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Director, Operational Test and Evaluation

(U) DOT&E Assessment of Post-IOT&E F-35 Block 4 Operational Testing

February 2024

(U) This report on the F-35 Joint Strike Fighter fulfills the provisions of Title 10, United States Code, Sections 4171 and 4172. It assesses the adequacy of testing and the operational effectiveness, operational suitability, and survivability of the F-35 in order to inform Milestone C and Full Rate Production decisions.

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(U) DOT&E Assessment of Post-IOT&E F-35 Block 4 Operational Testing

(U) This report provides an assessment of operational testing (OT), directed by DOT&E-approved test plans, of aircraft software and capability upgrades fielded after the delivery of the final F-35 Block 3F capabilities that were evaluated in initial operational testing and evaluation (IOT&E). Effectiveness assessments in this annex are based on open-air OT of aircraft software versions 30R06 and 30R07.[1] These assessments are based on DOT&E observation of test events and independent analyses of the test results and observations reported by the U.S. Operational Test Team (UOTT).

(U) The suitability of the Block 4 hardware and software upgrades was not assessed. The overall reliability, maintainability, and availability of the U.S. F-35 fleet remains below Service expectations. Suitability assessments herein are based on analyses of reliability, maintainability and availability data for all variants in the U.S. fleet, collected during an expanded time period to reveal historical trends. Cybersecurity testing was completed on updated software versions of the Autonomic Logistics Information System (ALIS) and the Mode 5 version of Identification Friend or Foe functionality of the aircraft. No additional vulnerability testing has been completed beyond that which was reported in the IOT&E report.

(U) Key Findings

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1 (U) F-35 IOT&E was accomplished with each 30 series release through 30R04 (and one weapon event with 30R06) to complete IOT&E testing. Formal OT was not accomplished using software version 30R03, because no new combat capability was delivered, or 30R05, because the program and Services decided that it would not be released to the field.

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(U) DOT&E assesses that the Joint Strike Fighter (JSF) Program's Continuous Capability Development and Delivery (C2D2) development process is not working as intended at this point. C2D2 is failing to deliver new, fully functional capabilities on schedule, mostly due to test infrastructure (ground testing laboratories and test aircraft) and development processes that are not able to maintain the planned pace. This results in utilization of the developmental testing (DT) and OT aircraft fleets on a fly-fix-fly basis. Since the completion of 30R07 OT, the program moved from a 6-month to a 12-month C2D2 cadence, but has failed to deliver the next software version, 30R08, after more than 2 years of DT. Furthermore, as of this writing, 30R08 has introduced new deficiencies in previously delivered capabilities.

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(U) System Description

(U) Following the completion of the SDD phase of the program in April 2018, represented by the last developmental test flight, the F-35 Joint Program Office (JPO) and Lockheed Martin transitioned to a new development process, referred to as C2D2. This process

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was designed and originally anticipated to deliver planned Block 4 capabilities incrementally, at 6-month intervals, while simultaneously correcting deficiencies. The program also changed software nomenclature for the initial increments of Block 4: from "3FRXX" used during SDD, to "30RXX" for development and "30PXX" for fielded software. The 30 series of software is compatible with the Block 3F aircraft hardware configuration.

(U) Although the C2D2 process was intended to provide new capabilities and address deficiencies on a 6-month basis, that timeline was not achievable or sustainable. In fact, attempting to deliver on that timeline actually delayed the fielding of new capabilities, in comparison to the planned delivery dates for these capabilities in the original program-of-record schedules. Changes introduced in subsequent software versions often caused functionality originally fielded in earlier versions to experience stability problems and other adverse effects.

(U) Also, although the program planned to be able to rely more on modeling and simulation in C2D2, with the expectation of reducing dependency on flight tests, the development process included no significant additions to the simulation venues, and flight test became a "fly-fix-fly" process. Beginning with developmental flight testing of 30R08 in December 2021, the JPO extended the C2D2 development cycle for each software build to 12 months.

