operational test teams has been more successful; however, data analyses are ongoing.
  - ▪ Limited night vision capability. Although Lot 7 and later aircraft are fielded with the Gen III HMDS, which has shown improvement to the deficiencies with the earlier Gen II HMDS, limitations with night vision capability remain. Pilots using the Gen III helmet for night operations report that visual acuity is still less than that of the night vision goggles used in legacy aircraft, which makes identification of targets and detecting markers more difficult, if not impossible. Also, "green glow" – a condition where light leakage around the edge of the display during low-light conditions makes reading the projected information difficult – is improved over the Gen II HMDS, but is still a concern during low ambient illumination conditions. The program currently has two open "Category 1 High" deficiency reports for "green glow," with the most significant safety concerns pertaining to nighttime carrier operations.
  - ▪ Lack of target marking capability – a key capability for both Forward Air Controller-Airborne (FAC-A) and CAS missions. Legacy CAS platforms can mark targets with rockets, flares, and/or infrared (IR) pointers, none of which are currently available on the F-35. The F-35 has a laser designator as part of its Electro-Optical Targeting System (EOTS), but the laser is used for targeting from ownship when using the GBU-12 laser guided bomb or to "buddy-guide" a weapon from another aircraft. This limitation is not planned to be fixed during SDD.
- Other mission areas. In addition to the Block 3i limitations listed above that affect the CAS mission area, the following inherent Block 3i limitations will also affect the capability of the F-35 in other mission areas:
  - ▪ Poor ability to accurately locate (i.e., determine geographic location with precision needed for weapons employment) and identify threat emitters.
  - ▪ No standoff weapon. With only direct attack bombs, the F-35 in the Block 3i configuration will be forced to fly much closer to engage ground targets and, depending on the threat level of enemy air defenses and acceptable mission risk, it may be limited to engaging ground targets that are defended by only short-range air defenses, or by none at all.
  - ▪ The limited weapons loadout of the Block 3i F-35 makes effective attack of many expected types of targets in a typical theater a challenge. For example, unlike legacy aircraft, the Block 3i F-35 has no mixed weapons load capability, which limits flexibility to attack targets with appropriately matched weapons. Block 3i F-35 aircraft can only employ two internally carried bombs, and although internal carriage reduces the susceptibility of the F-35 relative to legacy aircraft, by virtue of the low observability it provides, it does not provide the ability to attack more than one or two targets.
  - ▪ Pilots report that inadequacies in Pilot Vehicle Interfaces (PVI) in general, and deficiencies in the Tactical Situation Display (TSD) in particular, which displays the results of sensor fusion and is designed to provide increased situation awareness, continue to degrade battlespace awareness and increase pilot workload. Workarounds to these deficiencies are time-consuming for the pilot and detract from efficient and effective mission execution.
- Block 3i has significant deficiencies that must still be addressed, despite the additional software release to the field, Block 3iP6.21, in May 2016. In addition to the limitations listed above, Block 3i also has hundreds of other deficiencies, the most significant of which must be fixed in Block 3F to realize the full warfighting capability required of the F-35. These deficiencies include, but are not limited to, the following:
  - ▪ Avionics sensor fusion performance is still unacceptable.
    - » Air tracks often split erroneously or multiple false tracks on a single target are created when all sensors contribute to the fusion solution. The workaround during early developmental testing was to turn off

some of the sensors to ensure multiple tracks did not form, which is unacceptable for combat and violates the basic principle of fusing contributions from multiple sensors into an accurate track and clear display to gain situational awareness and to identify and engage enemy targets.

      - Similarly, multiple false ground tracks often are displayed when only one threat emitter is operating. In addition, tracks that "time out" and drop from the display cannot be recalled, which can cause pilots to lose tactical battlefield awareness on enemy air defense radars that turn on only intermittently, as is typical of missile engagement radars.
      - Sharing erroneous tracks over the Multifunction Advanced Data Link (MADL) between aircraft in the F-35 formation multiplies the problems described above.
      - The Air Force IOC Readiness Assessment (IRA) report also identified deficiencies with fusion in Block 3i.
    - Electronic warfare (EW) capabilities, including electronic attack (EA), are inconsistent and, in some cases, not effective against required threats.
      - Although the details of the deficiencies are classified, effective EW capabilities are vital to enable the F-35 to conduct Suppression/Destruction of Enemy Air Defenses (SEAD/DEAD) and other missions against fielded threats.
      - The Air Force IRA report also identified significant EW deficiencies in Block 3i.
    - Datalinks do not work properly. Messages sent across the MADL are often dropped or pass inaccurate offboard inter-flight fusion tracks based on false or split air tracks and inaccurate ground target identification and positions.
    - Reduced on-station time and greater reliance on tanker aircraft. Although this limitation is not unique to the Block 2B or Block 3i configuration, the F-35 has high fuel burn rates and slow air refueling rates that extend air refueling times and decrease overall on-station time, which may reduce overall mission effectiveness.
  - The program was able to improve stability of the mission systems software to support the Air Force's plan to declare IOC. The Program Office reported improvements in Mean Flight Hours Between Instability Events (MFHBIE) for both start-up and in-flight of Block 2B and Block 3i. The latest inflight stability metrics from the Program Office are provided in the table to the right. Note that "2BS" versions of software refer to Block 2B versions delivered to flight test. For Block 3i, the program adopted a naming convention where a "P" version refers to software released for production aircraft and an "R" version is for flight testing. An "R" version of software has additional coding that permits data to be collected from data buses on the aircraft and stored on the DART pod or transmitted to ground stations for recording or playback. For IOT&E, since data will be collected with the instrumentation packages on the OT aircraft, IOT&E will be flown with an "R" version of software where selected data and messages can be directed for recording for post-flight analyses.
  - The operational effect of mission systems software instabilities on the F-35 will not be well understood before the completion of formal operational testing. One of the objectives of the Air Force IRA was to examine the frequency and effect of these instability events. The Air Force defined and scored instability events during the IRA in the same way as the Program Office and the contractor for comparison purposes and observed similar trends. An instability event is generally the initial failure, or the primary system failure, and does not account for subsequent failures of the same system or failures of subsystems. In addition, the Air Force collected data on instability occurrences, which includes a broader set of instabilities. An instability occurrence accounts for all failures of systems and associated subsystem failures, when each of the failures could have affected the mission capability of the aircraft. The Air Force collected data on instability occurrences with F-35A aircraft flying the most current Block 3i software and counted 25 occurrences in 34.1 flight hours, resulting in a Mean Flight Hours Between Instability Occurrences of 1.4 hours. During IOT&E, all relevant stability events and occurrences, on the ground or in the air, which impact mission effectiveness or suitability, including repeat events (unless attributed to a hardware failure) will be counted to assess overall mission effect. Similar to the table below, stability data from IOT&E will be compared with data from fielded aircraft with the "P" version of Block 3F software to assess any differences.
- The Air Force IRA test team at Nellis AFB flew a total of 18 mission scenarios (72 aircraft sorties) covering the mission sets of CAS, Air Interdiction (AI), and SEAD/DEAD. The missions were flown over the Western Test Ranges from March 1 through April 29, 2016. Additionally, the assessment included observations from an Air Force-led deployment to Mountain Home AFB, Idaho, with six F-35A

MISSION SYSTEMS SOFTWARE INFLIGHT STABILITY METRICS (DATA AS OF NOVEMBER 27, 2016)

Software Release	Number of Inflight Stability Events	Cumulative Flight Hours	Mean Flight Hours Between Instability Events
2BS5.2	31	224.8	7.3
2BS5.3	1	28.5	Insufficient data
3iP6.21	13	349.5	26.9
3iR6.21 (Edwards OT Aircraft)	6	75.8	12.6
3FR5*	222	950.1	4.3

* 3FR5 metrics are a summation of 8 versions of software used in flight testing: 3FR5, 3FR5.02, 3FR5.03, 3FR5.03QRC, 3FR5.04QRC, 3FR5.05, 3FR5.06, and 3FR5.07

aircraft from Edwards, supported by an ALIS SOU v2 with software 2.0.1. Although the Air Force has determined that the F-35A with Block 3i mission systems software provides "basic" capabilities for IOC, many significant limitations and deficiencies remain. In comparison to a dedicated operational test and evaluation, this was a brief, but revealing assessment of mission capability. However, until a full operational test and evaluation of the F-35 is completed, we will have low confidence that we understand all of the limitations in the system.

- The detailed results of the IRA, as reported by the Air Force, are consistent with the assessments in this Annual Report.
- Inflight stability of the Block 3i mission systems was assessed to be back to a level comparable to that in Block 2B, as measured by the number of inflight instability events per flight hour.
- If used in combat, F-35 aircraft will need support to locate and avoid modern threat ground radars, acquire targets, and engage formations of enemy fighter aircraft, due to unresolved performance deficiencies and limited weapons carriage available (i.e., two bombs and two air-to-air missiles).
- Unresolved Block 3i deficiencies in fusion, EW, and weapons employment continue to result in ambiguous threat displays, limited ability to effectively respond to threats, and, in some cases, a requirement for offboard sources to provide accurate coordinates for precision attack.
- Concerning the CAS mission area, the team concluded that the Block 3i F-35A does not yet demonstrate equivalent CAS capabilities to those of fourth generation aircraft.

Mission Data Load Development and Testing

- F-35 effectiveness in combat relies on mission data loads (MDL) – which are a compilation of the mission data files needed for operation of the sensors and other mission systems – working in conjunction with the system software data load to drive sensor search parameters so that the F-35 can identify and correlate sensor detections, such as threat and friendly radar signals. The contractor team produced an initial set of mission data files for developmental testing during SDD, but the operational MDLs – one for each potential major geographic area of operation – are being created, tested, and verified by a U.S. government lab, the U.S. Reprogramming Lab (USRL), located at Eglin AFB, Florida, which is operated by government personnel from the Services. The Air Force is the lead Service. These MDLs will be used for operational testing and fielded aircraft, including the Marine Corps and Air Force IOC aircraft. The testing of the USRL MDLs is an operational test activity, as was arranged by the Program Office after the restructure that occurred in 2010. The Department must have a reprogramming lab that is capable of rapidly creating, testing and optimizing MDLs, and verifying their functionality under stressing conditions representative of real-world scenarios, to ensure the proper functioning of F-35 mission systems and the aircraft's operational effectiveness in both combat and the IOT&E of the F-35 with Block 3F.
- Despite the critical requirement for developing and fielding F-35 MDLs, significant ongoing software and hardware deficiencies in the USRL have yet to be addressed, which continue to prevent efficient creating, testing, and optimization of the MDLs for operational aircraft fielded in the Block 2B and Block 3i configuration, and are preventing the development of MDLs for Block 3F.
  - The current reprogramming hardware and software tools are so cumbersome that it takes months for the USRL to create, test, optimize, and verify a new MDL. This time-consuming process was still not complete for the complete set of Block 3i AOR-specific MDLs.
  - The program has mismanaged sustainment and upgrades of the USRL to the point that it currently does not have the ability to start creating MDFs for Block 3F and will not have that capability until February 2017, at the earliest. Once the USRL can start creating Block 3F MDFs, it will take approximately 15 months to deliver a verified MDL for IOT&E and for fielded Block 3F aircraft.
  - The program plans to start delivering production aircraft in the Block 3F configuration in May 2017. Because the USRL will not be able to develop, test, and validate a Block 3F MDL until mid-2018, the Services will have to field Block 3F-capable aircraft with either Block 3i, or with a Block 3F test MDL provided by the contractor; however, either course of action will likely restrict these fielded Block 3F aircraft from use in combat.
- Additionally, the Program Office and Lockheed Martin have failed to complete necessary contracting actions to address current shortfalls in signal generation capability within the USRL, including the key hardware upgrades needed to create, test, and verify Block 3F MDFs to detect and identify emissions from currently fielded threat systems in scenarios with realistic threat densities. This failure occurred in spite of the requirement being clearly identified in 2012 and the Department programming $45 Million in the FY13-16 budgets to address it. The JPO sponsored a gap analysis study of USRL capabilities to determine the lab upgrade requirements at the engineering level before beginning contracting actions. When completed in 2014, the study concluded that between 16 and 20 upgraded radio frequency (RF) signal generator channels would be needed for the USRL to adequately create and test MDFs in the USRL for the fielded threats examined in the study, using realistic scenarios and threat densities. After receiving a proposal for the upgrades from the contractor priced at over $200 Million in May 2016, the JPO requested a new proposal, reportedly with options only for up to 12 upgraded signal generator channels, which the contractor indicated would not be answered until July 2017. Furthermore, once on contract, it would then take approximately 3 years after ordering the equipment for it to be delivered and installed, which will be late to need for

both IOT&E and fielding of Block 3F aircraft. As a result, even though the USRL will eventually have the capability to create MDLs for Block 3F in 2017, it still will not have the required signal generators to test and optimize the MDLs to ensure adequate performance against currently fielded threats.

- To provide the necessary and adequate Block 3F mission data development capabilities for the USRL, the Program Office must immediately fund and expedite the contracting actions for the necessary hardware and software modifications, including an adequate number of additional RF signal generator channels and the other required hardware and software tools. Unless these actions are taken immediately, the USRL will not be configured to create, test, and verify Block 3F MDLs for aircraft for current threat systems and threat scenarios until sometime in 2020, placing the operational aircraft at risk in combat against fielded threats and the program at risk of failing IOT&E. The program is working to find alternative facilities with the required signal generators to mitigate this lab capability shortfall for Block 3F.
- Significant additional investments are also required within 2-3 years to further upgrade the USRL to support F-35 Block 4 Follow-on Modernization (FoM) MDL development. Block 4.2 is currently planned to include new Technical Refresh 3 (TR3) processors and other new hardware which, due to the overlapping Block 4 increments, will require the USRL, or an additional reprogramming lab, to have two different avionics configurations simultaneously – a TR2 line for Blocks 3F and 4.1, plus a TR3 line for Block 4.2 and later. Although the Block 4 hardware upgrades in the USRL will need to begin soon to be ready in time, the reprogramming requirements for Block 4 have yet to be fully defined. The Program Office must expeditiously undertake the development of those requirements and plan for adequate time and resources within the DOD budget cycle, in order to ensure the USRL is able to meet Block 4 MDL requirements.
- The USRL, with JOTT observers, held an "Urgent Reprogramming Exercise (URE)" from April 20 to July 25, 2016. This type of exercise is intended to test the USRL's ability to respond to an urgent request from a Service to modify the mission data in response to a new threat or new mode of an existing threat. Due to USRL's ongoing production efforts, the URE was conducted concurrently with the lab's effort to produce an operational MDL, which is why the exercise period was several months, instead of a few days. The JOTT and USRL carefully tracked hours that were specific to the URE as they occurred and surveyed USRL personnel to identify process issues. The total hours recorded were double the Air Force standard for rapidly reprogramming a mature system. The JOTT identified several key process problems, many of which are described above, including the lack of necessary hardware, analysis tools that were not built for operational use, and missing capabilities, like the ability to quickly determine ambiguities in the mission data. These problems must be corrected in order to bring the USRL's ability to react to new threats up to the identified standards routinely achieved on legacy aircraft.
- In addition to the above deficiencies that involve overall laboratory capability and tools to develop MDLs, there are also deficiencies in the program's sustainment efforts to ensure a high state of readiness, particularly if the Services have an urgent reprogramming requirement at any time. To meet these tasks, the USRL must have all necessary equipment in a functioning status, similar to aircraft availability. Inadequacies in the current level of sustainment include, but are not limited to:
  - Insufficient number of Field Service Engineers (FSE) to assist in maintenance and operation of the lab equipment, which include both specialized equipment and aircraft mission equipment
  - Inadequate or insufficient training for most laboratory personnel, which is hindered by the insufficient number of FSEs
  - No engineering drawings or JTD for many critical components, making troubleshooting of failures of those components difficult and lengthening the time required to return the laboratory to full operational status
  - Insufficient spare parts for many critical components
  - Low supply priority, equivalent to that of a unit in training, resulting in long delays to receive required parts
  - Missing part numbers for many components, forcing USRL personnel to submit an Action Request (AR) first to determine the part number before a replacement part can be ordered through supply.

Weapons Integration and Demonstration Events

Block 3F Developmental Testing

- After the release of Block 3iP6.21 software in May 2016, the program focused on completing development of Block 3F capabilities, including weapons envelope and integration testing. To provide an operational employment flight envelope, the program accomplished flight sciences testing of external weapons carriage and employment, as well as integrating bombs (SDB-I, JSOW C-1, and PW-IV) and missiles (AIM-9X and AIM-132 ASRAAM) not previously integrated on the F-35 in Block 2B or 3i.
- The TEMP requires 26 Block 3F weapons delivery accuracy (WDA) events be completed as part of the Block 3F developmental testing effort. These WDAs are key developmental test activities necessary to ensure the full Block 3F fire-control capabilities support the "find, fix, track, target, engage, assess" kill chain. As of the end of November, only 5 of the 26 events (excluding the gun events) had been completed and fully analyzed. Several WDAs have revealed deficiencies and limitations to weapons employment. An additional 11 WDAs have occurred, but analyses are ongoing. Of the 10 remaining WDAs, 4 are still blocked due to open deficiencies that must be corrected before the WDA can be attempted. The program should correct deficiencies that are preventing completion of all of

the TEMP-required Block 3F WDA events and ensure they are completed prior to finishing SDD.

- Discoveries from the Block 3F WDA events include:
    - AIM-9X and AIM-132 ASRAAM seeker status tone problems
    - Out-of-date launch zones for AIM-120 missiles
    - Pilot Vehicle Interface (PVI) and mission planning problems with the U.S. Navy's JSOW-C1 missile that, if not corrected, may cause significant weapon employment limitations in the fleet's ability to attack moving ship targets and enable flexible engagement of land-based targets of opportunity
    - Ongoing radar and fusion deficiencies affecting air-to-air target track stability and accuracy, which could cause reduced missile lethality
    - Multiple hung stores, which typically result in an inflight emergency, occurred with the AIM-9X due to mission systems software and weapon integration deficiencies
    - Problems with integrating the British AIM-132 ASRAAM missile and Paveway IV bomb; changes to address these problems could have unintentionally affected the U.S. AIM-9X and laser-guided bomb capabilities, which may require regression testing of these U.S. weapons.
- In an effort to efficiently accomplish the WDA events, the program dedicated several test aircraft to a WDA surge period during June through August. Although the program had planned to begin WDA events as early as February 2016, the first live weapons event did not occur until July. Delays in starting the Block 3F WDAs were caused by immature software and deficiencies affecting weapons employment. The following table lists the Block 3F WDA events, software versions, scheduled and completion dates, overall results and assessments for each completed live fire event through the end of November. Many of the events were originally blocked from completion due to software deficiencies that had to be addressed using QRC versions of software in order to allow the weapons events to proceed.

Block 3F Developmental Testing Weapons Events Accomplished Through November 2016

WDA Number	Weapon Event	Software Configuration	Scheduled Date	Result	Assessment
			Completion Date		
301	AMRAAM	3FR5.03	Feb 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	Initial data analysis indicates that there was an inflight issue that may have affected targeting accuracy. Analysis in process to determine the root cause and impact(s).
			Jul 16		
302	AMRAAM with AIM-9X	3FR5.03	Feb 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	Initial data review indicated that the AIM-9X tones were not as expected and there was no missile post-launch timer indication to the pilot.
			Jul 16		
303	AMRAAM fired with target off-boresight	3FR5.03	Feb 16	Partially successful accomplishment; shot captured key radar capability data but failed primary test objective; shot required control room intervention.	Known issues with outdated F-35 AMRAAM Attack Model in mission systems software resulted in no shoot cues or dynamic launch zone displayed to pilot requiring the control room to provide a "shoot" call to the pilot. Initial data review indicates that there was also no post-launch timer indication to the pilot. Also, weapon quality track was erratic pre- and post-launch. More detailed analyses are pending, following data to be provided by the missile vendor.
			Aug 16		
307	2 X AMRAAM	3FR5.03	Jun 16	Partially successful accomplishment; shot required control room intervention.	The cockpit indication was a guidance failure on the missiles and required control room intervention to confirm the shot parameters and direct the pilot to shoot. More detailed analyses are pending, following data to be provided by the missile vendor.
			Aug 16		
308	2 X SDB-I (GBU-39) and 1 X AMRAAM	3FR5.06	Jun 16	Successful accomplishment of event.	All weapons initially appear to have functioned successfully. Analysis ongoing.
			Nov 16		
311	2 X AMRAAM	3FR5.03	Apr 16	Pending Data Review; shot required control room intervention.	Unsuccessful; also the pilot indications in the cockpit indicted a guidance fail resulting in control room intervention to accomplish the shot. More detailed analyses are pending, following data to be provided by the missile vendor.
			Jul 16		
316	AIM-9X fired against a non-maneuvering target	3FR5.03	Feb 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	Inflight weapon failed on first missile attempt (built-in test failure and no missile tone to the pilot); back-up missile functioned as expected. Deficiency report was written on missile tone anomalies.
			Jul 16		
317	AIM-9X fired against a maneuvering target	3FR5.03	Jun 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	Initial data review indicates that the missile tones were not correct, no dynamic launch zone indication in Dogfight mode and the gun symbology occluded the target in the helmet-mounted display. More detailed analyses on radar track accuracy and radar ranging accuracy following data to be provided by the missile vendor.
			Aug 16		
320	JDAM (GBU-31) delivered against a single target using Synthetic Aperture Radar (SAR) map coordinates	3FR5.03	Feb 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	The test team planned to use a known workaround for minor Launch Acceptability Region (LAR) inaccuracy due to an outdated LAR model in mission systems software. Pilot released the bomb using a "rule of thumb" guidance to determine "in-zone." JDAM LAR model update in mission systems software is required.
			Jul 16		
321	JDAM (GBU-31) delivered against a single target using Bomb-on-Coordinate employment	3FR5.03	Apr 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	The test team planned to use a known workaround for a minor LAR inaccuracy due to an outdated LAR model in mission systems software. Pilot released the bomb using a "rule of thumb" guidance to determine "in-zone." Post-mission initial data review indicates that the target elevation values available to the pilot were not consistent between the mission planned terrain elevation, the displayed elevation on the cockpit displays, and the value loaded into the JDAM in the transfer alignment.
			Jul 16		

Block 3F Developmental Testing Weapons Events Accomplished Through November 2016 (CONTINUED)

WDA Number	Weapon Event	Software Configuration	Scheduled Date	Completion Date	Result	Assessment
322	JDAM (GBU-31) X 2 Ripple release on two targets	3FR5.03	Jun 16	Aug 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	The test team planned to use a known workaround for a minor LAR inaccuracy due to an outdated LAR model in mission systems software. Pilot released the bomb using a "rule of thumb" guidance to determine "in-zone." Pilot released weapons on rule-of-thumb with minor impact for this DT scenario and Service representatives have stated that the rule-of-thumb workaround may be adequate for operations. Post mission data analysis showed a SAR map coordinate inaccuracy, but within the Circular Error Probable (CEP) of the weapon.
323	JDAM (GBU-31) Pattern on target (multiple weapons)	3FR5.05	Jul 16	Oct 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	Weapons impacted as expected with the selections made by the pilot and with accurate PVI indications. Dual voltage bomb rack unit (BRU) functioned properly with no power distribution issues.
324	SBD-I (GBU-39) X 2 on two targets	3FR5.03	May 16	Aug 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	The test team used a planned workaround for BRU-61; using the new dual-voltage BRU in single-voltage mode due to a mission systems software limitation.
325	SDB-I (GBU-39) Single release	3FR5.03	Feb 16	Jul 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	The test team used a U.S. non-operationally representative BRU-61, one with only a single voltage unit, to complete this WDA event. This older BRU-61 is representative for partner operations.
328	UK Paveway IV bomb	3FR5.05	Jul 16	Oct 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	Weapons integration deficiencies were identified during this event and deficiency reports completed.
SDB Seps	SDB-I (GBU-39) multiple ripple release for flight sciences separation test points, completed on mission systems aircraft.	3FR5.03	Feb 16	Jul 16	Successful accomplishment of event and sufficient data collected for weapons integration analyses.	The test team used a U.S. non-operationally representative BRU-61, one with only a single voltage unit, to complete this WDA event. This older BRU-61 is representative for partner operations. Awaiting data delivery for detailed analysis.

- The remaining 10 events are planned to be completed over the next several months, as the program provides versions of Block 3F software with necessary deficiency fixes to allow the rest of the events to proceed. The remaining events are complex multi-weapon, multi-target, and advanced threat presentations. Whether all WDAs will be completed with the final planned increment of Block 3F software – version 3FR6 – released in December is still to be determined, but several key deficiency fixes related to weapons employment are apparently not included and the probability of additional discoveries during the remaining weapons test events is high, based on results to date.

Gun Testing

- All three variants add gun capability with Block 3F. The F-35A gun is internal; the F-35B and F-35C each use a gun pod. Differences in the outer mold-line faring mounting make the gun pods unique to a specific variant, i.e., a gun pod designated for an F-35B cannot be mounted on an F-35C aircraft.
- Flight sciences testing of the F-35A internal gun was completed in May 2016. The first firing of the gun in flight occurred October 30, 2015, and the entire flight sciences test effort consisted of 11 flights over the 7-month period. Testing revealed that the small doors that open when the gun is fired induce a yaw (i.e., sideslip), resulting in gun aiming errors that exceed accuracy specifications. As a result, software changes to the flight control laws were needed to enable adjustments, which are still to be determined by flight testing, to cancel out the yaw when the gun doors are open. These control law changes, and the resulting regression testing, delayed the start of gun accuracy flight testing on mission systems test aircraft until December 2016, at the earliest. Since no mission-systems-capable developmental test aircraft were built with an internal gun, the program modified one of the operational test F-35A aircraft (AF-31) to conduct the needed gun testing events. Until testing is completed on AF-31, it is unknown if the F-35 gun system, aimed by the Gen III HMDS, will meet accuracy requirements for effective air-to-air and air-to-ground gun employment.

- The program has conducted ground testing of the F-35B gun pod and plans to start airborne testing in January 2017. Initial ground firing of the F-35C gun pod occurred in mid-November 2016 and airborne gun testing is planned to start in March 2017. New discoveries, as well as determining the amount of adjustment to the flight control laws to counter the pitching moments induced by firing the gun pod, are likely.
- Accuracy testing of the gun with the HMDS has not yet been completed and continues to be delayed as new discoveries are made. Hence, the effectiveness of the gun, aimed via the gunsight in the HMDS, is still unproven for both air-to-air and air-to-ground gun employment. The effects of the canopy transparency on gun aiming – i.e., the pilot aiming the gun via the HMDS gunsight looking through the thick canopy material, associated distortions, and attempted software-programmed corrections – are not yet characterized.
- Although aimed firing of the gun had yet to occur, both DT and OT pilots have flown with the air-to-ground gun strafing symbology displayed in the helmet and reported concerns that it is currently operationally unusable and potentially unsafe to complete the planned aimed gun fire testing. These deficiencies may cause further delays to the start of gun accuracy flight testing. Also, testing of the air-to-air symbology by both DT and OT pilots revealed that the gunsight is very unstable when tracking a target aircraft. Fixing these deficiencies may require changes to the mission systems software that controls symbology to the helmet, or to the radar software, as the program is working to finalize the last version of Block 3F. Plans to begin aimed flight testing of the gun on the F-35A were planned for this fall, but will likely not start until December 2016, at the earliest.
- Because of the late testing of the gun and likelihood of additional discoveries, the program's ability to deliver gun capability with Block 3F before IOT&E is at risk, especially for the F-35B and F-35C, which have not yet fired the gun in flight.

Weapons Demonstration Events by the Operational Test Teams

- The JOTT and the associated Service operational test squadrons (VMX-1, 31TES, and 422TES) assigned to Edwards AFB, California, and Nellis AFB, Nevada accomplished 6 air-to-air missile events, 19 GBU-31/32 JDAM air-to-ground events, and 28 GBU-12 laser guided bomb events during 2016. For one of these events, the team accomplished one combined AMRAAM missile with one GBU-12 laser guided bomb event, as described in the AMRAAM Air-to-Air Missile Event Table on the following page. These weapon delivery events were accomplished on range complexes at the Naval Weapons Center China Lake, California; Marine Corps Air Station Yuma, Arizona; and Eglin AFB, Florida. All of the OT weapon events were planned and accomplished in operationally representative scenario profiles constructed to evaluate the F-35's ability to find-fix-track-target-engage-assess airborne and fixed and moving ground targets.
- The following tables and accompanying assessments show the weapon events, aircraft Block configuration, date accomplished, and results.

AMRAAM Air-to-Air Missile Events Accomplished by Operational Test Teams				
Event Identifier	**Event Description**	**Aircraft Block Software Configuration**	**Date Accomplished**	**Results**
WDA-108	Cruise Missile Defense	3iR6.01	May 16	This event was a re-shoot of a developmental test event. The reshoot was required by the operational test community because of control room workarounds needed during the DT event. The OT profile was successful.
OT 2.1	2 F-35 aircraft in MADL network attacking one F-16 drone target with jamming	2BR5.3	Aug 16	Profile did not meet test objectives due to issues with the target presentation. Data analysis in progress.
OT 2.2	2 F-35 aircraft in MADL network defending against an off-boresight attacker	2BR5.3	Aug 16	Partially successful. Missile guided to objective target, however secondary objective compromised due to issues with the target presentation. Data analysis in progress.
OT 2.3	2 F-35 aircraft in MADL network vs 2 jamming equipped F-16 drones	2BR5.3	Aug 16	Profile did not meet test objectives due to issues with the target presentation. Data analysis in progress.
OT 2.4	F-35 combined Air-to-Air AMRAAM and GBU-12 Air-to-Ground profile	2BR5.3	Aug 16	Primary test objective to confirm ability of the F-35 to support a laser guided bomb to impact while simultaneously supporting a missile inflight was successful. Secondary objective was unsuccessful due to issues with the target presentation.
MAWTS-2	2 F-35 aircraft attacking a high closure rate supersonic target	2BR5.3	Aug 16	This profile was a USMC engagement scenario to support ongoing tactics development. Profile objective was successful

Air-to-Air General Observations

- The operational test teams completed the missile profiles in accordance with the DOT&E-approved test plan; however, some weapons integration objectives were not successful due to the drone target presentation failures (details are classified). The failures in the drone target presentations prevented either the primary or secondary test objectives to verify the F-35's capability to complete the find-fix-track-target-engage-assess fire control thread. The test team is conducting data analyses to determine whether engineering characterization runs or re-shooting of the profiles are required.
- Although four of the five missile events fell short of addressing all of the specific data objectives, they were successful in identifying key deficiencies in the ability of the aircraft to support selected missile functionality, stores management system anomalies, and the instability of the shoot cues provided to the pilot to support missile employment. Data analyses to identify root cause for all the noted deficiencies are ongoing and the operational test team will recommend specific mission systems software fixes to address the noted deficiencies.

GBU-31/32 Joint Direct Attack Munition (JDAM) and GBU-12 Laser Guided Bomb (LGB) Air-to-Ground Event Summary				
Weapon Type	**Number of Weapons Events**	**F-35 Variant******	**Date Accomplished**	**Results**
GBU-12 LGB	28 Laser Guided Bomb (LGB) Events*	21 F-35A	Jan to July 2016	22 successful/6 partially successful*** events.
		7 F-35B		
GBU-31 or GBU-32 JDAM	15 GBU-31 (BLU-109) Events (8 inert/7 live)**	F-35A		10 successful/5 partially successful***
	3 inert GBU-32 (Mk-83) Events**	F-35B		2 successful/1 partially successful***

*GBU-12 OT events were conducted against an operationally representative mix of fixed and moving targets; self-, airborne buddy-, and ground tactical control party target-lasing; target cueing via voice, VMF digital, and F-35 shoot-list sharing via MADL.
**JDAM GBU-31/32 events were accomplished against an operationally representative mix of fixed target coordinates consisting of: pre-planned targeted coordinates, F-35 self-targeting using SAR map and EOTS derived coordinates, and target cueing via voice, VMF digital, and F-35 shoot-list sharing via MADL.
***Air-to-Ground fully successful missions achieved weapon miss distances within expected mean radial error. Partially successful missions were cases where the weapon was employed but with larger miss distances and observed mission systems issues described below.
****Mission Systems software for all variants was 2BS5.2 or 2BS5.3

Air-to-Ground General Observations

- Although initial observations from weapons integration can be characterized in general, detailed data analyses are ongoing to determine precise mean radial error results for both the LGB and JDAM weapons delivery events, and to identify root causes for the observed mission systems deficiencies and weapon delivery issues.
- The JDAM predictive launch acceptability region (LAR) and dynamic launch zone (DLZ) information were consistently in error compared to the expected pilot drop cues calculated from both the JDAM truth model and initial DT characterizations. In the majority of the OT JDAM drops, there were wide discrepancies between the LAR presentations to the pilot via the HMDS, the corresponding presentations on the in-cockpit controls and displays, and the actual JDAM in-weapon LAR. In a number of cases, the mission systems bombing cues available to the pilot via the Tactical Situation Display on the Panoramic Cockpit Display were in conflict with the HMDS shoot cues and the DLZ. This inconsistency is both confusing to the pilot and can result in erratic and inaccurate weapon impact relative to the target desired impact point. Also, the tactical displays available to the pilot did not allow the pilot to confirm the actual target coordinates passed to the weapon. This confirmation of the in-weapon target coordinates is usually required by rules of engagement (ROE) in operational areas in order to enable positive target information confirmation to the ground controllers prior to clearance to drop any weapon. The F-35 in the Block 2B or Block 3i configuration is not currently able to comply with these ROE.
- In general, pilots were able to use the F-35 Synthetic Aperture Radar (SAR) mapping function to derive weapons quality coordinates, which are adequate to deliver ordinance on target. Pilots were also able to share the SAR-map-derived coordinates between flight members to validate and confirm target positions and coordinates prior to releasing weapons.
- The EOTS was not able to provide the pilot with sufficient resolution at tactical employment ranges to enable a positive ID on the intended target. However, the EOTS generally was able to track targets, both moving and stationary, but only after the target identification was confirmed by an external source or multiple sources. However, there are still significant tracking limitations, as evidenced by a new, open Category 1-High deficiency titled “EOTS TFLIR Tracker Unable to Point or Area Track.” The EOTS system also was able to generate accurate weapon quality coordinates when cued to the correct target.
- The lack of any lead-point-compute or lead-laser guidance in the F-35 EOTS system required rule-of-thumb pilot techniques to provide limited capability with the GBU-12 on moving targets. The OT moving target attacks were generally successful; however, the successes relied on high levels of pilot experience and were not enabled by the F-35 mission systems. While the rule-of-thumb procedures allowed the technical requirements of the weapons delivery event to be met, they did not allow the pilot to maintain positive target ID using the PVI procedures to designate, track, and employ the weapon for the full attack timeline. Most importantly, these procedures would likely not have met the current positive target ID requirements for operational employment rules of engagement. Due to these limitations, which threaten the effectiveness of the F-35 to engage moving targets, the program and Services are exploring other options to meet this ORD requirement. One option, which is being considered by the Air Force, is to integrate the GBU-49, a fielded weapon that has similar size, weight, and interfaces as the GBU-12, or a similar weapon that does not require lead-laser guidance, in Block 3F. Otherwise, the program plans to develop and field lead-laser guidance in Block 4.2, which would be delivered in CY22, at the earliest. However, because of the similarities, the GBU-49 could be quickly integrated with Block 3F to provide a robust moving target capability for the F-35 much earlier.
- Pilots were able to use the digital Variable Message Format (VMF) system to communicate between F-35 aircraft and tactical ground controllers. The VMF links and data provided the expected data to both the pilot and the ground parties. In previous developmental testing, the VMF has exhibited significant issues with both reliability and accuracy; however, in the OT events the system was both reliable and accurate. Data analysis is ongoing to determine the differences between the uses of VMF in developmental testing compared to the operational weapons test events. The ground parties used in the operational testing were equipped with the most up-to-date software, firmware, and hardware and were staffed by fully qualified ground controllers.
- Pilots experienced multiple inflight failures of the Fuselage Remote Interface Unit (FRIU), an electronic component that provides the interface between the aircraft avionics and all weapon stations, which often disrupted the ground attack profile. The failures resulted in degraded weapons at critical phases of the target attack profile and required the pilots to abort the attack, reset the FRIU to regain control and communications with the weapon, and then recommit to a follow-on target attack. Such target attack interruptions are unacceptable for combat operations.
- Pilots consistently rated the Offboard Mission Support (OMS) mission planning system as cumbersome, unusable, and inadequate for operational use. As a result, the time required for operational planners to build a mission plan is excessive and cannot support current planning cycle requirements for multiple aircraft combat missions. Additionally, the post-mission download times are too long to support operational debriefing requirements.

Pilot Escape System

- Testing of the pilot escape system in CY15 showed that the risk of serious injury or death is greater for lighter-weight pilots, which led to the decision by the Services to restrict pilots weighing less than 136 pounds from flying the F-35.

In an effort to reduce this risk, the program developed three modifications associated with the escape system and began testing them in late CY15 and throughout CY16. These modifications include:

- Reduction in the weight of the pilot's Generation III helmet (the new helmet is called Gen III Lite) to reduce the effect of forces on the pilot's neck during the ejection sequence.
- Installation of a switch in the seat that allows lighter-weight pilots to select a slightly delayed activation of the main parachute. This delay allows the drogue chute, which deploys almost immediately during the ejection sequence, to further slow and align the pilot before the main parachute deploys. This delay is designed to reduce the severity of loads on the neck experienced during opening shock.
- The addition of a Head Support Panel (HSP) between the risers of the parachute designed to prevent the pilot's neck from "snapping back" through the risers during the opening of the main parachute.

- Concerned with the problems with the escape system and the possibility of more discoveries, the U.S. Air Force asked the JPO in June 2016 to gather and provide information on potential costs and challenges to changing ejection seats from the Martin Baker US16E seat currently installed in all F-35 variants to the United Technologies ACES 5 seat as an alternative for the F-35A.
- After prototypes of the design changes were available, twenty-two qualification test cases were completed between October 2015 and September 2016, with variations in manikin weight, speed, altitude, helmet size and configuration, and the seat switch settings. Seven of the tests were accomplished with the lightweight (103 lbs) manikin. Data from these tests showed that the HSP significantly reduced neck loads under conditions that forced the head backwards, inducing a rearward neck rotation, during the ejection sequence. Data also showed that the seat switch delay reduced the opening shock from the main parachute for lighter-weight pilots at speeds greater than 160 knots. Results of the additional tests were provided to the Services in late CY16 to update their risk assessments associated with ejections. Despite the improved results, the extent to which risks have been reduced to lighter-weight pilots (i.e., less than 136 pounds) by the modifications to the escape system and helmet is still to be determined by these analyses. If the Services accept the risk associated with the modifications to the escape system for pilots weighing less than 136 pounds, restrictions will likely remain in effect until aircraft have the modified seat with the switch and HSP installed, and the Gen III Lite helmets are procured and delivered to the applicable pilots in the fleet.
- The program plans to start retrofitting fielded F-35s with the modifications to the ejection seats in February 2017 and delivering aircraft with the upgraded seat in Lot 10, starting in January 2018. The Gen III Lite helmets will be included with the Lot 10 aircraft delivery, and will be delivered starting in November 2017. If these delivery timelines are met, the Air Force may open F-35 pilot training to lighter-weight pilots (i.e., below 136 pounds) as early as December 2017.
- Part of the weight reduction to the Gen III Lite HMDS involved removing one of the two visors (one dark, one clear). As a result, pilots that will need to use both visors during a mission (e.g., during transitions from daytime to nighttime), will have to store the second visor in the cockpit. However, there currently is not adequate storage space in the cockpit for the visor; the program is working a solution to address this problem.
- The program has yet to complete additional testing and analysis needed to determine the risk of pilots being harmed by the Transparency Removal System (which shatters the canopy first, allowing the seat and pilot to leave the aircraft) during ejections in other than ideal, stable conditions (such as after battle damage or during out-of-control situations). Although the program completed an off-nominal rocket sled test with the Transparency Removal System in CY12, several aspects of the escape system have changed since then, including significant changes to the helmet, which warrant additional testing and analyses. DOT&E recommends the program complete these tests, in a variety of off-nominal conditions, as soon as possible, so that the Services can better assess risk associated with ejections under these conditions.

Static Structural and Durability Testing

- Structural durability testing of all variants using full-scale test articles continues, with plans for each variant to complete three full lifetimes (one lifetime is 8,000 equivalent flight hours, or EFH). Although all variants are scheduled to complete testing before the end of SDD, the complete teardown, analyses, and damage assessment and damage tolerance reporting is not scheduled to be completed until August 2019. Testing on all variants has led to discoveries requiring repairs and modification to production designs and retrofits to fielded aircraft.
- F-35A durability test article (AJ-1) completed the second lifetime of testing, or 16,000 EFH in October 2015. After completing second lifetime inspections, third lifetime testing began on March 11, 2016. As of November 16, 2016, 20,000 EFH, or 50 percent of the third lifetime had been completed. Third lifetime testing is projected to complete in December 2017.
- F-35B durability test article (BH-1) completed 14,051 EFH by November 17, 2016, which is 6,051 hours (76 percent) into the second lifetime. Due to the amount of modifications and repairs to bulkheads and other structures in the current F-35B ground test article, it may not be adequate to continue testing and a new one may be needed and durability testing repeated to ensure adequate lifetime testing is completed. The program needs to conduct an assessment to determine the extent to which the results of further durability testing are representative of production aircraft and if necessary procure another test article for the third life testing.