(U) Autonomic Logistics Information System

(U) ALIS is a large, distributed information system that is integral to all F-35 operations, maintenance, supply, and training. ALIS is composed of hardware and software components located at the squadron or unit level, the country level, and the enterprise level; including both government- and contractor-owned assets. Different logistic, sustainment and operational functions occur at each of these levels. This distributed and networked nature is inherent to the design of ALIS. At a unit-level, support personnel and pilots regularly use the suite of ALIS software applications to generate sorties and sustain the aircraft, but the full functionality of these applications is dependent on connectivity and data exchange between these levels.

(U) The Standard Operating Unit (SOU) is the unit-level ALIS hardware component, a set of servers that provide the capabilities necessary to carry out mission support roles for the F-35 aircraft assigned to each squadron. These roles include (1) flight operations support, (2) off-board processing of aircraft data used to identify faults and track the remaining usable life of critical components – particularly for propulsion components, (3) determination of aircraft LO signature based on documented accumulated exterior damages and repairs, (4) aircraft health management, (5) maintenance management, (6) supply chain management, (7) customer support services, and (8) other logistics and support functions.

(U) Portable Maintenance Aids (PMA) are ruggedized laptops set up for maintainers to use while working on the flight line. These maintenance aids can be connected to the aircraft to read some aircraft configuration information, such as fuel and oil levels, or to control some aircraft functions to facilitate maintenance. PMAs do not have access to the full suite of ALIS applications or all the data required to conduct and manage aircraft maintenance. Maintainers can use the Computerized Maintenance Management System application on the PMA to see relevant

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aircraft maintenance records for the jet they are working on, and they can use the PMA to document maintenance actions as they are conducted. During normal operations, the unit's SOU is online, maintainers typically login to ALIS from desktop computers to document maintenance and to access the full suite of ALIS applications.

(U) ALIS to ODIN Transition

(U) The JPO has begun efforts to replace ALIS with a new cloud-based logistics information system referred to as the Operational Data Integrated Network (ODIN). ODIN is designed to feature faster computer hardware and intends to employ containerized applications to allow for agile software development and more frequent application updates when warranted. ODIN, while cloud-based, is still dependent on the same unit-, country-, and enterprise-level construct with different functions and capabilities enabled at each level. At the time of this report, ODIN hardware was being deployed across the fleet, but still running ALIS software. The first ODIN hardware increment is the unit-level ODIN Base Kit (OBK), designed to replace the SOU for squadron use. Currently, for the unit-level ALIS Squadron Kit, some squadrons are equipped with an SOU while others have an OBK. The most recent program projections place the complete transition from SOUs to OBKs in 2025.

(U) Test Adequacy

(U) The UOTT[2] developed test plans and conducted limited OT of aircraft capabilities developed and fielded after the SDD contract was completed. The overall test strategy associated with the C2D2 development process involved conducting a cross-section of operational mission trials and weapon events in order to complete regression testing, qualitatively assess performance, and identify problems, in operationally representative scenarios. The UOTT created test plans that involved three levels of effort, each with distinct objectives:

- (U) **Capability Test Events (CTE)**. For these events, the UOTT became, in effect, an extension of DT, as they completed test flights with early versions of the software, to help characterize performance of new capabilities and provide feedback on performance. Weapon demonstration events are CTEs.
- (U) **Mission Area Trials (MAT)**. The teams also followed F-35 participation in large force joint exercises, in order to collect data in scenarios more operationally representative than the tightly controlled scenarios used in the CTEs. These exercises provided the added benefit of opportunities to evaluate interoperability features of the F-35, in interactions with other types of aircraft, including operations with other Service's air warfare platforms. The results from the MATs also provided feedback to the program by identifying additional, new deficiencies or verifying corrections of deficiencies identified in earlier versions of software. These MATs also provided input to support overall readiness to conduct dedicated operational test (DOT)

[2] (U) None of the foreign partners participated in the Block 4 testing described in this annex. The U.S. Operational Test Team, as the name implies, is manned entirely by U.S. Service personnel, and is composed of three geographically dispersed operational test units, one for each F-35 variant.

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missions. However, the exercises in which the MATs addressed in this report were conducted, were not under the direct control of the UOTT test teams.

- (U) **Dedicated Operational Test Missions.** For these test events, the test plans required full mission-level evaluations similar to IOT&E effectiveness trials. These DOTs included variations in operational factors, such as the number of threat aircraft and type of ground threat system, to support problem identification; however, they were not statistically designed in accordance with design-of-experiments principles.