  - Two main wing carry-through bulkheads, FS496 and FS472, are no longer considered production-representative due to the extensive repairs that have been required. The program plans to continue durability testing, repairing the bulkheads as necessary, through the second lifetime (i.e., 8,001 through 16,000 EFH), which is projected to be complete in February 2017.
  - Prior to CY16, testing was halted on September 29, 2013, at 9,056 EFH, when the FS496 bulkhead severed, transferred loads to, and caused cracking in the adjacent three bulkheads (FS518, FS472, and FS450). The repairs and an adequacy review of the repairs to support further testing were completed on December 17, 2014, when the program determined that the test article could continue testing. Testing restarted on January 19, 2015, after a 16-month delay.
  - The program determined that several of the cracks discovered from the September 2013 pause at 9,056 EFH were initiated at etch pits. These etch pits are created by the etching process required prior to anodizing the surface of the structural components; anodizing is required for corrosion protection. Since the cracks were not expected, the program determined that the etch pits were more detrimental to fatigue life than the original material design suggested. The program is currently developing an analysis path forward to determine the effect on the overall fatigue life.
  - After the durability test completed 11,915 EFH on August 13, 2015, the load cycling was stopped to allow removal and replacement of the FS496 bulkhead outer segments (both left- and right-hand sides), removal and replacement of the left-hand-side aft fuselage close-out frame, repairs to the engine thrust mount shear webs, installation of fasteners at the FS518 frame, maintenance of the right-hand-side EHAS panel, repairs to the right-hand-side of the mid-fairing longeron, and repairs to the FS556 upper arch. The entire repair activity took about 9 months, with an 85-EFH testing effort conducted in early March 2016 that reached 12,000 EFH.
  - Testing resumed in early May 2016, reached 13,000 EFH in mid-June 2016, and then stopped for another month to repair the FS472 lower flange.
  - Testing resumed in mid-July. At 13,086 EFH, cracks were discovered on the forward fuselage including FS236 bulkhead, left-hand-side FS223 frame, and right-hand-side FS191 upper frame.
  - Testing continued with buffet loads until it reached 13,980 EFH before stopped to implement fuselage repairs in August 2016.
  - Testing resumed on September 17 and had reached 14,051 EFH on November 17, 2016.
- F-35C durability test article (CJ-1) completed the second lifetime of testing, or 16,000 EFH on October 29, 2016. The third lifetime testing is scheduled to begin in late December 2016.
  - In October 2015 with 13,731 EFH accomplished, cracks were discovered on the left-hand side and right-hand side of one wing front spar and one left-hand-side wing forward root rib; this discovery was considered significant because wing spar and wing root rib are primary structural components and the cracks were not predicted by the finite element model (FEM) used in the design of these components. The repairs took over 3 months before the test resumed in early February 2016.
  - On February 9, 2016, with 13,827 EFH accomplished, a crack was found on the left-hand-side inverter/converter/controller and power distribution center/inverter bay floor. Testing continued with catapult and trap load cycling.
  - In late February 2016 with 13,931 EFH accomplished, cracks were found on the left- and right-hand sides of the FS496 bulkhead flanges, which were deemed significant. The repairs took another 3 months to complete before the test resumed in May 2016.
  - In August 2016 with 14,831 EFH accomplished, small cracks were found on the right-hand-side armpit (below wing root) and were quickly repaired with a simple blend.
  - In August 2016 with 14,892 EFH accomplished, cracks were found on the FS518 lower frame and some nearby broken fasteners. A weld repair for the titanium frame was completed. Further investigation revealed cracks on the right- and left-hand-side wing rear spars. While a repair disposition was being developed, the durability test resumed with loading only for catapult takeoffs and carrier trap landings.
- The program plans to use Laser Shock Peening (LSP), a mechanical process designed to add compressive residual stresses in the materials, in an attempt to extend the lifetime of the FS496 and FS472 bulkheads in the F-35B. The first production line cut-in of LSP will start with Lot 11 F-35B aircraft. Earlier Lot F-35B aircraft will undergo LSP processing as part of a depot modification. Testing is proceeding in three phases: first, coupon-level testing to optimize LSP parameters; second, element-level testing to validate LSP parameters and quantify life improvement; and third, testing of production and retrofit representative articles to verify the service life improvements. All three phases are in progress, with full qualification testing scheduled to be completed in August 2017. As of December 1, 2016, 122 of 211 durability tests had been conducted with results within expectations, which is a 58 percent completion.

Joint Simulation Environment (JSE)

- The JSE is a man-in-the-loop, mission systems software-in-the-loop simulation developed to meet the operational test requirements for Block 3F IOT&E. The Program Office made the decision in September 2015 to stop development on the contractor's effort to build a similar system, the Verification Simulation (VSim), instead tasking the Naval Air Systems Command (NAVAIR) to lead the building of a government-owned Joint Simulation Environment (JSE), with the contractor providing only the F-35 aircraft and sensor models. However, negotiations for the F-35 models have not yet been successful, which has prevented NAVAIR from fully defining the simulation's architecture and environment (the virtual software environment in which aircraft, sensor, and threat models interact with one another).

- While the Program Office continued to negotiate with the contractor, and had success in meeting the hardware requirements (facilities, cockpits, etc.), the lack of definition of the simulation environment makes any integration schedule not credible. In the next year, the program must acquire the F-35 models, integrate them into an as-yet undefined and undeveloped battlespace environment, complete development of several dozen threat aircraft and surface system models, ensure that aircraft sensor models correctly perceive the threat system models, and validate the entire simulation. Previous efforts of this magnitude have taken several years, so it is unlikely that NAVAIR will complete the project as planned in time to support IOT&E. Current Program Office estimates are that JSE will deliver late to need in May 2019, but before the end of IOT&E. Verification, Validation, and Accreditation (VV&A) activities remained effectively stalled in 2016 and are also a very high risk to timely completion of the simulation.
- Without a high-fidelity simulation, the F-35 IOT&E will not be able to test the F-35's full capabilities against the full range of required threats and scenarios. Nonetheless, because aircraft continue to be produced in substantial quantities (essentially all of which require modifications and retrofits before being used in combat), the IOT&E must be conducted without waiting for the JSE, to demonstrate F-35 combat effectiveness under the most realistic conditions that can be obtained in flight testing, once the aircraft hardware and software meet the IOT&E entrance criteria, which is expected to occur long before the completion and successful VV&A of JSE. It is now clear that the JSE will not be available and accredited in time to support the Block 3F IOT&E. The currently approved IOT&E detailed test design, which was developed entirely around open-air flight testing, mitigates the lack of an adequate simulation environment as much as possible.

Live Fire Test and Evaluation (LFT&E)

F-35C Full-Scale Aft Fuselage and Empennage Structure Test

- The F-35 LFT&E program completed the F-35C full-scale aft fuselage and empennage structure tests. The Navy's Weapons Survivability Laboratory in China Lake, California, accomplished three test events using the CG:0001 full scale structural test article. The tests evaluated the ability of the vertical tail and aft boom structure to withstand damage from high-explosive incendiary (HEI) projectile and simulated Man-Portable Air Defense System (MANPADS) threats. A preliminary review of the test results indicates that:
  - The F-35 vertical tail is capable of withstanding an HEI projectile impact. The threat can target and fail one attachment lug but the remaining lugs demonstrated their ability to handle normal flight loads after the impact. However, the pilot receives no alerts from the Integrated Caution, Advisory and Warning (ICAW) system from this type of structural damage, so there is a potential that a damaged vertical tail could fail without warning the pilot if the pilot demands higher than normal flight loads on the vertical tail after the damage occurs.
  - Two MANPADS shots were completed against the aft boom structures, which support the horizontal and vertical tails. Combined with results from earlier tests on an F-35A and F-35B test articles, these tests showed that the structures are sufficiently robust against these threats to retain all control surfaces. Although damage to a single control surface actuator is possible, earlier flight control tests showed sufficient controllability within a limited flight envelope to allow controlled flight back to a safe area where the pilot could eject.
  - The MANPADS tests demonstrated the potential for damage to the fueldraulics system – the engine fuel-based hydraulics system – which can result in a sustained fire leading to further damage to the aircraft and a pilot ejection over enemy territory. The data will be used to support an assessment in 2017 that will determine the contribution of this issue to the overall aircraft vulnerability.
  - While extended fires occurred in the MANPADS tests, there has been no effort expended to determine what catastrophic damage might result and the timeframe for that to occur. Current procedures are for an immediate ejection upon determination of a sustained fire. However, if the time-to-failure could be established for this sort of fire, it might allow the pilot time to depart a combat area and eject somewhere relatively safe. Further analysis of these test results and the related issue are needed.

PAO Shut-Off Valve

- The program has not provided an official decision to reinstate this vulnerability reduction feature. There has been no activity on the development of the PAO-shut-off valve technical solution to meet criteria developed from 2011 live fire test results. As stated in several previous reports, this aggregate, 2-pound vulnerability reduction feature, if installed, would reduce the probability of pilot incapacitation, decrease overall F-35 vulnerability, and prevent the program from failing one of its vulnerability requirements.

Vulnerability to Unconventional Threats

- The full-up, system-level chemical-biological decontamination test on an SDD aircraft, which began 4QFY16 and is scheduled to end in 2QFY17 at Edwards AFB, was supported by two risk-reduction events:
  - A System Integration Demonstration of the proposed decontamination equipment and shelter was conducted on an F-16 test article during 1QFY15 at Edwards AFB to simulate both hot air chemical and hot/humid air biological decontamination operations. Extensive condensation inside the shelter and on the test article during the

hot/humid air biological decontamination event indicated the need for process and shelter modifications.
  - A 2QFY16 event demonstrated that a modified system process and a better insulated shelter can maintain adequate temperature and humidity control inside the shelter, even in a cold-weather environment.
- The test plan to assess chemical and biological decontamination of pilot protective equipment is not adequate. Compatibility testing of protective ensembles and masks has shown that the materials survive exposure to chemical agents and decontamination materials and processes, but the program has neither tested nor provided plans for testing the HMDS currently being fielded. Gen II HMDS compatibilities were determined by analysis, comparing HMDS materials with those in an extensive DOD aerospace materials database. A similar analysis is planned for the Gen III HMDS design. However, even if material compatibilities were understood, there are no plans to demonstrate a process that could adequately decontaminate either HMDS from chemical and biological agents.
- The Joint Program Executive Office for Chemical and Biological Defense approved initial production of the F-35 variant of the Joint Service Aircrew Mask (JSAM-JSF) during 1QFY16. This office and the F-35 Joint Program Office are integrating the JSAM-JSF with the HMDS, which is undergoing Safety of Flight testing.
- The Navy evaluated an F-35B aircraft to the EMP threat level defined in Military-Standard-2169B. Follow-on tests on other variants of the aircraft, including a test series to evaluate any Block 3F hardware/software changes, are planned for FY16-17.

Gun Ammunition Lethality and Vulnerability

- The 780th Test Squadron at Eglin AFB, Florida, completed the ground-based lethality test of the PGU-47/U Armor Piercing High Explosive Incendiary with Tracer (APHEI-T) round (also known as Armor Piercing with Explosive (APEX)) against armored and technical vehicles, aircraft, and personnel-in-the-open targets. Ground-based lethality tests for the APEX correlated well with pre-test predictions for the round penetrations, but potential problems were discovered with fuze functioning when impacting rolled homogeneous armor at high obliquity. Nammo, the Norwegian manufacturer, conducted additional testing to identify the cause of the dudded rounds during the ground tests and subsequently modified the fuze design to increase reliability. The program will determine the effect of the ground-based lethality test data on the ammunition lethality assessment.
- Per the current mission systems software schedule, the weapons integration characterization of the gun and sight systems will not be ready for the air-to-ground gun strafe lethality tests until December 2016, at the earliest. Strafing targets will include a small boat, light armored vehicle, technical vehicle (pickup truck), and plywood mannequins for each round type tested.

Operational Suitability

- The operational suitability of all variants continues to be less than desired by the Services. Operational and training units must rely on contractor support and workarounds that would be challenging to employ during combat operations. In the past year some metrics of suitability performance have shown improvement, while others have been flat or declined. Most metrics still remain below interim goals to achieve acceptable suitability by the time the fleet accrues 200,000 flight hours, the benchmark set by the program and defined in the Operational Requirements Document (ORD) for the aircraft to meet reliability and maintainability requirements. This level of maturity is further stipulated as 75,000 flight hours for the F-35A, 75,000 flight hours for the F-35B, and 50,000 flight hours for the F-35C.
- Reliability growth has stagnated, so it is highly unlikely that the program will achieve the ORD threshold requirements at maturity for the majority of reliability metrics, most notably the Mean Flight Hours Between Critical Failures, without redesigning aircraft components.
- Aircraft fleet-wide availability averaged 52 percent for 12 months ending October 2016, compared to the modest goal of 60 percent. It is important to note that the expected combat sortie rates will require significantly greater availability than 60 percent; therefore, if the F-35 is to replace legacy aircraft for combat taskings, availability will likely need to improve to near 80 percent.
- Monthly availability had been averaging in the mid-30s to low-40s percent for the 2-year period ending September 2014. Monthly availability then increased rapidly and significantly from October to December, peaking at 56 percent in December 2014. However, since then it has remained flat, centering around the low-50s percent with no strong improving trend over time.
- Only two out of nine reliability metrics that have ORD requirement thresholds have improved since last year's report. All nine are below the interim goals that were set to determine if the metrics will meet the thresholds by maturity. None are within 5 percent of their interim goal, whereas previously, several of these metrics were reported as being above or within 5 percent of their interim goal. In particular, reliability metrics related to critical failures have decreased over the past year. This decrease in reliability correlates with the simultaneously observed decline in the Fully Mission Capable (FMC) rate for all variants, which measures the percentage of aircraft not in depot status that are able to fly all defined F-35 missions. The fleet-wide FMC rate peaked in December 2014 at 62 percent and has fallen steadily since then to 21 percent in October 2016.
- In addition to the nine ORD metrics, there are three contract specification metrics, Mean Flight Hours Between Failure scored as "design controllable," or DC, one for each variant. DC failures are equipment failures due to design flaws considered to be the fault of the contractor, such as components not withstanding stresses expected to be found

in the normal operational environment. It does not include failures caused by improper maintenance, or caused by circumstances unique to flight test. This metric exhibited the highest rate of the growth in the past and, for this metric, all variants are currently above program target values for this stage in development. However, since May 2015, DC reliability has generally decreased or remained flat as well.

- Although most measures of reliability have not improved significantly over the past year, three of six measures of maintainability have improved slightly. Maintainability metrics record the amount of time required to troubleshoot and repair faults on the aircraft. Additionally, the number of flight hours each aircraft flies per month, known as the utilization rate, has also increased marginally.
- F-35 aircraft spent 9 percent more time down for maintenance than intended (fleet average of 16.4 percent compared to 15 percent goal), and waited for parts from supply for 71 percent longer than the program targeted (fleet average of 17 percent compared to goal of 10 percent). At any given time, from 10 to 20 percent of aircraft were in a depot facility or depot status at the home base for major rework or planned upgrades. Of the remaining aircraft not in any depot status, on average less than a third were able to fly all missions of even a limited capability set that is associated with the Block 2B or Block 3i aircraft.
- Accurate suitability measures rely on adjudicated data from fielded operating units. A Joint Reliability and Maintainability Evaluation Team (JRMET), composed of representatives from the Program Office, the JOTT, the contractor (Lockheed Martin), and Pratt and Whitney (for engine records), reviews maintenance data to ensure consistency and accuracy for reporting measures; government representatives chair the team. However, the Lockheed Martin database that stores the maintenance data, known as the Failure Reporting and Corrective Action System (FRACAS), was not in compliance with U.S. Cyber Command information assurance policies implemented in August 2015 through late summer of 2016. Because of this non-compliance, government personnel were not able to access the database via government networks, preventing the JRMET from holding regularly scheduled reviews of maintenance records for nearly a year, other than a few ad hoc reviews. Regular JRMET meetings resumed in September 2016, but the program is currently working through reviewing a large backlog of un-adjudicated field data. The program restarted publishing monthly reliability and maintainability (R&M) status reports from adjudicated data in October 2016, after roughly a year-long hiatus.

F-35 Fleet Availability

- Aircraft availability is determined by measuring the percent of time individual aircraft are in an available status, aggregated over a reporting period (e.g., monthly). The program assigns aircraft that are not available to one of three categories of status: Not Mission Capable for Maintenance (NMC-M); Not Mission Capable for Supply (NMC-S); and depot status.
  - Program goals for these not-available categories have remained unchanged since 2014, at 15 percent for NMC-M, 10 percent for NMC-S, and 15 percent of the fleet in depot status. Depot status is primarily for completing the modifications required to bring currently fielded aircraft in compliance with their expected airframe structural lifespans of 8,000 flight hours and to incorporate additional mission capability. The majority of aircraft in depot status are located at dedicated depot facilities for scheduled modification periods that can last several months, and they are not assigned as a part of the operational or training fleet during this time. A small portion of depot activity can occur in the field when depot field teams conduct a modification at a main operating base, or affect repairs beyond the capability of the local maintenance unit. Similar to being at a depot facility, aircraft are temporarily assigned to depot status during these periods and are not considered a part of the operational or training fleet.
  - These three not-available category goals sum to 40 percent, resulting in a fleet-wide availability goal of 60 percent for 2016.
  - In addition to these overall program goals, the program has implemented a Performance Based Logistics (PBL) construct with Lockheed Martin that ties contract incentive awards to a slightly different set of tailored fleet performance targets. These tailored targets prioritize improvement efforts for Marine Corps F-35B performance as the first branch to declare Initial Operational Capability (IOC), and also because the F-35B variant has shown the lowest overall availability performance. Current PBL-based goals are 53 percent availability, 35 percent FMC, and 70 percent mission effectiveness rates for the F-35B training and operational fleets assigned to Marine Corps Air Station (MCAS) Beaufort and MCAS Yuma. The majority of the incentive structure is tied to these goals. To ensure Lockheed Martin continues to try to improve performance across the board, a smaller portion of the incentive fee is tied to overall fleet performance metrics of 60 percent F-35A, 50 percent F-35B, and 60 percent F-35C availability, regardless of operating site.
- Aircraft monthly availability averaged 52 percent for the 12-month period ending October 2016 in the training and operational fleets, with a maximum availability of 55 percent in May 2016 and a minimum availability of 44 percent in October 2016. This is only a minor improvement over the average 51 percent monthly availability reported in the FY15 DOT&E Annual Report for the 12 months ending October 2015. Further, some groups of aircraft continue to experience minimum availability well below 50 percent.
  - In no month did the overall fleet exceed its goal of 60 percent availability. Only the F-35C variant exceeded the 60 percent goal, in 6 of 12 months, with a maximum availability of 71 percent in April 2016. The F-35A and F-35B variants never exceeded 60 percent, but the F-35A

achieved 59 percent in May 2016 and the F-35B reached a maximum 50 percent in January, April, and July 2016.

- The table below summarizes aircraft availability by operating location for the 12-month period ending October 2016. The first column indicates the average availability achieved for the whole period, while the maximum and minimum columns represent the range of monthly availabilities reported over the period. The number of aircraft assigned at the end of the reporting period is shown as an indicator of potential variance in availability. Sites are arranged in order of when each site began operation of any variant of the F-35, and then arranged by variant for sites operating more than one variant. The Marine Corps terminated F-35B operations at Eglin AFB in February 2015, so there were no F-35Bs at that site for the 12-month period of this report; thus, that entry, previously reported in the FY15 DOT&E Annual Report, has been removed. The Navy operational test squadron at Edwards AFB received its first F-35C in August 2016, the only new operating site to stand up since the FY15 DOT&E Annual Report.
- Trend analysis of monthly fleet availability from August 2012 through October 2016 showed a weak rate of improvement of approximately 5 percent growth per year over this period. This is consistent with the growth rate reported in the DOT&E FY15 Annual Report – but, again, the growth was neither steady nor continuous. The majority of this growth still results from a concentrated increase in availability that occurred during the months of September 2014 through December 2014. Analysis of availability from January 2015 through October 2016, the time period after this concentrated increase, shows a more modest less than 1 percent annual growth rate, which is in better agreement with recent observations.
- The combined fleet of designated, instrumented OT aircraft currently at Edwards AFB, which was built in Lots 3 to 5, averaged 48 percent availability from January to October 2016. Seventeen instrumented OT aircraft were assigned to Edwards AFB as of October 2016. This is well-short of the target of 80 percent that will be needed to conduct an efficient IOT&E, or combat operations.

F-35 AVAILABILITY FOR 12-MONTH PERIOD ENDING OCTOBER 2016[1]

Operational Site	Average	Maximum	Minimum	Aircraft Assigned[2]
Whole Fleet	52%	55%	44%	178
Eglin F-35A	38%	49%	32%	25
Eglin F-35C	60%	71%	54%	21
Yuma F-35B	55%	62%	40%	19
Edwards F-35A	53%	74%	40%	8
Edwards F-35B	46%	64%	30%	7
Edwards F-35C[3]	27%	40%	4%	2
Nellis F-35A	50%	62%	42%	13
Luke F-35A	61%	68%	44%	44
Beaufort F-35B	43%	53%	33%	24
Hill F-35A	57%	80%	22%	15

1. Data do not include SDD aircraft.
2. Aircraft assigned at the end of October 2016.
3. Edwards AFB F-35C operations began August 2016.