(U) None of the OT events were intended to identify performance differences in variants. However, some weapon capabilities that were tested were only delivered to specific variants.

(U) Operational suitability testing is ongoing but is not complete. The UOTT has conducted operational suitability testing using calendar-based test plans that were intended to be updated and approved annually. Testing has been conducted with DOT&E-approved test plans (shown in Table 1), with the exception of a period between July 1, 2022 and October 26, 2023, during which the UOTT continued to collect data but there was no DOT&E-approved test plan. Post-IOT&E Block 4 suitability testing has primarily focused on the availability, reliability, and maintainability of the F-35 aircraft assigned to the U.S. operational test squadrons. The UOTT also conducted interviews with maintenance personnel and pilots on training, technical orders, the use of ALIS, software updates, support equipment, and maintenance of the low-observable characteristics of the aircraft.

(U) Table 1. F-35 FOT&E Suitability Test Plans

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DOT&E Approval Date	Test Dates	Scope
Aug 14, 2020	Jul 1, 2020 – Jun 30, 2021	Annual Operational Suitability Test Plan
Sep 24, 2021	Sep 30, 2021 – Jun 30, 2022	Annual Operational Suitability Test Plan
None	Jul 1, 2022 – Oct 26, 2023	No DOT&E-Approved Test Plan
Aug 11, 2023	Aug 14 – 25, 2023	ALIS Disconnected Operations Test Plan
Oct 27, 2023	Oct 27, 2023 – Oct 27, 2024	Annual Operational Suitability Test Plan

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(U) In August 2023, the UOTT conducted a formal test of F-35A flight operations and maintenance with the ALIS Squadron Kit offline, per the DOT&E-approved test plan. The scope, which was limited, partially tested the ability of an F-35 unit to conduct operations with ALIS (or ODIN) disconnected from supporting infrastructure. Further testing under additional ALIS or ODIN degraded conditions must still be conducted.

(U) Test Resources

(U) Following the completion of IOT&E open-air testing, the U.S. Air Force F-35A OT squadron relocated to Nellis Air Force Base (AFB), Nevada, and the F-35B OT squadron relocated to Marine Corps Air Station Yuma, Arizona. The F-35C OT squadron remained at Edwards AFB, California. Development and verification, validation, and accreditation (VV&A) of the Joint Simulation Environment (JSE) was completed in CY23, enabling the completion of testing called for in the IOT&E test plan. JSE is not yet configured or accredited to support

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testing of the F-35 for any post-SDD software and capability updates. Accordingly, the JSE was not used to test 30R06 or 30R07, and no further OT has been conducted in the JSE beyond that reported in the main body of this report for the Block 3F SDD configuration of the aircraft.

(U) The test teams continued using the same range infrastructure and threat representation they had used during IOT&E (see Section 2 of the IOT&E report for specifics).

(U) Test Limitations

(U) The immaturity of planned additional capabilities limited the utility of OT events. [redacted]

(U) Due to delays in completing the development and VV&A of the JSE, in order to complete IOT&E with 30R02 software, the JSE was not available to accomplish testing with 30R06 or 30R07 capabilities.

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(U) Software Version 30R03

(U) The program transitioned the development effort from SDD to C2D2 during the later portion of IOT&E. Based on Service priority, the program added an Automatic Ground Collision Avoidance System capability for the F-35A and F-35B, fielding the capability in software 30P03.03. The testing was not completed for the F-35C before the program transitioned to developing the next increment of software, 30R04, so the capability was not fielded for that variant. No formal OT was completed using the 30R03 software because it did not deliver new combat capability.

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(U) Software Version 30R04

(U) Operational testing of software version 30R04.52, the final version used in mission-level effectiveness trials in IOT&E, was completed during between July and October 2020. The results are detailed in the IOT&E report.

(U) Software Version 30R05

(U) The program planned to develop and field 30R05 software, but significant unresolved deficiencies and the need to continue development of the next increment of software (the 30R06 series), resulted in the program and Services deciding that 30R05 would not be released to the field. No formal OT was completed with 30R05 software.

(U) Software Versions 30R06 through 30R07

(U) The UOTT conducted OT of the next two increments of software from April 2021 through June 2022. Table 2 shows the software versions, the OT period dates, the open-air DOTs, and weapon events that were completed.

(U) Table 2. Operational Testing of Block 4 Software and Capabilities

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Software Version[a]	Test Period	Post-SDD Dedicated Operational Test Events				
		CAS Trials	DCA Trials	OCA Trials	S/DEAD Trials	Weapon Events
30R06 (30R06.03, 30R06.041, 30R06.042)	April to August, 2021	Five 2-ship trials (F-35A and F-35B)	Four (F-35A and F-35C, with and without 4th fighter integration)	Three (F-35A and F-35C)	Two (F-35A and F-35C)	1 X GBU-12 2 X GBU-49
30R07 (30R07.03, 30R07.031, 30R07.041, 30P07.041, 30P07.042, 30P07.045)[b]	October 2021 to June 2022	Four 2-ship (F-35B)	Three (F-35A and F-35C)	Two	Four (F-35A and F-35C)[c]	2 X GBU-38 3 X GBU-54 2 X AIM-9X 2 X AIM-120D

a. This column lists all of the development versions of software used during OT.

b. The UOTT flew with three versions of "productionized" software – designated as 30P07.04X – to support fielding recommendations to each U.S. Service.

c. Two of the S/DEAD missions were flown in combination with the 2 OCA trials, as was done during IOT&E.

Acronyms: CAS – close air support; DCA – defensive counter-air; OCA – offensive counter-air; SDD – System Development and Demonstration; S/DEAD – suppression or destruction of enemy air defenses

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(U) Operational Effectiveness

(U) Testing of Software Version 30R06

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(U) Variable Message Format

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(U) Weapons Integration

(U) The test team completed Weapons Demonstration Events (WDE) as software regression tests, in order to see if any changes introduced in 30R06 adversely affected weapons integration.

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- (U) The test team completed the remaining AIM-120 missile weapon demonstration event from the IOT&E test plan using 30R06.042 software. The results of this event are included in Section 3 of the main body of this report.
- (U) The test team completed one GBU-12 event with a 4-ship of F-35A aircraft, each delivering a GBU-12 on static targets. The results were successful.
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(U) Testing of Software Version 30R07

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(U) Variable Message Format (VMF)

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(U) Weapons Integration

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(U) Miscellaneous Deficiencies

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(U) Small Diameter Bomb II (F-35B Only)

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(U) Due to limited F-35B developmental test aircraft being available (the developmental test fleet began transitioning to the upgraded avionics architecture known as Technical Refresh-3), the program has become reliant on UOTT aircraft to support developmental flight testing. The 30R07 OT plan included 14 live SDB II weapon events. The F-35B OT unit completed one SDB II test event in September, 2022, using software version 30R07.041, which is the test version of the 30R07 software currently fielded in the F-35B by the U.S. Marine Corps. The rest of the required weapon events have been deferred to later software releases.

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(U) Operational Suitability

(U) The suitability of the Block 4 hardware and software upgrades was not assessed. Post-IOT&E OT has started, but is yet to be completed. The overall reliability, maintainability, and availability of the U.S. F-35 fleet remains below Service expectations.

(U) The U.S. fleet reached maturity in the second quarter of FY22 when the F-35C fleet accumulated more than 50,000 hours. The JSF Operational Requirements Document defined maturity as 200,000 hours for the fleet, with a minimum of 50,000 hours on each variant, and is the milestone for evaluating all variants against reliability and maintainability metrics.

(U) This section discusses the observed trends in aircraft availability and aircraft reliability and maintainability (R&M) of the U.S. F-35 fleet since September 2019 (the end of

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the IOT&E R&M data evaluation period). The IOT&E results were based on flight hours and maintenance events completed between December 3, 2018 through September 30, 2019.

(U) The historical suitability trends in the U.S. fleet are also presented during an expanded time period starting in FY15 through the end of FY23 (for aircraft availability) and FY22 (for R&M metrics). The difference in end dates is because there is a lag in publishing R&M data, resulting from the adjudication and review of maintenance records by the government and contractor teams.