- Due to concurrent development and production, which resulted in delivering operational aircraft before the program has completed development and finalized the aircraft design, the Services must send the current fleet of F-35 aircraft to depot facilities. This is to receive modifications that have been designed since the aircraft were originally manufactured and are now required for full capability. Some of these modifications are driven by faults in the original design that were not discovered until after production had started, such as major structural components that do not meet the requirements for the intended lifespan, and others are driven by the continuing improvement of the design of combat capabilities that were known to be lacking when the aircraft were first built. These modifications are a result of the concurrency of production and development and cause the program to expend resources to send aircraft for major re-work, often multiple times, to keep up with the aircraft design as it progresses. Since SDD will continue at least to the middle of 2018, and by then the program will have delivered nearly 200 aircraft to the Services in other than the 3F configuration, the depot modification program and its associated concurrency burden will be with the Services for years to come.
  - Sending aircraft to depot facilities for several months at a time to bring them up to Block 3i capability from Block 2B (i.e., upgrading avionics processors) and to meet life limit requirements, and eventually to the Block 3F configuration, reduces the number of aircraft at field sites and thus decreases fleet availability. For the 12-month period ending October 2016, the proportion of the fleet in depot status averaged 15 percent, compared to 16 percent for the 12-month period ending October 2015 stated in the DOT&E FY15 Annual Report. The proportion of aircraft in depot status was relatively flat over the majority of this period with little overall trend, ranging between a maximum monthly value of 22 percent and a minimum value of 11 percent. The maximum value of 22 percent occurred in October 2016, and was partly driven by one-time repairs to shedding foam insulation around PAO lines in the fuel tanks for 15 fielded F-35A aircraft. DOT&E expects this rise in the depot rate to be a one-time occurrence, and not indicative of a general trend.
  - There is evidence from Program Office reports, however, that later production lot aircraft achieve higher availability rates than earlier lots. For example, for the period from October 2015 to September 2016, accounting for 30 Lot 4 aircraft of all variants, each variant averaged a monthly availability between 43 and 44 percent. For the same time period and accounting for 33 Lot 7 aircraft of all variants, each variant averaged a monthly availability between 64 and 68 percent, which was a statistically significant

increase. However, a significant amount of this increase in availability can be attributed to the newer lot aircraft requiring fewer depot modifications. Over this period the Lot 4 aircraft averaged a monthly depot rate between 19 and 26 percent, depending on variant, whereas the Lot 7 aircraft averaged a monthly depot rate between 0 and 6 percent, considering variant.

  - Projections of depot rates beyond 2016 are difficult, since testing and development are ongoing and discoveries continue, including the need for redesigned outer wing structure on the F-35C to accommodate AIM-9X missile carriage. This structural modification was installed on an F-35C developmental test aircraft for testing in late 2016. Also, the program does not yet know the full suite of modifications that will be necessary to bring currently produced aircraft up to the final Block 3F configuration. However, as the program continues to ramp up production rates, the later lot aircraft, which generally require fewer modifications, will comprise a larger proportion of the fleet and may exert a downward influence on the depot percentage rate.
- To examine the suitability performance of fielded aircraft, regardless of how many are in the depot, the program reports on the Mission Capable (MC) and Fully Mission Capable (FMC) rates for the F-35 fleet. The MC rate represents the proportion of the fleet that is not in depot status and that is ready to fly any type of mission (as opposed to all mission types). This rate includes aircraft that are only capable of flying training flights, however, and not necessarily a combat mission. The FMC rate calculates only the proportion of aircraft not in depot status that are capable of flying all assigned missions and can give a better view into the potential combat capability available in the fielded units.
  - F-35 aircraft averaged a 62 percent MC rate for the 12-month window ending in October 2016 considering all variants, a slight decrease from the 65 percent reported in the FY15 DOT&E Annual Report. The rate showed little change over time, ranging from a minimum value of 57 percent to a maximum value of 66 percent for the whole fleet, and was relatively consistent across variants as well. The F-35A achieved the highest variant-specific rate at 64 percent, followed by 63 percent for the F-35C, and 59 percent for the F-35B.
  - The FMC rate continued to exhibit a steady decline first observed in 2015, and averaged only 29 percent over the period, compared to 46 percent reported in the FY15 DOT&E Annual Report. The rate started at 32 percent in November 2015, which was close to the peak of 33 percent in April 2016, but generally dropped month over month to a minimum value of 21 percent by October 2016. The FMC rate has not been consistent across variants. The F-35A fleet achieved the highest average FMC rate for the period at 37 percent, followed by the F-35C at 24 percent. The F-35B fleet exhibited only a 14 percent average FMC rate, however. Failures in the Distributed Aperture System (DAS), electronic warfare (EW) system, and Electro-Optical Targeting System (EOTS) were the highest drivers pushing aircraft into Partial Mission Capable (PMC) status.
  - Analysis of the MC rate of each production lot reveals that later lot aircraft have a greater MC rate than earlier lot aircraft; the difference is less pronounced than the comparison of availability, but still significant. The 30 Lot 4 aircraft averaged between 52 and 61 percent MC over this period by variant, compared to 68 to 73 percent for the Lot 7 aircraft by variant.
  - The OT fleet at Edwards AFB averaged an MC rate of 53 percent from January to October 2016.
- The first table below shows F-35 MC and FMC rates for the total fleet and each variant for the 12-month period ending October 2016, including the average, maximum, and minimum monthly values observed. The second table shows F-35 availability and MC rates by production lot and by variant for the 12-month period ending September 2016.

F-35 MC AND FMC RATES BY VARIANT FOR 12-MONTH PERIOD ENDING OCTOBER 2016

Variant	MC			FMC		
	Avg.	Max	Min	Avg.	Max	Min
Fleet	62%	66%	57%	29%	33%	21%
F-35A	64%	70%	55%	37%	42%	27%
F-35B	59%	65%	53%	14%	17%	10%
F-35C	63%	73%	55%	24%	44%	13%

F-35 AVAILABILITY AND MISSION CAPABLE RATES BY LOT (OCTOBER 2015 TO SEPTEMBER 2016)

Lot	No. of Aircraft				Availability			Mission Capable		
	F-35A	F-35B	F-35C	Total	F-35A	F-35B	F-35C	F-35A	F-35B	F-35C
2/3	14	13	-	27	33%	37%	N/A	57%	54%	N/A
4	10	17	3	30	44%	44%	43%	61%	59%	52%
5	22	3	7	32	51%	50%	57%	62%	52%	60%
6	23	6	7	36	62%	60%	67%	63%	66%	68%
7	22	7	4	33	67%	64%	68%	73%	68%	68%
8	14	3	3	20	49%	65%	79%	68%	65%	80%

- The monthly NMC-M rate averaged 16 percent over the period and was relatively stable, with a minimum value of 14 percent and a maximum value of 20 percent. This rate achieved the program goal of 15 percent, or lower, in 4 of the 12 months of the period. It also shows a slight decreasing (improving) trend over time that indicates with further improvement it may be possible to achieve and sustain program targets within the next calendar year.
  - Completing directed modifications or upgrades on still-possessed aircraft in the field also affects the NMC-M rate. In such cases, squadron-level maintainers, instead of the depot or contractor field teams, are tasked to complete Time Compliance Technical Directives (TCTDs). The "time compliance" limits for these directives vary, normally allowing the aircraft to be operated for a certain period of time without the modification. This permits maintenance personnel to do the work at an opportune time, without taking the aircraft off the flight schedule to do so, such as by combining the TCTD with other maintenance activities. While maintainers accomplish these TCTDs, the aircraft are designated as NMC-M status, and not in depot status. Incorporating these TCTDs will drive the NMC-M rate up (worse) until these remaining modifications are completed. Publishing and fielding new TCTDs is expected for a program under development and is needed to see improvement in reliability and maintainability; however, they inherently add to the maintenance burden in the fielded operational units.
- The NMC-S rate averaged 17 percent and showed no significant trend over the period. In no month did the rate achieve the program goal of 10 percent or less, with a minimum value of 14 percent and a maximum value of 20 percent.
  - Several factors have contributed to the NMC-S rate underperforming relative to its goal more than either the NMC-M or depot not-available categories. First, the program originally funded spares to a 20 percent NMC-S rate. To determine the quantity and type of spares needed to achieve this, the program used incorrect engineering predictions that overestimated component reliability (fleet data were not available when this modeling was done early in the program). Actual mean time between failures for many components is lower than the forecasted values used in the spares model. Second, contracting for spares has often been late to need to support the first aircraft delivery for several of the initial production lots. Third, the program has been late to stand up organic depot capabilities to repair existing parts that have failed but can be refurbished instead of being replaced with new parts. Such a capability would reduce the strain on suppliers to produce more spare parts.
  - The lack of spares available in the supply system is driving operating units to take good parts from one NMC aircraft and install them in other aircraft down for those parts, bringing the latter back to available status. This process, known as cannibalization, is performed by units when supply cannot provide needed parts in a timely manner. Cannibalization results in a significant increase in maintenance man-hours compared to replacing a bad part with a new or repaired part. For the 12-month period ending in October 2016, the monthly cannibalization rate averaged 9.8 cannibalization actions for every 100 sorties against a program goal of no more than 8 actions for every 100 sorties. The fleet met this goal in only 1 month, performing 6.2 cannibalizations per 100 sorties in December 2015, but analysis over this period does not demonstrate a statistically significant trend in the cannibalization rate.
  - Modifying aircraft also has an effect on the NMC-S rate as the Services can cannibalize parts from aircraft in the depots to support field units when replacement parts are not otherwise available from normal supply channels or stocks of spare parts on base. With the large number of aircraft in depot status, the program may have been able to improve the NMC-S rate by using depot cannibalizations, instead of procuring more spare parts, or reducing the failure rate of parts installed in aircraft, or improving how quickly failed parts are repaired and returned to circulation. If the Services endeavor to bring all of the early lot aircraft into the Block 3F configuration, the program will continue to have an extensive modification program for several years. While this will continue to provide opportunities for depot cannibalizations during that time, once the Block 3F modifications are complete, there will be fewer aircraft in the depot serving as spare parts sources and more in the field requiring parts support. If demand for spare parts remains high, this will put pressure on the supply system to keep up with demand without depot cannibalization as a source.
  - While the fleet was much closer to achieving the NMC-M goal than the NMC-S goal, these two rates are not necessarily completely independent. Specifically, poor diagnostics or difficult-to-conduct troubleshooting – issues that are maintainability problems at root cause – can drive the NMC-S rate up as well. For example, if troubleshooting efforts initially isolate faults to incorrect parts, units may inadvertently take good parts off the aircraft, return them to the supply system for depot or manufacturer checks, and demand replacement parts, unnecessarily straining the supply system for repair actions that will not resolve the fault. Units will report aircraft in NMC-S status until these replacement parts arrive. Once the unit receives and installs these parts, it would discover that the original problem remains, and return the aircraft to NMC-M status until further troubleshooting hopefully isolates the correct part. Thus, actions to reduce higher-than-targeted NMC-S rates may include improving the accuracy of diagnostics and troubleshooting procedures as well as increasing the availability of spare parts.
- The following table summarizes depot, NMC-M, and NMC-S rates for the total F-35 fleet and each variant for the 12-month period ending October 2016, including the average, maximum, and minimum monthly values observed.

F-35 DEPOT, NMC-M, AND NMC-S RATES BY VARIANT FOR 12-MONTH PERIOD ENDING OCTOBER 2016

Variant	Depot (Goal of 15% or less)			NMC-M (Goal of 15% or less)			NMC-S (Goal of 10% or less)		
	Avg.	Max	Min	Avg.	Max	Min	Avg.	Max	Min
Fleet	15%	22%	11%	16%	20%	14%	17%	20%	14%
F-35A	14%	27%	8%	17%	24%	12%	17%	21%	12%
F-35B	20%	25%	14%	17%	25%	11%	16%	20%	13%
F-35C	6%	15%	2%	14%	20%	9%	20%	27%	13%

- Low availability is preventing the fleet of fielded operational F-35 aircraft from achieving the originally planned, Service-funded flying hour goals. The original Service beddown plans were based on F-35 squadrons ramping up to a steady state, fixed number of flight hours per tail per month, allowing for the projection of total fleet flight hours.
    - Since poor availability in the field has shown that these original plans were unexecutable, the Program Office has since produced modeled-achievable projections of total fleet flight hours, basing these projections on demonstrated fleet reliability and maintainability data, as well as expectations for future improvements. The most current modeled-achievable projection is from March 2016.
    - Through November 21, 2016, the fleet had flown approximately 91 percent of the modeled-achievable hours. This is an improvement since November 2015, the date used in the FY15 DOT&E Annual Report, when the fleet had flown 82 percent of modeled-achievable hours; however, recent updates to the model revised the projected hours downward. The completion of actual flight hours against modeled-achievable flight hours was consistent across all three variants, with each variant completing between 90 or 96 percent of its variant-specific projection. By comparison, the fleet had flown only 72 percent of the original beddown plan hours, with wide discrepancy between variants. The F-35A had flown 82 percent of its original beddown plan hours, while the F-35C had flown only 49 percent, for example.
    - The following table shows the planned versus achieved flight hours by variant for both the original plans and the modeled-achievable projections for the fielded production aircraft through November 21, 2016.

F-35 FLEET PLANNED VS. ACHIEVED FLIGHT HOURS AS OF NOVEMBER 21, 2016

Variant	Original Beddown Plan Cumulative Flight Hours			"Modeled Achievable" Cumulative Flight Hours		
	Est. Planned	Achieved	Percent Planned	Est. Modeled	Achieved	Percent Planned
F-35A	41,000	33,754	82%	36,788	33,754	92%
F-35B	29,000	19,644	68%	21,935	19,644	90%
F-35C	12,500	6,070	49%	6,348	6,070	96%
Total	82,500	59,469	72%	65,071	59,469	91%

F-35 Fleet Reliability

- Aircraft reliability assessments include a variety of metrics, each characterizing a unique aspect of overall weapon system reliability.
    - Mean Flight Hours Between Critical Failures (MFHBCF) includes all failures that render the aircraft not safe to fly, and any equipment failures that would prevent the completion of a defined F-35 mission. It includes failures discovered in the air and on the ground.
    - Mean Flight Hours Between Removal (MFHBR) gives an indication of the degree of necessary logistical support and is frequently used in determining associated costs. It includes any removal of an item from the aircraft for replacement. Not all removals are failures, and some failures can be fixed on the aircraft without a removal. For example, some removed items are later determined to have not failed when tested at the repair site. Other components can be removed due to excessive signs of wear before a failure, such as worn tires.
    - Mean Flight Hours Between Maintenance Event Unscheduled (MFHBME_Unsch) is a useful reliability metric for evaluating maintenance workload due to unplanned maintenance. Maintenance events are either scheduled (e.g., inspections, planned removals for part life) or unscheduled (e.g., maintenance to remedy failures, troubleshooting false alarms from fault reporting or defects reported but within limits, unplanned servicing, removals for worn parts— such as tires). One can also calculate the mean flight hours between scheduled maintenance events, or total events including both scheduled and unscheduled. However, for this report, all MFHBME_Unsch metrics refer to the mean flight hours between unscheduled maintenance events only, as it is an indicator of aircraft reliability and the only metric with an ORD requirement for mean flight hours between maintenance event.
    - Mean Flight Hours Between Failures, Design Controllable (MFHBF_DC) includes failures of components due to design flaws under the purview of the contractor, such as the inability to withstand loads encountered in normal operation. Failures induced by improper maintenance practices are not included.
- The F-35 program developed reliability growth projection curves for each variant throughout the development period as a function of accumulated flight hours. These projections were established to compare observed reliability with target numbers to meet the threshold requirement at maturity, defined by 75,000 flight hours for the F-35A and F-35B, and by 50,000 flight hours for the F-35C, for a total 200,000 cumulative fleet flight hours. In November 2013, the program discontinued reporting against these curves for all ORD reliability metrics, and retained only the curve for MFHBF_DC, which is the only reliability metric included in the JSF Contract Specification (JCS). DOT&E reconstructed the growth curves for the other metrics analytically for this report. The following discussion and tables compare the

3-month reliability metrics to the growth goals required to be on track to meet threshold requirements at maturity.

  - As of the end of July 2016, the F-35 fleet, including operational and flight test aircraft, had accumulated nearly 60,300 flight hours, or approximately 30 percent of the total 200,000-hour maturity mark defined in the ORD. Unlike the above table, which accounts only for fielded production aircraft, the flight test aircraft are included in the fleet hours which count toward reliability growth and maturity. By variant, the F-35A had flown approximately 32,400 hours, or just over 43 percent of its individual 75,000-hour maturity mark; the F-35B had flown approximately 20,300 hours, or 27 percent of its maturity mark; and the F-35C had flown approximately 7,600 hours, or 15 percent of its maturity mark.

- The program reports reliability and maintainability metrics on a 3-month rolling window basis. This means, for example, the MFHBR rate published for a month accounts only for the removals and flight hours of that month and the two previous months. This rolling 3-month window provides enough time to average out variability often seen in month-to-month reports, while providing a short enough period to distinguish current trends.
- The first table, below, compares the most recently reported and projected interim goal MFHBCF values, with associated flight hours. It shows the ORD threshold requirement at maturity and the values for May 2015, the month used in the FY15 DOT&E Annual Report, for reference as well.
- The three similar tables on the next page compare the most recently reported and projected interim goals for MFHBR, MFHBME_Unsch, and MFHBF_DC rates for all three variants. MFHBF_DC is contract specification, and its JCS requirement is shown in lieu of an ORD threshold.
- Note that data more current than July 2016 were not available at the time of this report due to the backlog of maintenance events awaiting JRMET review as a result of the Lockheed Martin database (FRACAS) not being compliant with all applicable DOD information assurance policies mandated by U.S. Cyber Command.
- Reliability values decreased (worsened) for 8 of 12 metrics between the May 2015 and the July 2016 values. All three MFHBCF metrics decreased between May 2015 and July 2016, and usually showed the greatest degree of reduction compared to the other reliability metrics. This aligns with the declining FMC rates for all variants. Of the remaining metrics, F-35A MFHBR and MFHBME_Unsch, and F-35A and F-35B MFHBF_DC, improved slightly. A more in-depth trend analysis over the 12-month period showed that all three variants exhibited declining MFHBCF; F-35B and F-35C MFHBR and MFHBME_Unsch were either flat or decreasing slowly; and MFHBF_DC for all variants were also either flat or decreasing. Only F-35A MFHBR and MFHBME_Unsch increased over this period.
- All nine of the ORD metrics are below interim program goals based on their planned reliability growth curves to meet threshold values by maturity. Furthermore, none of the ORD metrics are within 5 percent of their interim goals. Of the ORD metrics, F-35B MFHBME, at 86 percent, was the closest to its interim goal, while F-35C MFHBCF, at 39 percent, was the farthest. All of the JCS metrics, which are the MFHBF_DC for each variant, are above their growth curve interim values, ranging from 12 percent above for the F-35A to 28 percent above for the F-35B. This pattern indicates that the performance of the contract specification reliability metrics exceeding their interim values is not translating into the ORD reliability metrics showing the same improvement, which are operational requirements that will be evaluated during IOT&E.
- The fact that all the contract specification metrics are above their growth curve does not necessarily imply that the F-35 will deliver desired reliability in the field, especially in light of the fact that all ORD requirements are below their growth curves. The ORD requirements reflect how the aircraft will perform in combat, while the JCS metrics are limited to failures that are definitively the fault of component design. However, several situations can divorce improvement in the JCS metrics to similar improvements in the ORD metrics or availability. For example, components that are easily broken during maintenance, such as nutplates, may not be scored as design-controllable failures, but repairing and replacing these fragile components will adversely affect the ORD reliability metrics. Likewise, when old versions of redesigned components fail in the field, depending on circumstances, these failures may not be reported in the reliability metrics, but the effect on downing the aircraft will always be reflected in the availability metrics.
- The effect of lower (poorer) MFHBCF values is reduced aircraft fully mission capable, mission capable, and

F-35 RELIABILITY: MFHBCF (HOURS)

Variant	ORD Threshold		Values as of July 31, 2016				Values as of May 2015*	
	Flight Hours	MFHBCF	Cumulative Flight Hours	Interim Goal to Meet ORD Threshold MFHBCF	Observed MFHBCF (3 Mos. Rolling Window)	Observed Value as Percent of Goal	Cumulative Flight Hours	Observed MFHBCF (3 Mos. Rolling Window)
F-35A	75,000	20	32,358	17.8	8.0	45%	15,845	8.8
F-35B	75,000	12	20,256	10.0	4.6	46%	11,089	7.2
F-35C	50,000	14	7,648	10.9	4.2	39%	3,835	7.5

* The JPO revised past R&M metrics based on applying the current JRMET scoring rules to past data. As a result, values reported for May 2015 in this report may be different than the values for the same month in the FY15 DOT&E Annual Report. See the Reliability Growth section below for more details.

F-35 RELIABILITY: MFHBR (HOURS)								
Variant	ORD Threshold		Values as of July 31, 2016				Values as of May 2015	
	Flight Hours	MFHBR	Cumulative Flight Hours	Interim Goal to Meet ORD Threshold MFHBR	Observed MFHBR (3 Mos. Rolling Window)	Observed Value as Percent of Goal	Cumulative Flight Hours	Observed MFHBR (3 Mos. Rolling Window)
F-35A	75,000	6.5	32,358	5.8	4.7	81%	15,845	4.4
F-35B	75,000	6.0	20,256	5.0	2.8	56%	11,089	4.0
F-35C	50,000	6.0	7,648	4.7	2.3	49%	3,835	3.9

F-35 RELIABILITY: MFHBME_Unsch (HOURS)								
Variant	ORD Threshold		Values as of July 31, 2016				Values as of May 2015	
	Flight Hours	MFHBME_Unsch	Cumulative Flight Hours	Interim Goal to Meet ORD Threshold MFHBME_Unsch	Observed MFHBME_Unsch (3 Mos. Rolling Window)	Observed Value as Percent of Goal	Cumulative Flight Hours	Observed MFHBME_Unsch (3 Mos. Rolling Window)
F-35A	75,000	2.0	32,358	1.77	1.36	77%	15,845	1.13
F-35B	75,000	1.5	20,256	1.25	1.08	86%	11,089	1.10
F-35C	50,000	1.5	7,648	1.13	0.74	65%	3,835	0.98

F-35 RELIABILITY: MFHBF_DC (HOURS)								
Variant	JCS Requirement		Values as of July 31, 2016				Values as of May 2015	
	Flight Hours	MFHBF_DC	Cumulative Flight Hours	Interim Goal to Meet JCS Requirement MFHBF_DC	Observed MFHBF_DC (3 Mos. Rolling Window)	Observed Value as Percent of Goal	Cumulative Flight Hours	Observed MFHBF_DC (3 Mos. Rolling Window)
F-35A	75,000	6.0	32,358	5.2	5.8	112%	15,845	5.4
F-35B	75,000	4.0	20,256	3.2	4.1	128%	11,089	3.6
F-35C	50,000	4.0	7,648	2.9	3.3	114%	3,835	4.2

availability rates. MFHBR values lagging behind planned growth targets drive a higher demand for spare parts from the supply system than originally envisioned. When MFHBME_Unsch values are below expectation, there is a higher demand for maintenance manpower than anticipated.

Reliability Growth

- In the fall of 2016, the Program Office revised reliability and maintainability (R&M) metrics that had been previously reported by applying new or updated JRMET scoring rules that had been created or modified at different times over the course of system development, and agreed to by the JRMET members, to historical maintenance event data. Scoring rules determine such criteria as when a maintenance event is considered relevant and should be included in R&M metrics, when an event is not relevant and will not be included in metrics, such as failures in test-specific instrumentation that will not be installed in operational aircraft, and when an event is chargeable to the design-controllable metric as being the fault of the design as opposed to induced by improper maintenance. There are many detailed scoring rules to ensure similar maintenance situations are scored consistently. As the JRMET developed new scoring rules and changed some existing ones, the program realized that previously reported metrics needed to be revised – scored by the new rule set – in order to ensure current R&M metrics could be compared more accurately with past R&M performance. The effects on each reliability metric of this revision were mixed, with 7 of 12 of the May 2015 metrics being revised downward (worsening), and the remaining 5 increasing compared to their originally reported values; however, 4 of these improved metrics decreased, or worsened, by July 2016. Note the values in the tables above reflect the JPO revised past R&M metrics based on applying the current JRMET scoring rules to past data. As a result, values reported for May 2015 in this report may be different than the values for the same month in the FY15 DOT&E Annual Report.
- In the two prior Annual Reports, DOT&E reported the results of reliability growth analysis based on the Duane Postulate, using R&M data provided by the Program Office, to determine the rate of growth for MFHBR and MFHBME_Unsch. In 2016, DOT&E conducted an updated analysis of reliability growth using the more refined U.S. Army Materiel Systems Analysis Activity (AMSAA)-Crow model, examining data from the start of the program to July 2016. The AMSAA-Crow model characterizes growth by a single growth parameter, using a method that is similar to the Duane Postulate. A growth rate between zero and one implies improvement in reliability, a growth rate of zero

implies no growth, and a growth rate less than zero implies reliability decay. Since it is logarithimic, a growth rate of 0.40 represents much faster than twice the growth of a rate of 0.20.

- Unlike the Duane Postulate, the AMSAA-Crow model enables the determination of statistical confidence intervals on its estimated growth rate based on the underlying mathematics in the model. Further, the expected growth rate is determined by Maximum Likelihood Estimator (MLE) methods, rather than linear regression as in the Duane Postulate, allowing for the quantity of data to have an effect on the growth parameter estimate.
  - Previous DOT&E Annual Report reliability growth analyses included only the F-35A and F-35B variants, and only for the MFHBR and MFHBME metrics, due to a small amount of hours on the F-35C, and fewer critical failures than removals and unscheduled maintenance events. For this year's updated analysis, sufficient data for the MFHBCF metric and the F-35C variant were available for these metrics and estimates to be included.
  - The first table below shows the most likely growth rate and 95 percent upper and lower confidence bound growth rates, providing a range of likely values for the actual growth rate, for all three variants and all three ORD reliability metrics. It also includes the projected values of these three metrics for each variant based on the most likely, upper, and lower bound growth rates at maturity; i.e., 75,000 flight hours for the F-35A and F-35B and 50,000 flight hours for the F-35C.

Metric	Variant	July 2016 Growth Rates			Projections at Maturity			ORD Threshold
		Most Likely	Lower Bound	Upper Bound	Most Likely	Lower Bound	Upper Bound	
MFHBCF	F-35A	0.137	0.109	0.164	9.6	9.0	10.2	20.0
	F-35B	-0.051	-0.089	-0.014	N/A *			12.0
	F-35C	-0.107	-0.180	-0.039	N/A *			14.0
MFHBR	F-35A	0.192	0.173	0.211	6.1	5.8	6.4	6.5
	F-35B	0.126	0.103	0.148	4.1	3.9	4.4	6.0
	F-35C	-0.068	-0.119	-0.020	N/A *			6.0
MFHBME _Unsch	F-35A	0.170	0.161	0.179	1.38	1.35	1.41	2.0
	F-35B	0.359	0.351	0.367	2.01	1.96	2.08	1.5
	F-35C	0.189	0.174	0.205	1.26	1.20	1.33	1.5

* No estimates for projections at maturity were made for metrics with negative growth rates.

Aircraft	MFHBME_Unsch Growth Rate
F-15	0.14
F-16	0.14
F-22 (at 35,000 flight hours)	0.22
B-1	0.13
"Early" B-2 (at 5,000 flight hours)	0.24
"Late" B-2	0.13
C-17 (at 15,000 flight hours)	0.35

  - The growth rates listed in the first table were calculated with approximately 32,400 hours for the F-35A, 20,300 hours for the F-35B, and 7,600 hours for the F-35C. For comparison, historically observed MFHBME_Unsch growth rates for several currently fielded aircraft are shown in the second table. Analogous rates for MFHBR and MFHBCF are not available.
- The updated reliability growth analysis through July 2016, using the AMSAA-Crow model, accounts for the recent tapering off of reliability growth better than the Duane Postulate. As a result, most of the growth rates in the table above are lower than those reported in prior DOT&E Annual Reports. For the nine ORD metrics, the current growth analysis predicts that only one will meet or surpass the ORD threshold value at maturity, F-35B MFHBME_Unsch. As the analysis showed no growth for F-35B and F-35C MFHBCF, and F-35C MFHBR, no projections out to maturity were made for those metrics and current estimates do not meet threshold requirements.
  - Comparing the currently exhibited MFHBME_Unsch growth rates to historical aircraft shows that from program initiation to July 2016, F-35 reliability has improved faster than average for all variants. However, F-35 reliability remains below program interim goals for its current stage of development in all cases, and is not projected to achieve threshold values by maturity in most cases, due to very low initial reliability at the start of the program, well below the assumed initial reliability values that informed program interim goals.
  - Although there were approximately 7,600 hours on the F-35C fleet for this year's analysis, usually enough time to establish a growth trend, the lack of evidential growth in the MFHBCF and MFHBR metrics may be explained by the fact that the F-35C fleet has only recently begun to send aircraft to the depot for modifications. Also, the F-35C fleet has the least hardware improvements incorporated relative to the F-35A and F-35B fleets. The relatively strong growth in the MFHBME metric, by contrast, can be partly explained for all variants by a reduction in false alarms from the aircraft Prognostics and Health Management (PHM) system, driving fewer overall unscheduled maintenance actions, in addition to the natural learning curve process.
- Based on current reliability trends, projections to maturity may not be appropriate. Reliability growth projection methodologies often assume that a system is in a single phase of testing, characterized by a nearly constant operating mode and environment, and gets reliability improvements incorporated while the system is under test. For most of the F-35 program, these conditions have held sufficiently true such that reliability growth displayed consistent behavior; however, with the release of Block 2B capabilities, including increased flight envelope, beginning in 2015, both the operating mode and environment apparently changed enough to constitute a new phase for the purpose of analyzing reliability growth. Programs with multiple phases

of development, where each phase is defined by different environments or operational usage, normally generate separate reliability planning curves (used to determine interim goals during that phase) and separate reliability growth tracking curves for each phase, as a single curve is not sufficient to mathematically represent reliability growth behavior across multiple phases. Because the reliability projections are based on data that span the periods of time, both before and after the Block 2B fleet release, they may not best capture reliability trends.

  - For programs with multiple phases, it is common for reliability to decrease or level off at the start of a new phase when the system is subjected to a more stressing operating mode or environment that exposes new failure modes. As a result, reliability growth can come to a halt or even decline; however, after a while, growth may resume as the program starts to implement reliability improvements for these new failure modes.
  - Reliability growth may resume as a result of ongoing program reliability improvement initiatives, continuing to send aircraft through the depot modifications program, replacing lower reliability components with higher reliability versions via TCTDs, and other reliability initiatives. However, DOT&E also expects that the Block 3F envelope and capabilities release, incrementally released between CY17 and CY18, will reveal new failure modes (e.g., new weapons, higher airspeeds and g with Block 3F envelope) that will limit the overall effect of these reliability improvement initiatives.
  - Despite the difficulty projecting accurate reliability values at maturity, given the phased introduction of F-35 block capabilities, DOT&E does not expect any variant to achieve interim threshold goals for MFHBCF by the start of IOT&E, considering the recent decline in this metric over the past year. In fact, indications are that for each variant, this metric is the furthest from its current interim goal.

- Failing to grow reliability sufficiently by the start of IOT&E will make achieving the necessary 80 percent availability to accomplish all mission trials within the planned time span very difficult. Further, a failure to achieve adequate MFHBCF reliability in particular will impede the ability of the Operational Test Squadrons (OTS) to generate multiple four-ship formations with all required mission systems functional, a necessary condition for a set of the planned mission trials.
- A number of components have demonstrated reliability much lower than predicted by engineering analysis. This drives down the overall system reliability and can lead to long wait times for resupply as the field demands more spare parts than the program planned to provide. Aircraft availability is also negatively affected by longer-than-predicted component repair times. The table at top right shows some of the high-driver components affecting low availability and reliability, grouped by components common to all variants, followed by components failing more frequently on a particular variant or which are completely unique to it.

HIGH-DRIVER COMPONENTS AFFECTING LOW AVAILABILITY AND RELIABILITY

Variant	Common to All Variants	Additional High Drivers by Variant
F-35A	• Avionics Processors • Low Observable Maintenance • Shock Struts • Cold Air Duct • IPP Vent Fan Controller • Main Landing Gear Tires • Nutplates • On-Board Oxygen Generating System	• Horizontal Tail Actuation • Vertical Tail Bulb Seal • Electronic Warfare Receiver
F-35B		• Fuel System Components and Mods • Flexible Linear Shaped Charge
F-35C		• Main Landing Gear Retract Actuator * • Nose Landing Gear Steering Motor *

* Unique to the F-35C
IPP – Integrated Power Package

  - The composition of the list of some of the high-driver components has changed as the program has progressed and either fielded more reliable components, or new failures have occurred to displace previous high drivers. For example, compared to the list reported in previous DOT&E Annual Reports, the 270V DC battery and associated components, the F-35B Upper Lift Fan Door Actuator, and the exhaust nozzle assembly components used on the F-35A and F-35C, are no longer high drivers. Improving aircraft availability can be realized by more than just improving the reliability of components and restocking supply with improved, redesigned parts; updating JTD and improving repair procedures can contribute to increased aircraft availability as well. However, in the current reporting period, overall reliability has not increased and new components have become high drivers, such as the Electronic Warfare Receiver and the Vertical Tail Bulb Seal. Note also that the program released Block 2B capabilities and flight envelope to the fleet in the period of this report. As the flight envelope is expanding and the fleet uses more mission system capabilities, new failure modes will likely emerge to dampen the overall effect of individual reliability improvements, consistent with recent trends observed in reliability growth analysis.

Maintainability

- The amount of time needed to repair aircraft and return them to flying status remains higher than the requirement for the system when mature, but has improved over the past year. The program assesses this time with several measures, including Mean Corrective Maintenance Time for Critical Failures (MCMTCF) and Mean Time To Repair (MTTR) for all unscheduled maintenance. MCMTCF measures active maintenance time to correct only the subset of failures that prevent the F-35 from being able to perform a specific mission; it indicates how long it takes, on average, for maintainers to return an aircraft from NMC to Mission Capable (MC) status. MTTR measures the average active maintenance time for all unscheduled maintenance actions; it is a general indicator of the ease and timeliness of repair.

Both measures include active touch labor time and cure times for coatings, sealants, paints, etc., but do not include logistics delay times, such as how long it takes to receive shipment of a replacement part.

- The tables below compare measured MCMTCF and MTTR values for the 3-month period ending in July 2016 to the ORD threshold and the percentage of the value to the threshold for all three variants. The tables also show the value from May 2015, the month reported in the FY15 DOT&E Annual Report, for reference. [Note that the May 2015 values may be different than those in the FY15 DOT&E Annual Report due to the revision of the scoring rules described at the beginning of the Reliability Growth section above.] For maintainability, lower repair times are better. Three of six metrics improved marginally, while three metrics, F-35B and F-35C MCMTCF, and F-35A MTTR, increased or worsened. Currently, all mean repair times are at least or nearly twice as long as their ORD threshold values for maturity, reflecting a heavy maintenance burden currently being carried by fielded units.

F-35 MAINTAINABILITY: MCMTCF (HOURS)

Variant	ORD Threshold	Values as of July 31, 2016 (3 Mos. Rolling Window)	Observed Value as Percent of Threshold	Values as of May 2015 (3 Mos. Rolling Window)
F-35A	4.0	10.6	265%	11.4
F-35B	4.5	13.2	293%	12.7
F-35C	4.0	10.1	253%	8.4

F-35 MAINTAINABILITY: MTTR (HOURS)

Variant	ORD Threshold	Values as of July 31, 2016 (3 Mos. Rolling Window)	Observed Value as Percent of Threshold	Values as of May 2015 (3 Mos. Rolling Window)
F-35A	2.5	6.3	252%	4.7
F-35B	3.0	7.3	243%	7.7
F-35C	2.5	4.9	196%	5.3

  - A more in-depth analysis of data from between August 2015 and July 2016, in order to capture longer-term 1-year trends, shows that for the MCMTCF metric, the F-35A and F-35B repair times are decreasing, while for the F-35C it is relatively flat. For overall mean repair times, however, the F-35A exhibited a slight increasing, or worsening trend; the F-35B showed a slight decreasing, or improving, trend; and the F-35C was relatively stable. Prior to May 2015, all six metrics were improving. In contrast, the more recent trend from this period generally indicates a slowing of improvement in the maintainability metrics.
  - All six maintainability metrics exhibit high month-to-month variability. Due to this variability, it is difficult to make projections in trends for maintenance metrics; however, it will be challenging for the program to meet the threshold values by maturity with the rate of improvement slowing and when current values for repair times are at least twice as high as requirements.
  - Several factors negatively influenced the ability to conduct quick and efficient maintenance. Extensive adhesive cure times for structural repairs, such as attaching hardware (e.g., nutplates and installing heat blankets around the engine bay), as well as long material cure times for low observable (LO) repairs, remain drivers. The cure time for some LO materials can be as high as 168 hours, for example, although units can accelerate this if they have appropriate tools.
  - Other factors that indirectly affect maintainability metrics have also been raised as concerns by maintainers. Maintainers must physically connect Portable Maintenance Aid (PMA) laptops to the aircraft in order to conduct most maintenance activities. The PMAs enable the maintainers to get status and configuration information from the aircraft, as well as control aircraft functions to enable other maintenance, such as opening the bomb bay doors where the cooling-air receptacle is located in order to apply air conditioning while running avionics on the ground. Maintainers also access the Anomaly Fault Resolution System (AFRS), which automatically troubleshoots Health Reporting Codes (HRCs) generated by the on-aircraft PHM system, and access JTD, which tells maintainers how to effect repairs identified by AFRS, via the PMA. Finally, maintainers record their work with the PMAs as well. However, synching the PMAs to the aircraft to conduct maintenance has been difficult, time-consuming and, in many instances, maintainers must attempt to synch several PMAs with an aircraft before finding one that will successfully connect. These connections are called Maintainer Vehicle Interface (MVI) sessions. Occasionally PMAs disconnect in the middle of an MVI session, which also hampers efficient maintenance. Recently, the program introduced improved MVI cable adapters to prevent accidental physical disconnection, which has helped. Software-related problems persist as well, such as PMAs taking anywhere from seconds to minutes to connect. This occasionally leads maintainers to disconnect a PMA they incorrectly believe is failing to connect, which prevents that PMA from connecting to an aircraft until an Automatic Logistics Information System (ALIS) administrator resets it, which can be a lengthy process.

- Maintainers have reported several difficulties with troubleshooting the aircraft, which is the first step in many maintenance actions. Normally, the aircraft PHM system produces HRCs and then maintainers use AFRS to identify possible root causes for those HRCs as well as determine the appropriate repair action. Often, AFRS will provide a "solution set," which lists several possible root causes for an HRC, rank ordered by probability of occurrence. While AFRS coverage is improving, it currently provides effective solution sets only approximately 70 percent of the time.

Particularly, when an aircraft fails a Vehicle Systems (VS) Built-In Test (BIT), an aircraft self-check conducted pre- and post-flight, there is no specific HRC produced, making these relatively frequent occurrences difficult to troubleshoot. When there is no HRC, such as in a VS BIT failure or manually reported fault, or AFRS does not produce a solution set for an HRC, or all the solutions offered by AFRS fail to resolve a fault, units must use other resources to troubleshoot the discrepancy. The primary method is to submit Action Requests (AR) to the joint JPO-Lockheed Martin Lightning Support Team (LST), whose engineers will further troubleshoot the aircraft remotely. The AR response times vary significantly, depending on category and urgency, but average several days to get a final response. Alternatively, or in conjunction, maintainers can use experience to troubleshoot on their own; however, in most cases they lack any system theory-of-operation or troubleshooting manuals that tell them how aircraft systems work. The current JTD are primarily dedicated to instructions only for repair actions for which AFRS has already identified a solution, and not for teaching maintainers the details of systems operations. Recently, the program and Lockheed Martin have started to provide some troubleshooting manuals to field maintainers for select mission systems to try to improve the poor fleet FMC performance. The extent to which these manuals will help troubleshooting and result in higher FMC rates remains to be determined.

- F-35 flying squadrons also have a heavy burden of scheduled maintenance. In particular, maintenance units have reported that daily servicing and inspection tasks, known as the Before-Operations Servicing (BOS), Inter-Operations Servicing (IOS), and Post-Operations Servicing (POS), are very time-consuming compared to similar inspections on legacy aircraft. Some of these daily inspections also require power and cooling air application on the aircraft, so a unit's ability to perform them is a function of the amount of Support Equipment (SE) assigned or available when needed. As the fleet matures and more data become available, the Services may be able to increase intervals between certain scheduled inspection tasks to reduce the man-hours that units must dedicate to this type of maintenance, if field experience warrants this. However, it is not clear the scheduled maintenance burden will reduce in the near future.