(U) U.S. F-35 Fleet Operational Availability and Fully Mission Capable Rates

(U) The operational availability (Mission Capable (MC) rates) and Fully Mission Capable (FMC) rates of the U.S F-35 fleet are below, and well below, the Services' target values respectively. In the post-IOT&E period, the U.S. fleet results show a decrease in operational availability for the F-35A and F-35B and generally flat with variation year to year for the F-35C. The MC rate indicates the proportion of all fielded aircraft not in depot that are capable of flying at least one mission of the F-35 mission set, while the FMC rate reports the proportion that can fly all defined F-35 missions. The materiel availability is the percentage of aircraft that are in an MC status accounting for the time when aircraft are in depot status.

(U) Following FY19, there was a notable increase in the operational availability of the F-35A and F-35B and a corresponding decrease in the proportion of aircraft that were down due to supply (i.e. waiting for parts). During the same time period the proportion of aircraft that were down for maintenance has been relatively flat. Since FY19, the F-35C operational availability have had more year-to-year variability but remained below the target values. These trends are shown in Figure 1 which plots the results from FY15 through the end of FY23. The annual average value for each metric is indicated by the short dark colored bars, the minimum and maximum monthly value in a given fiscal year are indicated by longer lighter colored bars, and the target values are indicated by the horizontal lines. Arrows have been added to the plots of Not Mission Capable due to supply (NMC-S) and operational availability to guide the eye and to highlight the trends discussed above. There has been more variability in the proportion of aircraft that are down due to supply (i.e. waiting for parts) than aircraft that are down for maintenance. The trends suggest that the most impactful near-term lever to improve aircraft availability is by increasing the available spares – either by purchasing more or by increasing depot repair capacity and throughput.

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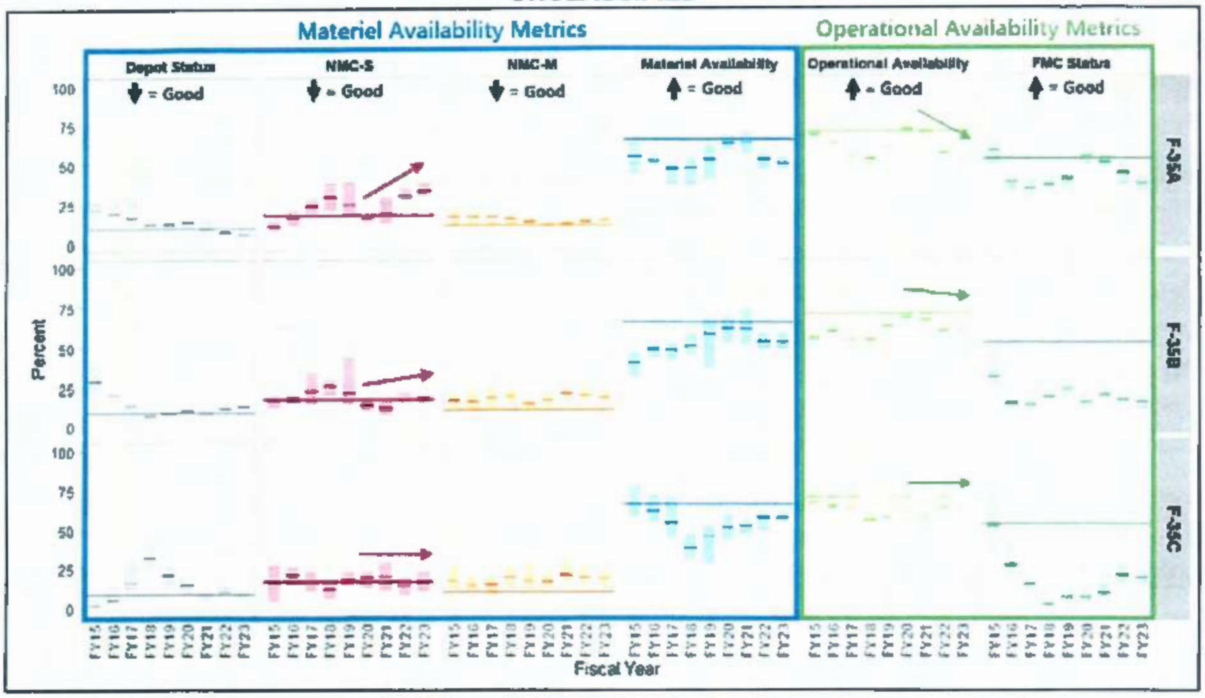