Autonomic Logistics Information System (ALIS)

- The program continues to fall behind in ALIS development and fielding. Although the program planned to test and field the next iteration of capability, designated ALIS 2.0.2, in 2016 to support the Air Force's decision to declare Initial Operational Capability (IOC) in August, the program failed to do so. Additionally, the program continued to defer planned content from ALIS 3.0 to post-SDD development.
- ALIS includes hardware and software that connects with all aspects of F-35 operations, including maintenance management, aircraft health, supply chain management, Offboard Mission Support (OMS) mission planning, along with tracking and management of pilot and maintainer training. Units rely on ALIS for planning and executing deployments by managing the data required to transfer aircraft, materiel, and personnel from home station to a deployed or expeditionary environment. Similar to the manner in which the program develops and fields mission systems capability in the air vehicle, it fields ALIS in increments.
  - The program fielded ALIS software version 2.0.1.1 in late 2015. Since that time, the program has released two updates, 2.0.1.2 and 2.0.1.3, to address previously identified, usability-related deficiencies. These software updates include fixes to existing deficiencies and usability problems, but do not add new capabilities to ALIS. Prior to the release of the first update with ALIS 2.0.1.2, the program attempted to field ALIS software versions with both new capabilities and deficiency corrections, a process which tended to add new problems while fixing some existing problems. Instead, the program now plans to continue fielding updates dedicated only to correcting deficiencies every three months until the release of ALIS 3.0, the final release scheduled for SDD.
  - Although the program had planned to field a new version of ALIS software, version 2.0.2, in the second half of 2016, in time to support the U.S. Air Force IOC declaration, it was unable to do so. ALIS 2.0.2 includes propulsion integration, a key capability the Air Force had planned to have for IOC; however, the Air Force declared IOC with ALIS 2.0.1 in August, forgoing those capabilities. Because the program continued to experience technical difficulties integrating propulsion functionality into ALIS, fielding of 2.0.2 slipped into CY17. As a result, operational units began 2016 with ALIS 2.0.1.1 and will finish the year with ALIS 2.0.1.3; receiving only updates to address deficiencies and without any additional capability fielded in ALIS.
  - Delays in ALIS 2.0.2 have affected the development of the next, and last, major release of ALIS software within SDD, ALIS 3.0, because Lockheed Martin shifted personnel from ALIS 3.0 development to support completing ALIS 2.0.2 development. Because the program can no longer complete ALIS 3.0 with all of the additional capability development planned by the end of SDD, it has restructured the planned ALIS increments for the remainder of SDD and for Follow-on Modernization (FoM). This restructuring reduces the content of ALIS 3.0 from earlier plans, defers content from ALIS 3.0 that the program has now determined is not required for IOT&E to post-SDD development, and also adds Service and partner priorities and emerging requirements for security updates. The resulting plan from the restructuring was to field four increments of software at 6-month intervals; the first, ALIS 3.0, scheduled to field in mid-to-late 2018, which is required for IOT&E, followed by the remaining three after SDD. These incremental software releases are also intended to resolve ALIS deficiencies and usability

problems. At the mid-point between each of these major releases, the program plans to deliver software updates to continue addressing usability problems and deficiencies. Because no fielding or Logistics Test and Evaluation (LT&E) events of additional ALIS capability have occurred for over a year, the program's plan to develop, test, and field these ALIS 3.0 and later versions appears overly ambitious with a low likelihood of actually being realized. Regardless of whether ALIS 3.0 or a later version has been fielded, or which capabilities are included, IOT&E will evaluate the suitability of the F-35 and ALIS in operationally realistic conditions.

- Until 2016, formal testing of ALIS software only took place at the Edwards AFB, California, flight test center on non-operationally representative ALIS hardware, which relied on reach-back capability to the Lockheed Martin facilities at Fort Worth, Texas. Although some formal testing will continue to occur in this manner, the program developed and fielded a dedicated end-to-end developmental testing venue for ALIS located in part at Edwards AFB and in part at Lockheed Martin in Fort Worth in 2016. This venue, referred to as the Operationally Representative Environment (ORE), reflects the end-to-end Autonomic Logistics infrastructure used to support fielded operations, including one Autonomic Logistics Operating Unit (ALOU), which represents the main hub at Lockheed Martin Fort Worth, two Central Points of Entry (CPEs), representing the country-unique portal from the main hub, and two Standard Operating Units (SOUs), representing squadron-level ALIS components, all networked together in a closed environment. Although the ORE provides for more realistic developmental testing of ALIS hardware and software for early problem discovery and fixing deficiencies, the current closed environment does not adequately represent the variety of ways in which the Services operate ALIS in different environments. ALIS testing at the flight test center is limited in several ways. First, the inability of ALIS to support their engines and lift fans, which differ from production models, so LT&E of propulsion functionality in ALIS cannot take place there. Also, the flight test center does not use ALIS capabilities routinely, such as Squadron Health Management (SHM), AFRS, or the Computerized Maintenance Management System (CMMS), as operational units do. Finally, the flight test center does not use PHM capabilities, as they are used by operational units, since the flight test aircraft have additional sensors and onboard instrumentation that provide the flight test center with more information than is available through PHM.

ALIS Software Testing and Fielding in 2016

- Although the program planned to test and field new capability with ALIS 2.0.2 software release in 2016, it failed to do so. The plans for added capability in ALIS 2.0.2 include:
  - Life Limited Parts Management (LLPM), which includes:
    - Propulsion integration. Currently propulsion data are downloaded from aircraft portable memory devices and provided to Pratt & Whitney Field Service Engineers for processing and generation of maintenance work orders. Propulsion integration will allow ALIS to process propulsion data in the same manner as aircraft data.
    - Production Aircraft Inspection Requirements (PAIRs). ALIS 2.0.2 will include the first phase of the PAIRs system. The program added PAIRs as part of the PHM after eliminating most of the originally planned prognostic algorithms. The program plans to include 8 prognostic algorithms in ALIS 2.0.2 and 8 in ALIS 3.0 out of the originally planned 128 SDD algorithms.
  - Sub-squadron reporting. This will allow the air vehicle to report its status back to the home squadron SOU even when it is deployed away from the majority of a squadron's assets.
  - SOU-to-SOU communication. Currently, information on one U.S. SOU is transferred to another by routing files from the originating SOU through the CPE at Eglin AFB, Florida, to the ALOU at Fort Worth, Texas, back through the CPE and to the receiving SOU. This new capability will permit targeted routing of files between SOUs under specific circumstances and is geared primarily toward making aircraft deployments more efficient.
  - Deployability improvements. This includes improved deployment planning and the bulk transfer of all deploying assets at once. The current release of ALIS makes deployment planning inefficient as it does not provide a centralized location in ALIS for this function. During deployments, squadrons currently transfer aircraft, supply, and support equipment data files individually.
  - Commercial Off-the-Shelf (COTS) hardware replacement. This allows the program to plan for hardware obsolescence and substitute newer hardware over time.
  - ALIS Readiness Check. Improves the health monitoring of ALIS processes.
- Testing of ALIS 2.0.2 will occur in multiple stages at multiple venues. The program plans to conduct an LT&E on the air vehicle portion of the ALIS 2.0.2 software package in early 2017, including initial testing of the propulsion module of the software in the ORE. Once those tests are complete, the program plans to do a validation and verification of the process to upgrade to ALIS 2.0.2, including the data migration, at an operational unit – possibly Luke AFB, Arizona – before fielding ALIS across the rest of the F-35 operating locations.
- Releasing ALIS 2.0.2 to field units will require significant manual intervention and data verification efforts to transition each site, which will likely affect flight operations. The data migration effort for ALIS 2.0.2 will be more complex and will take longer than previous ALIS releases because of propulsion integration and changes in data structures. For example, the Program Office noted that one ALIS domain alone, Customer Relationship Management, will require 40 man-hours for data migration and verification. Currently, the program estimates that each site will require 8 days

to complete the transition of all assets. Lockheed Martin will conduct the migration and has plans to complete the transition at each site by using the Friday through Monday time period of two consecutive weeks. Whether or not the affected squadron can continue flying operations between the two transition periods is unknown. As of September 2016, the program must transition 56 sites—either SOUs or CPEs—through this process. As of the time of this report, the program had not released a comprehensive transition plan.

Assessment of ALIS Support to Deployment Demonstrations with Operational Units

- Because of delays in ALIS release 2.0.2, fielded units have operated with ALIS 2.0.1 since October 2015. As planned, the Marine Corps used this release for a deployment demonstration to the Marine Corps Air Ground Combat Center (MCAGCC) Twentynine Palms, California, in December 2015, which DOT&E reported on in the FY15 DOT&E Annual Report. Similarly, the Air Force conducted a deployment demonstration to Mountain Home AFB, Idaho, in February 2016. The operational test squadrons from Edwards AFB participated in each of these demonstrations; however, the ALIS hardware came from operational units (a Marine Corps squadron from MCAS Yuma for the MCAGCC demonstration and an Air Force squadron from Hill AFB, Utah, for the Mountain Home demonstration).
- The Air Force completed its first F-35A deployment away from Edwards AFB, California, with six aircraft from the 31st Test and Evaluation Squadron (31TES) to Mountain Home AFB, which has no organic F-35 capability, from February 8 to March 2, 2016. All aircraft that participated in the deployment were in Block 2B configuration with software version 2BR5.2. This deployment was a Service-led assessment.
  - This deployment was the first time the Air Force deployed with a modularized, more transportable version of the ALIS hardware, referred to as SOU v2. ALIS software version 2.0.1 was used for this deployment, as well as for the Marine Corps' deployment to Twentynine Palms; the previous "cross ramp" deployment at Edwards AFB in May 2015 used the bulky SOU v1.[1] Deployed personnel had no difficulty setting up and configuring the ALIS network at Mountain Home AFB; however, they had a great deal of difficulty using ALIS on the local base network. After several days of troubleshooting, Information Technology (IT) personnel and ALIS administrators determined that they had to change several settings on the base network at Mountain Home and in the web interface application (i.e., Internet Explorer) to permit users to log on to ALIS. One of these changes involved lowering the security setting on the base network, an action that may not be compatible with required cybersecurity and network protection standards in place.
  - Data file transfers took place more quickly than in the previous F-35 deployment demonstrations, (i.e., the F-35A cross ramp deployment and the Marine Corps' deployment demonstration to MCAGCC Twentynine Palms). However, Lockheed Martin provided the five ALIS administrators normally assigned to the 31TES and three additional, highly experienced ALIS administrators from other locations to provide deployment support, more than for any previous deployment. Whether the Service's concept of operations for deploying ALIS will call for this level of ALIS administrative support, to ensure timely and accurate transfer of aircraft data at the deployed location, is still not known. Although the process was time-consuming and labor-intensive, they completed the transfer of all data to the deployed SOU v2 before deployed flight operations were scheduled to begin. To account for the expected extended time for data transfers, the 31TES allocated the ferry date and two additional days to complete the transfers; flight operations began on the third day of the deployment, as planned. Service deployment concepts of operations may need to account for time to transfer aircraft data files and ensure accuracy before beginning – or at least sustaining – operations at deployed locations.
  - Because of ambiguity in the ordnance loading technical data, one aircraft experienced major damage to a weapons bay door and horizontal tail early in the deployment when a bomb, which was incorrectly loaded, struck the aircraft following release. Aircraft repairs were extensive enough to require most of the remainder of the deployment to complete. The Marine Corps had previously discovered this ambiguity in the technical data, but the program did not disseminate this information across the F-35 enterprise.
  - Preparations to redeploy back to Edwards AFB began on March 1, 2016, with aircraft departing on March 2 and aircraft data file transfer from the deployed SOU beginning as soon as the aircraft took off from Mountain Home AFB. Though ALIS administrators transferred all data off the deployed SOU at Mountain Home AFB, administrators at Edwards AFB did not finish inducting aircraft files back onto the Edwards AFB SOU until March 4. The redeployed aircraft were ready for flight at Edwards on March 5, a 4-day transition period.
- Since the Services have not yet completed ALIS Concept of Operations (CONOPs) development, they will likely need to take into account the results of these deployments when determining the procedures and timing of F-35 deployments. Although the aircraft may be flown for short periods of time without ALIS, operational planners may need to allow for additional time between aircraft deployment and the beginning of deployed flight operations, compared to legacy

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[1] The 31st TES previously conducted a "cross ramp deployment" at its home base, Edwards AFB, from April 27 to May 8, 2015, to support deployment concept of operations development. DOT&E reported on this activity in the FY15 Annual Report.

platforms. Deployed operations, including the set-up and support from ALIS, will be evaluated during IOT&E.

- The challenges facing the Services and program in making ALIS deployable now involves software. Previously, the program identified the need to move from the bulkier, heavy SOU version 1 (v1) racks, which weighed approximately 1,600 pounds each, to the more customizable, modularized, two-man portable components in the SOU v2, so that the ALIS "footprint" could meet F-35 deployability requirements. Although the SOU v2 has improved the deployability of the ALIS hardware, these recent deployments show that lack of flexibility exhibited in integrating ALIS into new or existing networks, along with deficiencies in ALIS functionality and usability, contribute more to deployability problems than just the previously-identified hardware limitations.

ALIS Software and Hardware Development Planning from 2016 through the End of SDD

- In CY16, the program continued to struggle with providing the planned increments of capability to support the scheduled releases of ALIS software 2.0.2 to such an extent that the program now cannot accomplish the original plan for ALIS 3.0 development. As the objective date for Air Force IOC neared, the program considered releasing ALIS 2.0.2 in two increments: the first with all capabilities aside from propulsion integration in time to support an August 2016 Air Force IOC declaration; the second with propulsion integration, when the program overcame technical problems and completed formal testing. When the Air Force declared IOC without ALIS 2.0.2, using the already-fielded version of ALIS 2.0.1.3 instead, the need for a two-phase release no longer existed. As a result, the program now plans to conduct the LT&E of ALIS 2.0.2 in two parts in early 2017; the first with all functionality except propulsion integration at the flight test center, then propulsion integration in the ORE. ALIS 2.0.2 has been delayed for over a year from the release schedule approved in CY15.
- The Program Office planned for the release of ALIS 3.0 in June 2017, in time to support its planned start date for IOT&E, but now plans to release it in mid-to-late 2018. However, the ongoing delays with ALIS 2.0.2 and the resulting restructuring of ALIS 3.0 and beyond, have caused the program to defer capability that had been planned to be delivered with ALIS 3.0. The following list includes major capabilities the program planned for ALIS 3.0 inclusion, and identifies which ones are now being deferred – in full or in part – out of SDD:
  - Decentralized maintenance. This will enable execution of the sortie generation cycle with a deployable PMA for independent maintenance workflow while maintainers work in the shadow of the aircraft. Decentralized maintenance is now divided into two parts, both deferred to post-SDD software versions.
  - Resource sharing. This capability will allow the sharing of tools, support equipment, pilots, and training records across squadrons without requiring the transfer of data between SOUs. Deferred to post-SDD software release.
  - Security enhancements. This includes additional ALIS readiness checks to validate and monitor user accounts and additional penetration testing.
  - Offboard Prognostic Health Management (PHM). Additional algorithms to assess materiel condition independently of ALIS releases and to implement a correlation function between the Integrated Caution, Advisory and Warning (ICAW) system and HRCs. Partially deferred to post-SDD software release; only 16 of 128 planned prognostic algorithms are now included within SDD.
  - Life Limited Parts Management (phase 2). Adds an Identify Locate (IDLO) viewer for product life-cycle management, support for lightning protection and On-Board Inert Gas Generation System (OBIGGS), Illustrated Parts Breakdown product, Complex PAIRs to manage remaining life of aircraft components, support for quick engine changes, the HMDS, and back-shop visibility for supply chain management. Full Life Limited Parts Management in ALIS was a capability the program originally planned for ALIS 2.0.0 to support Marine Corps IOC; however, the re-baselining of this technically difficult-to-implement capability has resulted in it not being fielded for at least 2 years after IOC declaration.
  - COTS hardware replacement.
  - Corrosion Management System. Will improve the ability of ALIS to track and report the corrosion conditions of aircraft using two sensors located in designated positions within the aircraft and includes corrosion HRCs in ALIS. Deferred to post-SDD software release.
  - Low Observable Health Assessment System (LOHAS) enhancements. Partially deferred to post-SDD release.

Prognostic Health Management (PHM) within ALIS

- The PHM system is designed to collect performance data to determine the operational status of the air vehicle and, upon reaching maturity, will use data collected across the F-35 enterprise and stored within PHM to predict maintenance requirements based on trends. The PHM system is designed to provide the capability to diagnose and isolate failures, track and trend the health and life of components, and enable autonomic logistics using air vehicle HRCs collected during flight and saved on aircraft PMDs. The F-35 PHM system has three major components: fault and failure management (diagnostic capability), life and usage management (prognostic capability), and data management. PHM diagnostic and data management capabilities remain immature. The program has yet to integrate any prognostic capabilities; the first set of algorithms is planned for ALIS 2.0.2.
- Diagnostic capability should detect true faults within the air vehicle and accurately isolate those faults to a line replaceable component. However, to date, F-35 diagnostic capabilities continue to demonstrate poor accuracy, low

detection rates, and also have high false alarm rates. Although coverage of the fault detection has grown with the fielding of each Block of F-35 capability, all metrics of performance remain below threshold requirements. The table below compares specific diagnostic measures from the ORD with current values of performance through April 2016.

- PHM monitors nearly every on- and offboard system on the F-35. It must be highly integrated to function as intended and requires continuous improvements for the system to mature.
- Poor diagnostic performance increases maintenance downtime. Maintainers often conduct BITs to see if the fault codes detected by the diagnostics are true faults. False failures (diagnostics detecting a failure when one does not exist) require Service personnel to conduct unnecessary maintenance actions and often rely on contractor support to diagnose system faults more accurately. These actions increase maintenance man-hours per flight hour, which in turn can reduce aircraft availability rates and sortie generation rates. Poor accuracy of diagnostic tools can also lead to desensitizing maintenance personnel to actual faults.
- The number of false alarms recorded within ALIS can be artificially lowered, as qualified maintenance supervisors can defer or cancel an HRC without generating a work order for maintenance actions, if they know that the HRC corresponds to a false alarm not yet added to the nuisance filter list. The deferred or canceled HRC will not result in the generation of a work order, and it will not count as a false alarm in the metrics in the table below. The program does not score an HRC as a false alarm unless a maintainer signs off a work order indicating that the problem described by the HRC did not occur. Because PHM is immature and this course of action saves time for the maintainers, it occurs regularly at field locations; however, this means the number of recorded false alarms is not always an accurate reflection of the HRC false alarm rate.
- Comparing the values in the table below with those in the FY15 DOT&E Annual Report shows improvement in Fault Detection Coverage, Fault Detection Rate, Fault Isolation Rate for non-electronic faults to one Line Replaceable Component (LRC), and – most significantly – Mean Flight Hours Between Safety Critical False Alarms. Mean Flight Hours Between False Alarms and Fault Isolation Rate for non-electronic faults to three or fewer LRCs show no significant improvement, and Fault Isolation Rate for electronic faults to one LRC has gotten worse since last year's report. At this time, Mean Flight Hours Between Flight Safety Critical False Alarm and Fault Isolation Rate for non-electronic faults to one LRC are the only diagnostic metrics which appear to be improving adequately toward meeting their threshold requirements. The program planned for accurate diagnostics to support a planned level of sustainment; poor diagnostics contribute to poor reliability and maintainability metrics, reducing aircraft availability and increasing aircraft downtime.
- Following are the systems most likely to result in missed fault detections, incorrect fault isolations, and false alarms as of April 2016.
  - Missed detections: Integrated Core Processor (ICP), Communications, Navigation, and Identification (CNI) rack modules, Panoramic Cockpit Display, Power and Thermal Management System (PTMS), and vehicle system processing.
  - Incorrect isolation: ICP, PTMS, EW, electric power, and hydraulic power system.
  - False alarms: Propulsion, CNI system, EW, ICP, and displays and indicators in general.
- The Program Office initiated a PHM maturation plan in 2015 to improve the performance of each of the three major components of PHM:
  - Improving BIT functionality, PHM software handling of BIT results, and off-aircraft filter lists and fault isolation instructions; also focusing on identified high-fault drivers to prioritize developing AFRS solutions with the greatest impact on fault detection and isolation, false alarm

METRICS OF DIAGNOSTIC CAPABILITY
(6-month rolling window as of April 2016. Data provided by Program Office considered "preliminary" as they have not completed formal adjudication process by the data review board.)

Diagnostic Measure	Threshold Requirement	Demonstrated Performance		
		Block 1	Block 2	Block 3
Developmental Test and Production Aircraft				
Fault Detection Coverage (percent mission critical failures detectable by PHM)	N/A	88	88	93
Fault Detection Rate (percent correct detections for detectable failures)	98	88	88	93
Fault Isolation Rate (percentage): Electronic Fault to One Line Replaceable Component (LRC)	90	65	64	42
Fault Isolation Rate (percentage): Non-Electronic Fault to One LRC	70	71	73	86
Fault Isolate Rate (percentage): Non-Electronic Fault to Three or Fewer LRCs	90	87	87	100
Production Aircraft Only				
Mean Flight Hours Between False Alarms	50	0.09	0.41	0.50
Mean Flight Hours Between Flight Safety Critical False Alarms	450	61	537	437
Accumulated Flight Hours for Measures	N/A	61	6,440	6,111
Ratio of False Alarms to Valid Maintenance Events	N/A	135:1	19:1	19:1

  performance, unnecessary maintenance, high maintenance man-hours, aircraft availability, and excess cost
  - Improving the functionality of PAIRS and algorithms which assess materiel condition based on usage and repair feedback, potentially adding new life tracking items based on fleet experience
  - Improving or adding data collection from the air vehicle, improving data downloading and processing from the aircraft to ALIS, and improving distribution and storage of data to better support user needs
- Structural PHM (SPHM) is a key element of overall airframe life-cycle management. It includes conditional event detection and analysis, including over-g, hard landing, overspeed, and overload conditions, and is planned to provide a corrosion monitoring and predictive modeling capability. The air vehicle currently includes two corrosion sensors—one on the forward face of the radome bulkhead and the other on the wall of the bay housing the fuel/heat exchanger. ALIS 2.0.0 included a logging function for these corrosion sensors. A Program Office study completed in November 2015 determined that 27 percent of the corrosion sensors in the fleet had failed, so the program is in the process of developing a new sensor manufactured with more precise sealing applications to be used during production instead of upon installation.

Air-Ship Integration and Ship Suitability Testing

F-35B

- The integrated test team from Patuxent River, Maryland, conducted the third and final planned set of F-35B ship trials, referred to as Developmental Test III (DT-III), from October 28 through November 17, 2016, on USS *America*. The objectives for this 3-week developmental test event included:
  - Expanding the vertical landing flight envelope for both day and night operations (higher wind-over-deck conditions and operations at higher sea states than earlier ship trials, as well as operating from additional landing spots farther forward on the flight deck)
  - Evaluating the Gen III HMDS for nighttime landings, with or without landing aids on the ship
  - Assessing Joint Precision Approach Landing System (JPALS) functionality
  - Conducting vertical landings and short take-offs with symmetric and asymmetric external loads carriage
  - Expanding vertical take-off capability
  - Evaluating environmental effects from flight operations, such as the thermal tolerance and response of the flight deck to vertical landings and noise surveys from various ship locations
  - Conducting maintenance demonstrations – including engine and lift fan removal and replacement actions, and a power module maintenance demonstration – and loading and unloading of external stores
  - Evaluating the operational capability of the first deployment of an ALIS SOU v2 on the ship
- Besides the two developmental test aircraft from the Patuxent River test force (BF-1 and BF-5), the Marine Corps also supported the test activities by providing an additional three instrumented operational test aircraft assigned to VMX-1, the operational test unit at Edwards AFB, California, and two fleet aircraft from VMFA-211, one of the two operational units at MCAS Yuma, Arizona. Although primarily a developmental test event, the Marine Corps embarked fleet and operational test squadron personnel for training, and to inform the JSF Ship Integration Team in preparation for the first operational F-35B deployment onboard USS *Wasp*, planned for late 2017. From November 17 – 21, the Marine Corps also conducted a "Lightning Carrier" proof of concept demonstration, with an additional five F-35B fleet aircraft plus two MV-22 and two H-1 Air Combat Element (ACE) assets deployed to the ship to assess interoperability and the suitability of F-35B "Heavy" ACE configurations on LHA-class ships. Observations from this testing included:
  - The specialized secure space set aside for F-35-specific mission planning and the required Offboard Mission Support (OMS) workstations is likely too small and therefore unsuitable for regular ACE operations with the standard complement of six F-35B aircraft – let alone F-35B Heavy ACE configurations with more aircraft. Due to the classification of certain F-35 capabilities, pilots must conduct mission planning in a secure space. The ALIS SOU v2, which has several classified components, was also located in this space. However, pilots, the ALIS administrator, and security personnel commented that the compartment designated for the secure workspace onboard USS *America* was too small to accommodate enough OMS workstations and a sufficient briefing and debriefing area. Marine Corps and ship personnel are investigating using this compartment for ALIS only, and designating an alternate compartment for mission planning.
  - The power module maintenance demonstration was intended to show that a deployed unit could conduct modular engine maintenance at-sea. The F135 engine is modular, with a fan and compressor section; a power section with the combustion chamber and turbine stages; an afterburner section, which on the F-35B consists of a Three-Bearing Swivel Module (3BSM) that can rotate downward to more than 90 degrees for vertical flight; and a nozzle section. The general maintenance concept for a failed engine is to replace only the defective module on any given engine to return the overall engine to service more quickly, and send the defective module to depot-level repair. The demonstration consisted of splitting open an F135 engine mounted on two aligned Maintenance and Transportation Trailers (MTTs) into its modularized sections, removing a "bad" power module, taking a "good" spare power module out of its shipping and storage container, placing the good module into the

engine, and containerizing the bad module, all with the use of an overhead bridge crane in the aft high bay of the hangar bay. The demonstration showed that maintainers could swap a module at sea; however, the evolution took up a large amount of space in the hangar bay and occurred without a full ACE onboard. The Navy and Marine Corps should conduct some further analyses, such as an operational logistics footprint study which simulates flight deck and hangar bay spotting with a full ACE onboard, using data from this evolution to determine what the impact of this maintenance would be on integrated ship and ACE operations with a full ACE onboard.

- The detachment planned to stage an F135 engine removal and installation (R&I) demonstration, but early in the deployment maintainers discovered, during a Post-Operations Servicing, that one of the OT aircraft (BF-20) had a thrust pin that had unseated. There are several thrust attachments between the engine and the airframe that transfer the propulsive forces produced by the engine to the airframe, and this was the first time in program history that maintainers discovered a thrust pin had backed out of full engagement, a serious safety of flight concern. As a result, the unit submitted an AR to request disposition. The AR response directed that the engine be removed from the aircraft, and the thrust pin attachment points on both the engine and airframe be thoroughly inspected. This provided a natural opportunity to evaluate an actual engine R&I as opposed to a staged demonstration. The unit provided photos and dimensional data to the Lightning Support Team (LST), initiating a long investigation process to determine the root cause, but there were no immediately obvious signs of wear or damage. The LST eventually directed the squadron to replace the engine, as there was a full spare engine onboard, and the lift fan drive shaft. The squadron completed this maintenance in the hangar bay and, on November 16, conducted a High-Speed Low-Thrust (HSLT) engine operation on the flight deck to confirm that the new engine was installed correctly and fully functional. The unusual circumstances of this event primarily drove the 2-week long R&I process, as opposed to specific shipboard conditions and, by the time of this report, the program had not yet determined a root cause. However, the engine R&I was practically aided by the fact that, for this detachment, a full spare engine was available for immediate installation. Currently, the program's planned Afloat Spares Package of spare parts that will be loaded onboard the USS *Wasp* for the first F-35B deployment in 2017 will not have a full spare engine, only spare propulsion modules. See the F-35C ship suitability section for further details on F135 engine R&I concerns at sea.
- The squadron also conducted a staged lift-fan R&I demonstration on BF-20 while it was in an NMC status in the hangar bay for the engine R&I. Maintainers positioned the aircraft along the ship's centerline and directly beneath the bridge crane in the forward of two high bays. Organic Marine squadron personnel first used a collapsible, portable floor crane and an assembled support frame to cradle the upper lift fan door and remove it from the aircraft, and then place it on the deck. After maintainers attached another assembled frame to the top and sides of the lift fan, ship personnel used the overhead bridge crane to raise the lift fan out of the aircraft cavity and, via attached tether ropes to each of the four top corners of the frame to guide the lift fan, lowered it to a support cradle on the deck. Service personnel then reversed this process to reinstall the lift fan. After the upper lift fan door was reinstalled and maintainers were disassembling the support frame that attaches the door to the crane, a portion of this assembly fell onto the lift fan, damaging a stator strut at the top of the lift fan. Repairs to this strut took another couple of days to complete. Maintenance personnel noted several improvements that should be incorporated into this process; most importantly, the tether points for the lift fan support assembly need to be moved to the bottom four corners for better control, as the tethers provided very little control near the hook point of the crane; also the program should provide a protective maintenance cover for the lift fan to prevent damage during future lift fan R&I's or upper lift fan door maintenance.
- On November 15 and 16, a single fleet aircraft from VMFA-211 departed from USS *America* to drop live ordnance on targets on an inland range, hot-pitted for fuel from MCAS Yuma, Arizona, and returned to the ship each day. Both sorties dropped one GBU-12 laser-guided bomb and one GBU-32 JDAM. The Marine Corps originally intended to fly two loaded aircraft each day, but the lack of available mission-capable aircraft drove the detachment to launch only a single aircraft each day.
- While the set of sea trials were not focused on operational realism, several aspects were more operationally representative than the 2015 F-35B deployment demonstration onboard USS *Wasp*. The aircraft had a full suite of Block 2B electronic mission systems installed, unlike onboard USS *Wasp*; however, like the USS *Wasp* demonstration, these aircraft mission systems were not maintained to a full combat-mission-capable state of readiness. Unlike in 2015, the OT and fleet aircraft were cleared to carry live ordnance on the flight deck, with some workarounds. With this clearance, the test team intended to employ live ordnance on missions. Production-representative support equipment (SE) was onboard ship for the first time as well for use on the non-DT aircraft. Similar to the 2015 demonstration, the operational logistics support system, known as the Autonomic Logistics Global Sustainment system, was still not available. As a result, spares provisioning and supply support were not necessarily the same as would be expected on a combat deployment.

F-35C

- The third and final phase of F-35C ship suitability testing, designated Developmental Test III (DT-III), was conducted by VX-23, the developmental test team from Patuxent River, from August 10 – 26, 2016, aboard USS *George Washington*. The primary objective of DT-III was to complete characterization of the flying qualities of the F-35C aircraft for catapult launches and arrested recoveries, building on the results from two previous at-sea developmental test periods. The test team explored aircraft flight operations around the carrier in high crosswind conditions and, for the first time, with external ordnance, including asymmetric load-outs. Both day and night operations were conducted, allowing for assessments of the Gen III HMDS for night approaches and landings under varying light conditions. These investigations will help develop aircraft launch and recovery bulletins to an expanded envelope to support fleet operations. Also, while the ship was underway, VFA-101, the Navy's F-35C training squadron at Eglin AFB, Florida, participated in the event for other test objectives, including a Commander of Naval Air Forces (CNAF)-directed proof-of-concept demonstration of an F-35C engine R&I in the ship's hangar bay as well as initial day carrier qualifications for 12 pilots that would assess overall suitability of catapult launches and the Delta Flight Path capability for carrier approaches and landings.

- Initially, only developmental test aircraft CF-3 and CF-5 (transient aircraft needed for logistical support) and search and rescue helicopters deployed to the carrier. No air wing was present. Five VFA-101 aircraft deployed onboard the ship from August 14 – 18. The major contractor and test team were responsible for maintenance of CF-3 and CF-5, although fleet maintenance personnel supported the VFA-101 carrier qualifications and the engine R&I demonstration. ALIS was not installed on the carrier; it was accessed via satellite link to a location ashore.
- The developmental test team conducted night operations with modifications to the Helmet Display Unit for the Gen III HMDS that permitted lower illumination settings, intended to reduce the amount of "green glow" in the helmet display that makes seeing the lights on the carrier difficult during night operations. The test pilots reported that the refined brightness control somewhat improved the night carrier approaches; however, "green glow" was still a significant problem and is the subject of two Category 1 deficiency reports.
- From the carrier qualifications, the VFA-101 pilots found the F-35C catapult shot not operationally suitable due to excessive vertical (Nz) oscillations during launch. Although numerous deficiencies have been written against the F-35C catapult shot oscillations – starting with the initial set of F-35C ship trials (DT-I) in November 2014 – the deficiencies were considered acceptable for continued developmental testing. The fleet pilots reported that the oscillations were so severe that they could not read flight critical data, an unacceptable and unsafe situation during a critical phase of flight. Most of the pilots locked their harness during the catapult shot, which made emergency switches hard to reach, again creating an unacceptable and unsafe situation.
- The VFA-101 pilots reported that the Delta Flight Path mode of operation made carrier approaches easier on pilot workload and touchdown points more consistent. During the qualifications, pilots made 154 approaches and landings with 100 percent boarding rate and no bolters.
- The engine R&I proof-of-concept demonstration took 55 hours to complete and used about one-third to one-half of one of the three hangar bay partitions; this is much more space than that needed for an F/A-18 engine change. Because it was the first F-35C engine R&I demo at-sea, maintainers moved through all required steps at a slow pace to ensure safety first, which may have extended the timeline relative to what an experienced crew could achieve during routine maintenance operations. On the other hand, the maintainers had practically free use of most of the hangar bay space, which may have facilitated speedier maintenance relative to conducting an engine R&I with a full air wing onboard. As a result, actual engine R&I's during deployments may not differ drastically in time from this demonstration.
- While the proof-of-concept demonstration showed that an engine could physically be swapped at sea, it also revealed that such a major maintenance evolution would be very difficult, time consuming, take up a large amount of space, and be a drastic change from the engine R&I on legacy aircraft. The F-35C engine change is also more labor- and space-intensive than the F-35B engine R&I, such as conducted onboard the USS *America*. The F-35B engine R&I is aided by the aircraft's 3BSM doors, which open during regular operation to enable the exhaust nozzle to rotate downward to more than 90 degrees for vertical flight. Opening these doors for engine maintenance avoids the need to remove fixed panels, such as on the F-35A and F-35C. For the F-35C, many more skin panels and a large piece of structure known as the tail hook trestle, although not the tail hook itself, must be removed for an engine R&I. Storing these items, and the associated tubes and wire harnesses, so they will not be damaged while off the aircraft, also takes up additional space. The fact that the demonstration was conducted without a full air wing on the ship additionally limited the test team's ability to assess the likely impact of an F-35C engine change on integrated carrier-air wing operations. Such an assessment will be needed for IOT&E. Because of the complexity and time required to conduct an engine change, the Navy and JPO should investigate alternatives for determining the impact of an R&I while conducting carrier-air wing operations as well as improving the maintainability of the F-35 system at sea.

- Both the F-35B engine R&I onboard USS *America* and the F-35C engine R&I onboard USS *George Washington* were hampered by the lack of suitable strut locks approved for at-sea use, considering the rolling and pitching motion that may be experienced while underway. Since the engine is a significant part of the aircraft weight, without strut locks the airframe would raise up on the pressurized landing gear struts as soon as the engine was detached. This could potentially damage either the engine or airframe due to tight tolerances, or injure maintainers with hands in the area. In both cases, maintainers put the aircraft up on jacks to de-service the struts before the engine change, and then raised the aircraft back up on jacks to re-service the struts after the change, adding significant time to the process. Further, ship maneuvering is restricted when raising and lowering aircraft on jacks; engine R&I times could be decreased if the program develops, and the Navy approves, appropriate strut locks for at-sea use.

- Maintainers conducted a less extensive power module maintenance demonstration onboard USS *George Washington* than the one performed on USS *America*, consisting of removing a power module from its container in the hangar bay, moving it to the engine repair shop aft of the hangar bay, and returning it to its container. To open the container, maintainers used a motorized, wheeled, mobile crane that is part of the ship's SE complement to raise the container lid, which is composed of the roof and four side walls, over the encapsulated power module, and set it to the side in the hangar bay. A specialized Electric Pallet Jack (EPJ) was then used to move the power module, still attached to the container bottom, to the engine repair shop, where it could be transferred to an MTT via an overhead bridge crane. Maintainers expressed dissatisfaction with the container design, which required a large amount of space and a large piece of SE to remove, and stated that, while suspended on a possibly pitching and rolling ship, such a heavy item could present a safety hazard. They stated a preference for the type of container used for the T56 engine, installed on the E-2 Hawkeye and C-2 Greyhound aircraft. This type of container has a door on one side that opens outward, with the engine mounted on rails inside. An MTT can be wheeled up to the container and the engine slid onto it by hand. This configuration takes up less space to remove an engine, doesn't require any SE, is quicker, and presents fewer hazards. The current container is designed to a very high standard of structural integrity in order to withstand a fall if ever resupplied by moving it across a wire strung between a resupply ship and a carrier, a standard form of resupply at sea. However, only the planned heavy E-Stream wire system was capable of moving the heavy power module container, but this program is now canceled. The Navy now plans to resupply un-containerized power modules via internal carriage on a CV-22 aircraft, and containerize any spare modules onboard ship if needed for storage. The program and the Navy should investigate if the heavy power module container should be redesigned for better usability at sea.
- Current program plans do not provide a full spare engine for the envisioned Afloat Spares Package of parts that will go onboard Navy CVN and L-class ships to support F-35C and F-35B squadrons, respectively. This will significantly increase the amount of time required to conduct an actual engine change. The 55-hour timeline measured during the proof-of-concept demonstration provided above assumed a full spare engine ready for immediate install once the down engine is removed from the aircraft. Without a spare, the time required to troubleshoot the down engine to a bad module, disassemble the engine to swap that module, and then reassemble the engine to reinstall it into the aircraft must be added to the overall process; this can easily add several more days of downtime to the affected aircraft. Further, the probability of Foreign Object Damage (FOD) to engines is higher at sea than ashore, which may drive more frequent engine R&Is at sea. This is due to the close proximity of aircraft maintenance to the ship landing areas allowing foreign objects to migrate, and the more stressing arrested or vertical landings at sea, which can increase the probability of items like fasteners falling off an aircraft into the landing area.
- Access to ALIS offboard the ship via the ship's satellite communications was intermittent and troublesome, making transmitting large file sizes difficult. For example, a 200 MB file required 2 days to successfully transfer due to bandwidth limitations and inconsistent connectivity. These issues drove VFA-101 to operate in an ALIS offline mode for the majority of the detachment. While the root cause appeared to be due to limitations with the shipboard communications equipment vice ALIS directly, and deployed units will have an SOU onboard ship, the SOU will occasionally have to transmit large files to the CPE due to how data-intensive ALIS is. This requirement to communicate large amounts of information will likely be exacerbated after a ship emerges from a restricted Emissions Control (EMCON) period where transmissions from the ship are severely limited or cut-off completely. The program and the Navy should investigate potential options to improve ship-based communications bandwidth dedicated to ALIS connectivity off-ship, such as increasing the priority of ALIS transmissions, or reserving low-use times of the day for transmitting large volumes of ALIS message traffic.
- VFA-101 brought a suite of production-representative SE to the aircraft carrier, including electrically powered hydraulic, air conditioning, and polyalphaolefin (PAO) carts for use in the hangar bay. Personnel use the PAO cart to service the aircraft with this special fluid that cools the radar and some other avionics. The Navy prefers that SE for use in hangar bays be electrical vice diesel powered because of the enclosed environment. They also brought an engine R&I trailer and an engine maintenance trailer, needed for the engine maintenance demo. Collectively, these items of SE were larger than legacy items and took up a large amount of deck space. Hangar bay personnel commented that the size of the SE would also make them more difficult to move around a crowded hangar bay with a full air wing onboard. The Navy should investigate any efficient, multi-use opportunities for F-35 SE, such as using legacy SE on the F-35 or F-35 SE on legacy aircraft, to try to limit the impact on the overall SE footprint for an air wing with F-35

included. Additionally, the JOTT will evaluate SE operation and movement around the flight deck and hangar bay during IOT&E.

- Since the hangar-bay SE items are electrical, they rely on 440V power from outlets in the walls of the ship. Maintenance on a single F-35C can sometimes require external power, provided by a small transformer power cart that converts the 440V wall power to the 270V and 28V DC power used by the aircraft, along with air conditioning and hydraulic power, each requiring separate carts. Such maintenance activities would require the use of three wall outlets. However, most hangar bay partitions had four outlets, which would make simultaneous maintenance on more than one F-35C in a partition a coordination challenge. The Navy should investigate options for increasing the number of wall power outlets in hangar bays to help facilitate simultaneous maintenance on multiple F-35Cs, or the ability to interconnect multiple pieces of support equipment from a single outlet to permit simultaneous operations.
- The Navy is working on the following air-ship integration issues, primarily for carrier operations. Some of the following issues also apply to F-35B operations on L-class ships:
  - Flight deck Jet Blast Deflectors (JBDs) will require additional side panel cooling in order to withstand regular, cyclic limited afterburner use, during F-35C catapult launches. JBDs are retractable panels that redirect hot engine exhaust up and away from the rest of the flight deck when an aircraft is at high thrust for take-off. During IOT&E, an F-35C detachment will deploy to a CVN to evaluate sortie generation rate capability within an air wing context. The CVN used for IOT&E must have additional side panel cooling installed in the JBDs to enable the most operationally representative test to evaluate this Key Performance Parameter of the F-35C.
  - The Navy continues to procure a replacement mobile Material Handling Equipment crane for several purposes onboard carriers, including lifting the power module container lid as described above. This crane will only be used on CVNs, for F-35 maintenance only, as they lack the hangar-bay overhead cranes that L-class ships come equipped with. Since the FY15 DOT&E Annual Report, the crane acquisition has proceeded at a pace such that sufficient articles should be in the fleet in order to support a first F-35C deployment in the 2020 timeframe.
  - Two methods of shipboard aircraft firefighting for the F-35 with ordnance in the weapons bays are being developed, one for doors open and one for doors closed. Each method will use an adapter that can fit to the nozzle of a standard hose. The open door adapter will also attach to a 24-foot aircraft tow bar so firefighters can slide it underneath the aircraft and spray cooling water up into the bay. Development of this open door adapter is proceeding well and it was deployed to the USS *America* to support live ordnance carry by the OT and fleet F-35B aircraft during DT-III. However, the closed bay adapter, which intends to use water pressure to drive a saw to cut into the aircraft and lock a hose in place to douse a loaded weapons bay during a flight deck fire, was not yet ready for deployment. As a workaround, F-35B aircraft on USS *America* with live ordnance taxied with their weapons bay doors open, closing them only right before take-off, to mitigate the risk, but this will not be a standard practice for combat deployments.