(U) Acronyms: FMC – Fully Mission Capable; NMC-M – Not Mission Capable for Maintenance; NMC-S – Not Mission Capable due to Supply

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(U) Figure 1. F-35 Availability Metrics, U.S. Fleet (FY15 – FY23)

(U) Reliability Trends

(U) The U.S. F-35 fleet remains below the JSF ORD thresholds for some overall reliability metrics. Higher numbers reflect better performance and a more reliable system. Since FY15 there has been some reliability improvement with increased variability. In FY22 the F-35A met two, the F-35B met one, and the F-35C met none of the three reliability requirements.

(U) In FY22, the F-35A and the F-35B were significantly below, and the F-35C was slightly below, the threshold requirements for critical failure rate. Mean Flight Hours Between Critical Failure (MFHBCF) includes all failures that render the aircraft unsafe to fly, along with 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. The MFHBCF for the F-35A in FY22 was similar to the reported value in FY19, and has declined since FY20, following an increase FY19 and FY20. The F-35B showed a similar trend, the FY22 reported value was around 15 percent higher than in FY19. In FY22, the MFHBCF for the F-35C was around 20 percent higher than reported in FY19, and has decreased from the FY21 reported value.

(U) In FY22, the F-35A was slightly above, and the F-35B and the F-35C were below, the threshold requirements for removals. Mean Flight Hours Between Removal (MFHBR) indicates the degree of necessary logistical support and is frequently used in determining associated costs. MFHBR includes any removal of an item from the aircraft for replacement, except for consumables like fasteners. Not all removals are failures; some removed items are

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later determined to have not failed when tested at the repair site, and other components can be removed due to excessive signs of wear before a failure, such as worn tires. The MFHBR for all variants was 15 to 20 percent higher in FY22 than in FY19.

(U) In FY22, the F-35A and F-35B were above, and the F-35C was below, the threshold requirements for unscheduled maintenance events. Mean Flight Hours Between Maintenance Event Unscheduled (MFHBME-U) is a reliability metric for evaluating maintenance workload due to unplanned maintenance. Maintenance events are either scheduled (e.g., inspections or planned part replacements) or unscheduled (e.g., failure remedies, troubleshooting, replacing worn parts such as tires). In FY22, the F-35A and F-35B were slightly above and above the threshold requirement for MFHBME-U, both increasing since FY19. The MFHBME-U for the F-35C in FY22 that was similar to that reported in FY19, with little overall change.

(U) The overall trends in reliability of the U.S. F-35 fleet from FY15 through the end of FY22 are shown in Figure 2. This figure shows yearly average value for each metric for a given fiscal year, and the horizontal line indicates the threshold requirement. MFHBME-U and MFHBR both show more reliability improvement, with some metrics above requirement; but little apparent effect on operational availability rates. For reliability metrics, higher values are better.

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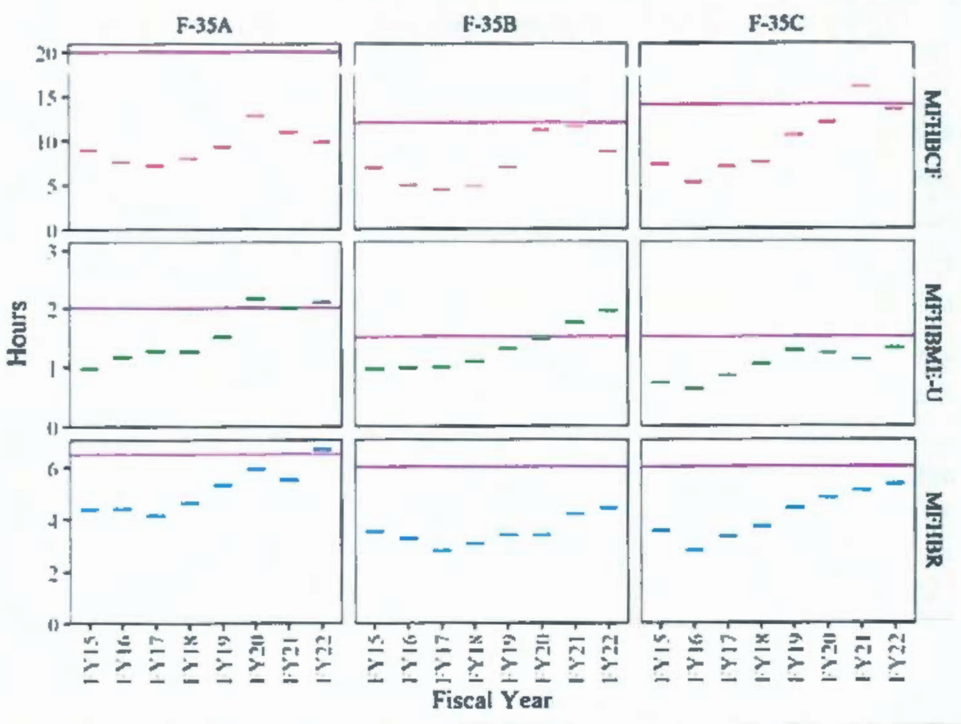

(U) Acronyms: MFHBCF – Mean Flight Hours Between Critical Failures; MFHBME-U – Mean Flight Hours Between Maintance Events – Unscheduled; MFHBR – Mean Flight Hours Between Removals

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(U) Figure 2. F-35 Reliability Metrics, U.S. Fleet (FY15 – FY22)

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(U) Maintainability Trends

(U) For all variants the average maintenance durations for the U.S. F-35 fleet longer the JSF ORD thresholds. These results show no significant changes in maintainability of the U.S. F-35 fleet in the post-IOT&E period. For maintainability metrics, lower numbers reflect better performance and less maintenance burden. There has been little improvement in these maintainability metrics since FY15. In FY22, no variant met the maintainability requirements.

(U) The time required to fix critical failures remains almost double or more than the threshold requirement, with no significant improvement over the period (the Mean Corrective Maintenance Time for Critical Failures). This metric measures the active maintenance time required to correct only the subset of failures that prevent the F-35 from being able to perform a specific mission. It indicates the average time for maintainers to return an aircraft from Not Mission Capable to MC status.

(U) The trend is similar for the average time for all unscheduled maintenance actions (Mean Time to Repair). This metric includes only active maintenance time and is a general indicator of the ease and timeliness of repair.

(U) The maintainability metrics for the U.S. F-35 fleet from FY15 through the end of FY22 are shown in Figure 3. This figure shows yearly average value for each metric for a given fiscal year, and the horizontal line indicates the threshold requirement. For maintainability metrics, lower values are better (shorter average maintenance durations).

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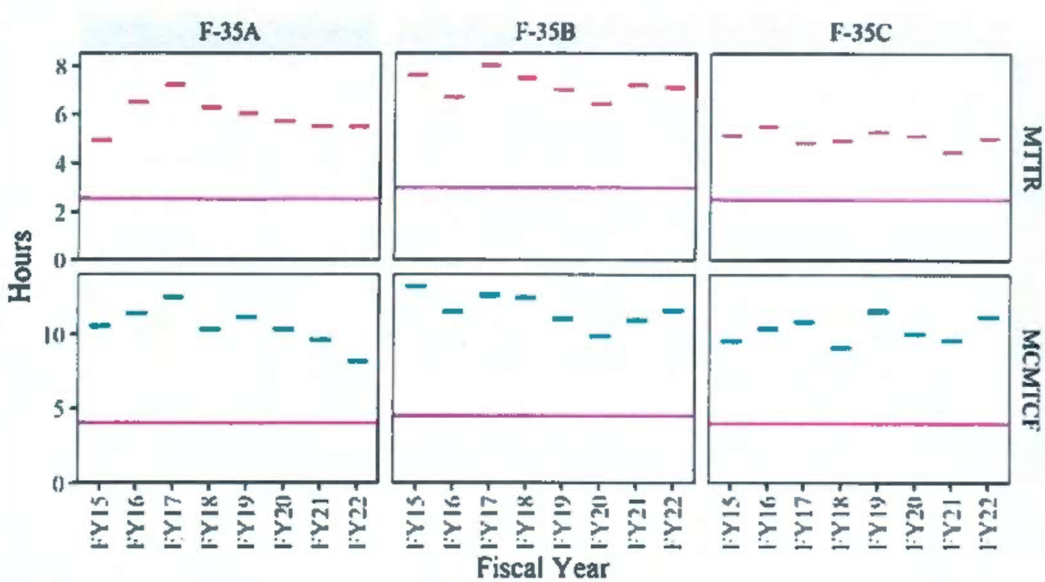