Cybersecurity Operational Testing

- The JOTT continued to accomplish testing based on the cybersecurity strategy approved by DOT&E in February 2015, with some modifications due to test limitations, discussed below. In accordance with this strategy, in FY16 the JOTT conducted adversarial assessments (AA) of the ALIS 2.0.1 Squadron Kit and Central Point of Entry (CPE), completing testing that began in Fall 2015, and conducted cooperative vulnerability and penetration assessments (CVPA) of the mission systems Autonomic Logistics Operating Unit (ALOU) used to support developmental testing (referred to as the DT-ALOU), and the operational ALOU. The JOTT also completed a limited cybersecurity assessment of the F-35 air vehicle. These tests were not conducted concurrently as originally planned; therefore, end-to-end testing of ALIS, from the ALOU to the air vehicle, has not yet been accomplished. The JOTT initially tested the DT-ALOU in lieu of the operational ALOU because the JPO did not approve an Interim Authority to Test for the ALOU due to concerns that cybersecurity testing would adversely affect the ALOU's operations; however, a limited test of the operational ALOU was completed in October 2016 and an AA was scheduled for December 5 – 9, 2016.
  - The U.S. Navy's Commander, Operational Test and Evaluation Force (COTF) conducted a CVPA and limited AA against the DT-ALOU, from April 1 – 15, 2016, at Lockheed Martin's Fort Worth facility. The COTF testing verified that the DT-ALOU, configured with ALIS 2.0.1.3, had mitigated several key vulnerabilities discovered on ALIS 2.0.1.1 systems during fall 2015 testing. However, this testing of the DT-ALOU was not operationally representative because several key systems and external interfaces, from which cyber-attacks might originate, were not present. The testing was further constrained because the Program Office and Lockheed Martin only permitted testing to occur during overnight hours while the DT-ALOU was disconnected from external networks to minimize interference with operations. The COTF testing still discovered several minor security problems with the DT-ALOU. The operational ALOU is still configured with ALIS 2.0.1.1.
  - The U.S. Marine Corps Information Assurance Red Team (MCIART) conducted an AA of the Marine Fighter Attack Squadron 211 (VMFA-211) ALIS 2.0.1.3 Squadron Kit at Marine Corps Air Station Yuma, Arizona, April 25 through May 6, 2016. The unit's Squadron Kit was in the process of being stood up, so it was not in a fully operational configuration during the test. The operational

  VMA-121 Squadron Kit was declared off-limits by Marine Corps personnel. MCIART verified that several key vulnerabilities discovered during the 2015 Squadron Kit testing had been mitigated; however, MCIART discovered several new vulnerabilities from insider and outsider threat postures.
  - The U.S. Air Force 177th Information Aggressor Squadron (IAS) conducted an AA against the ALIS 2.0.1.3 Central Point of Entry (CPE) at Eglin AFB, Florida, from June 2 – 10, 2016. The 177 IAS assessed the system as an outsider and near-sider threat, and discovered vulnerabilities with various components of the CPE, despite the fact that Lockheed Martin administrators and ALIS users had implemented new operating procedures during the test to improve the CPE security posture.[2] The CPE classified servers were not adequately assessed due to time constraints and a lack of approval for connecting 177 IAS equipment to the classified CPE network.
  - The JOTT, with support from the Air Force Research Laboratory (AFRL), conducted a limited CVPA of the F-35A Block 2B air vehicle, from September 26 – 27, 2016, at Edwards AFB, California. The CVPA tested the process by which the air vehicle validates the digital signature of files within the operational flight program when it is loaded onto the aircraft via the aircraft media device. This test was one of the test cases proposed by cybersecurity subject matter experts, and was the first cybersecurity assessment of an operational F-35 air vehicle. The successful accomplishment of this initial test should encourage the Program Office to examine other planned test cases in future air vehicle cybersecurity assessments. Analyses of the test results are ongoing.
  - The COTF and the JOTT conducted a CVPA of the operational ALOU October 17 – 28, 2016, at Lockheed Martin's Fort Worth facility. The test team was augmented by Lockheed Martin Red Team members so that the ALOU could be examined for vulnerabilities from the Lockheed Martin Intranet (LMI). COTF and the JOTT were not permitted to conduct any test activities on the ALOU unless it was disconnected from the LMI, limiting the operational realism of the test and precluding certain vulnerabilities from being assessed. Detailed analyses of the data collected are ongoing.
- In response to DOT&E's recommendation that active intrusion discovery and forensics, referred to as a Blue Hunt, be conducted on the Squadron Kit and CPE, the JOTT has scheduled the 855th Cyber Protection Team (CPT) to conduct two events for the end of CY16. Current plans are to perform mostly vulnerability assessment and traditional Red Team activities against these systems —not active intrusion discovery and forensics—and so it is still unclear whether these events will fulfill DOT&E's request. Additionally, the JOTT will need to conduct a Blue Hunt on the ALOU once ALIS 2.0.2.4 is loaded and then additional Blue Hunts on all ALIS levels (ALOU, CPE, and Squadron Kit) each time a full increment of ALIS software is released.
- While progress towards fulfilling missed test opportunities in 2015 was considerable in 2016, full end-to-end cybersecurity testing of the ALIS architecture, from the operational ALOU to the air vehicle, remains to be completed. The JOTT is planning concurrent assessments of the ALIS 2.0.2 Squadron Kit, CPE, and ALOU in 2017. The JOTT is also exploring testing opportunities on the F-35 training systems, and has begun exploring options for testing systems at the U.S. Reprogramming Laboratory, which generates mission data files for the F-35.
- The JPO continued to develop its Operationally Representative Environment (ORE); it plans to perform verification, validation, and accreditation (VV&A) testing in order to conduct future operational testing on ALIS components within the ORE. Regardless of whether the ORE completes VV&A, the JOTT is working with the JPO and Lockheed Martin to plan cybersecurity testing of ALIS components within the ORE for purposes of risk reduction ahead of continued cybersecurity testing of the operational ALIS systems.

DOT&E Response to Senator McCain's Questions Regarding the Completion of SDD

In a letter to the SECDEF on November 3, 2016, Senator McCain asked the Department to respond to questions regarding the completion of SDD. The letter was prompted by, and cited, recent revelations that the program would be experiencing yet another delay in completing SDD and cost overruns that may be upwards of $1 Billion.

Although USD(AT&L) responded to the Senator on behalf of the Department in a letter dated December 19, 2016, the following are DOT&E's responses to each of the questions.

Question #1: When will the Department complete the SDD phase of the F-35?

- DOT&E Answer: SDD will close out in multiple phases. Developmental flight testing is projected to end no earlier than mid-2018, based on independent estimates on completing mission systems flight testing – the testing that will likely take the longest to complete. These estimates—from the Director of Cost Assessment and Program Evaluation (CAPE) of March 2018, the Director of Developmental Test and Evaluation of March to June 2018, Deputy Assistant Secretary of Defense for Systems Engineering of July 2018, and my office of July 2018—are all later than the program's estimate, based on the amount of planned mission systems test points remaining. (These estimates are optimistic because they do not fully account for the corrections and verification testing needed for the more than 270 high-priority deficiencies in Block 3F performance identified by a recent review.) Then, incremental deliveries of the Block 3F

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[2] Outsider threats have neither physical access nor account privileges to a network; near-sider threats have physical access to a system, but no account or log-in privileges to a network.

capabilities (i.e., flight envelope, weapons, and avionics) for each variant will likely not be completed until late 2018 due to continued delays and discoveries with F-35B and C flight sciences testing, along with weapons testing. Finally, contract close out actions, including specification compliance and verification and validation, will complete no earlier than late 2019. Completion of all required contracting action for the SDD phase will likely continue for a number of years.

Question #2: How many additional funds, in each upcoming fiscal year budget, will be required to complete F-35 SDD?

- DOT&E Answer: Although DOT&E does not conduct independent cost estimates, CAPE estimated that the program would need an additional $550 Million in FY18 to finish the necessary and planned developmental test points and produce additional software versions to fix and verify the important known and documented deficiencies, then an additional $425 Million in FY19 and $150 Million in FY20 to complete SDD. These estimates add up to an additional $1.125 Billion required to complete SDD. The Program Office estimate is about one-half of the CAPE estimate.

Question #3: What other Service priorities will not receive funding in fiscal year 2018 due to the SDD delay and cost overrun?

- DOT&E Answer: Although the program recently claimed that their estimated SDD overrun can be covered by reallocating existing JSF program funding (other than $100 Million in flight test risk), the SDD cost increase will be much larger than the current program estimate for the reasons described in this report. Therefore, the overrun will not be completely covered with only program funds and the Services will likely need to address the SDD cost increase from within their budgets, or funding currently designated for Follow-on Modernization (FoM) will need to be reallocated to complete SDD.

Question #4: Is Secretary James' Block 3F full combat capability certification, as required by the Fiscal Year 2016 NDAA, still valid?

- DOT&E Answer: For many reasons, it is clear that the Lot 10 aircraft that will begin delivery in early 2018 will not initially have full Block 3F capability. These reasons include, but are not limited to, the following:
  - Envelope limitations will likely restrict the full planned Block 3F carriage and employment envelopes of the AIM-120 missile and bombs well into 2018, if not later.
  - The full set of geographically specific area of responsibility mission data loads (MDLs) will not be complete, i.e., developed, tested and verified, until 2019, at the soonest, due to the program's failure to provide the necessary equipment and software tools for the U.S. Reprogramming Laboratory (USRL).
  - Even after the MDLs are delivered, they will not be tested and optimized to deal with the full set of threats present in IOT&E, let alone in actual combat, which is part of full combat capability.
  - The program currently has more than 270 Block 3F unresolved high-priority (Priority 1 and Priority 2, out of a 4-priority categorization) performance deficiencies, the majority of which cannot be addressed and verified prior to the Lot 10 aircraft deliveries.
  - The program currently has 17 known and acknowledged failures to meet the contract specification requirements, all of which the program is reportedly planning to get relief from the SDD contract due to lack of time and funding.
  - Dozens of contract specification requirements are projected to be open into FY18; these shortfalls in meeting the contract specifications will translate into limitations or reductions to full Block 3F capability.
  - Estimates to complete Block 3F mission systems extend into the summer of 2018, not just from DOT&E, but other independent Department agencies, making delivery of full capability in January 2018 nearly impossible to achieve, unless testing is prematurely terminated, which increases the likelihood the full Block 3F capabilities will not be adequately tested and priority deficiencies fixed.
  - Deficiencies continue to be discovered at a rate of about 20 per month, and many more will undoubtedly be discovered during IOT&E.
  - ALIS version 3.0, which is necessary to provide full combat capability, will not be fielded until mid-2018; also, a number of capabilities that had previously been designated as required for ALIS 3.0 are now being deferred to later versions of ALIS (i.e., after summer of 2018).
  - The Department has chosen to not fund the CAPE estimate for the completion of Block 3F mission systems testing lasting until mid-2018, an estimate which is at least double the Program Office's latest unrealistic estimate to complete SDD. This guarantees the program will attempt a premature resource- and schedule-driven shutdown of mission systems testing, which will increase the risk of mission failures during IOT&E and, more importantly, if the F-35 is used in combat.
  - Finally, rigorous operational testing, which provides the sole means to evaluate actual combat performance, will not complete until at best the end of 2019—and more likely later.

Question #5: How will this delay and cost overrun affect the current overall schedule for Joint Strike Fighter deliveries to the Services?

- DOT&E Answer: The Program Office currently has no plans to delay the production and delivery schedule of aircraft to the Services. However, since Lot 10 aircraft will not initially be delivered with full combat capability, including operational MDLs for Block 3F, the Services will need to plan for accepting aircraft with less capability, possibly with Block 3i capability, until full Block 3F capability can be delivered.

Question #6: When will you complete the operational test and evaluation phase?

- DOT&E Answer: The IOT&E is planned to cover a span of approximately 12 months, and will start after the program is able to meet the TEMP entrance criteria and the Department certifies that the program is ready for test. These entrance criteria are common-sense and carefully defined requirements that were well-coordinated with the Services and JPO as the TEMP was being staffed. Meeting these criteria to enter IOT&E is necessary to ensure the test is conducted efficiently and effectively within the time span planned and to minimize the risk of failing IOT&E, or causing a "pause test" and having to reaccomplish costly test trials, which would only further delay the completion of IOT&E and increase program costs. Since the program will not be ready to start IOT&E until late 2018, at the earliest, and more likely 2019, completion of IOT&E will not occur until late 2019 or early 2020.

Question #7: When will you make the Milestone C/Full-Rate Production decision?

- DOT&E Answer: Since the Milestone C/Full-Rate Production decision cannot be made until after IOT&E is completed and DOT&E has issued its report, it cannot occur by the threshold date of October 2019 and will likely not occur until early 2020, at the soonest.

Question #8: Will you defer any planned F-35 capabilities from SDD into the F-35 Follow-on Modernization (FoM) program?

- DOT&E Answer: Multiple F-35 capabilities will be deferred from SDD or not function properly in Block 3F unless the program continues testing and fixing deficiencies. The program currently has hundreds of unresolved deficiencies and immature capabilities, including 17 documented failures to meet specification requirements for which the program acknowledges and intends to seek contract specification changes in order to close out SDD.

Question #9: How will the SDD delay affect the Follow-on Modernization (FoM) program?

- DOT&E Answer: Delays to the completion of SDD will impact both the FoM program schedule and content. While FoM is critical for the capabilities needed with the F-35 and the program is attempting to minimize delays, the program does not appear to be ready to complete all prerequisites to start full development in FY18, as planned. Also, IOT&E will not be complete until late 2019 or early 2020, which overlaps with the planned test periods for Block 4.1. Finally, the program's current plans for FoM are not executable, for many reasons, which include the following:
  - Too much technical content for the production-schedule-driven developmental timeline
  - Overlapping capability increments without enough time for deficiencies from OT to be fixed prior to releasing the next increment
  - High risk due to excessive technical debt and deficiencies from the balance of SDD and IOT&E being carried forward into FoM because the program does not have a plan or funding to resolve key deficiencies from SDD prior to attempting to add the planned Block 4.1 capabilities
  - Inadequate test infrastructure (aircraft, laboratories, personnel) in the current FoM plan to meet the testing demands of the capabilities planned and the multiple configurations (i.e., TR2, TR3, and Foreign Military Sales)
  - Insufficient time for conducting adequate DT and OT for each increment

Question #10: When will you provide your final response either to validate the current requirement for the F-35 Joint Strike Fighter total program of record quantity or identify a new requirement for the total number of F-35 aircraft that the Department would ultimately procure?

- DOT&E Answer: DOT&E is not aware of when the Department will complete these actions.

Recommendations

- Status of Previous Recommendations. The program adequately addressed 5 of the 14 previous recommendations. As discussed in the appropriate sections of this report, the program did not, and still should:
  1. Acknowledge schedule pressures that make the start of IOT&E in August 2017 unrealistic and adjust the program schedule to reflect the start of IOT&E no earlier than late CY18.
  2. The Department should carefully consider whether committing to a "block buy" is prudent given the state of maturity of the program, as well as whether the block buy is consistent with a "fly before you buy" approach to defense acquisition and the requirements of title 10 U.S. Code.
  3. Plan and program for additional Block 3F software builds and follow-on testing to address deficiencies currently documented from Blocks 2B and 3i, deficiencies discovered during Block 3F developmental testing, and during IOT&E, prior to the first Block 4 software release planned for 2020.
  4. Ensure the testing of Block 3F weapons prior to the start of IOT&E leads to a full characterization of fire-control performance using the fully integrated mission systems capability to engage and kill targets.
  5. Provide the funding and accelerate contract actions to procure and install the full set of upgrades recommended by DOT&E in 2012, correct stimulation problems, and fix all of the tools so the USRL can operate efficiently before Block 3F mission data load development begins.
  6. Complete the planned testing detailed in the DOT&E-approved USRL mission data optimization operational test plan and amendment. Although some

testing was completed, the program should ensure all operational Block 3i MDLs are tested per the approved test plan.

7. Along with the Navy and Marine Corps, conduct an actual operational test of the F-35B onboard an L-class ship before conducting a combat deployment with the F-35B. This test should have the full Air Combat Element (ACE) onboard, include ordnance employment and the full use of mission systems, and should be equipped with the production-representative support equipment.
8. Develop a solution to address the modification and retrofit schedule delays for production-representative operational test aircraft for IOT&E. These aircraft must be similar to, if not from, the Lot 9 production line.
9. Develop an end-to-end ALIS test venue that is production representative of all ALIS components. Although the program has developed the ORE, only limited testing has occurred.

- FY16 Recommendations.
  1. The program should complete all necessary Block 3F baseline test points. If the program uses test data from previous testing or added complex test points to sign off some of these test points, the program must ensure the data are applicable and provide sufficient statistical confidence prior to deleting any underlying build-up test points.
  2. In light of the fact that the program is unable to correct all open deficiencies prior to IOT&E, the program should assess and mitigate the cumulative effects of the many remaining SDD deficiencies on F-35 effectiveness and suitability, especially those deficiencies that, in combination or alone, may cause operational mission failures during IOT&E or in combat, prior to finalizing and fielding Block 3F. The program will need to add test points to troubleshoot and address deficiencies that are currently not resolved.
  3. The program should consider developing another full version of Block 3F software to deliver to flight test in order to address more known deficiencies.
  4. The program should ensure adequate resources remain available (personnel, labs, flight test aircraft) through the completion of IOT&E to develop, test, and verify corrections to deficiencies identified during flight testing.
  5. The program should address the deficiency of excessive F-35C vertical oscillations during catapult launches within SDD to ensure catapult operations can be conducted safely during IOT&E and during operational carrier deployments.
  6. The Program Office must immediately fund and expedite the contracting actions for the necessary hardware and software modifications to provide the necessary and adequate Block 3F mission data development capabilities for the USRL, including an adequate number of additional radio frequency signal generator channels and the other required hardware and software tools.
  7. The program should address the JOTT-identified shortfalls in the USRL that prevent the lab from reacting to new threats and reprogramming mission data files consistent with the standards routinely achieved on legacy aircraft.
  8. The program should correct deficiencies that are preventing completion of all of the TEMP-required Block 3F Weapons Delivery Accuracy (WDA) events and ensure the events are completed prior to finishing SDD.
  9. The program should ensure Block 3F is delivered with capability to engage moving targets, such as that provided by the GBU-49, or other bombs that do not require lead-laser guidance.
  10. The program should complete additional testing and analysis needed to determine the risk of pilots being harmed by the Transparency Removal System (which shatters the canopy first, allowing the seat and pilot to leave the aircraft) during ejections in other than ideal, stable conditions (such as after battle damage or during out-of-control situations). The program should complete these tests as soon as possible, with the new equipment, including the Gen III Lite helmet in a variety of off-nominal conditions, so that the Services can better assess risk associated with ejections under these “off-nominal” conditions.
  11. The program needs to conduct an assessment to determine the extent to which the results of further durability testing with BH-1, the F-35B durability test article, are representative of production aircraft and, if necessary, procure another test article for the third life testing.
  12. The Navy and the Program Office should investigate alternatives for determining the operational impact of an engine removal and install while conducting carrier air wing operations at sea.
  13. The Navy and Marine Corps should conduct an analysis, such as an operational logistics footprint study, which simulates flight deck and hangar bay spotting (aircraft placement) with a full ACE onboard, using data from the DT-III ship trials to determine what the impact of an engine removal and installation would be on integrated ship and ACE operations with a full ACE onboard.
  14. The program and the Navy should investigate if the heavy power module container should be redesigned for better usability at sea.
  15. The program and the Navy should investigate potential options to improve ship-based communications bandwidth dedicated to ALIS connectivity off-ship, such as increasing the priority of ALIS transmissions, or reserving low-use times of the day for handling large volumes of ALIS message traffic.
  16. The Navy should investigate any efficient, multi-use opportunities for F-35 support equipment (SE) such as using legacy SE on the F-35 or F-35 SE on legacy aircraft.
  17. The Navy should investigate options for increasing the number of wall power outlets in CVN hangar bays to help facilitate simultaneous maintenance on multiple F-35Cs, or the ability to interconnect multiple pieces of support equipment from a single outlet to permit simultaneous operations.