(U) Acronyms: MCMTCF – Mean Corrective Maintenance Time for Critical Failures; MTTR – Mean Time to Repair

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(U) Figure 3. F-35 Maintainability Metrics, U.S. Fleet (FY15 – FY22)

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(U) ALIS/ ODIN

(U) At the time of this report, ODIN hardware was being deployed across the fleet, running ALIS software. Maintainers reported that the ODIN hardware was faster than ALIS hardware, mitigating some issues with slow ALIS performance from IOT&E. However, planned ODIN software has not yet been delivered. The first step toward new ODIN software will be containerization of existing ALIS software, which has not yet happened. As a result, many of the usability concerns and specific software-related issues recorded during IOT&E are still present in the field.

(U) To improve the utility of ODIN, the JPO should ensure the ODIN data environment reduces the inconsistent, inaccurate, and missing data across all areas of sustainment as has been observed in ALIS, from aircraft configuration and component remaining life to spare part records. The program should also investigate improved methods for recording low-observable defects, and deliver capabilities requested by maintainers that are missing in ALIS, in particular functionality to identify and locate documentation.

(U) DOT&E also recommends that the UOTT conduct usability surveys of the most frequently used logistics information system applications for each major new information system version. This would aid ODIN development, and support evaluation of the progress in the ALIS to ODIN transition. The UOTT should make a concerted effort to survey for supply chain management applications, and should also explicitly include maintainer type as a factor in survey test designs and administration plans.

(U) ALIS Disconnected Operations

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(U) The offline condition was pre-planned and the unit had time to prepare for the disconnected operations. During this event the unit maintained these four aircraft using only PMAs. At the end of the offline period, they brought the SOU back online, resynced the PMAs, and resumed normal flight operations and maintenance. The test event was limited in scope (only the unclassified SOU was disconnected) and duration, with 6 flying days disconnected followed by 3 flying days to complete the resync. One objective was to evaluate guidance, provided by the contractor Lockheed Martin, for unit maintenance operations with the Squadron Kit offline and

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for the transition back to a working Squadron Kit (where flight and maintenance data accumulated offline is synchronized back to the SOU or OBK).

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(U) Table 3. ALIS SOU Offline Operations Summary

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(U) Maintainers found the contractor guidance useful, but incomplete. Based on their feedback, the UOTT developed recommendations for the program and Services to establish more in-depth instructions, forms, and tools to enable units to operate with less risk when the ALIS SOU offline.

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(U) Survivability

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(U) F-35 Post-IOT&E Cybersecurity Test Activity

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(U) Table 4. Post-IOT&E Cybersecurity Test Activity

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Test	Dates	SUT and Location	Supporting Team
IFF Mode 5 Testing	November 2021 February 2022	BF-4 aircraft in Chamber Patuxent River, Maryland	JSF ITF Patuxent River Mission Systems
ALIS Verification of Correction of Deficiencies	December 2022	CPE and SQKs Eglin AFB, Florida	48 CTS
ALIS 35P21.Q4: CVPA	March 27 to April 7, 2023	CPE and ESU Eglin AFB, Florida	48 CTS
	April 10 to 14, 2023	ALOU LM Ft. Worth, Texas	
	May 15 to 25, 2023	SQK (OBK Configuration) Eglin AFB, Florida	
ALIS 35P21.Q4: AA	July 10 to 21, 2023	CPE and ESU Eglin AFB, Florida	177 IAS

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Test	Dates	SUT and Location	Supporting Team
	August 21 to September 1, 2023	ALOU LM Ft. Worth, Texas	
	September 11 to 22, 2023	SQK (OBK Configuration) MCAS Yuma, Arizona	MCRT
Maintainer Vehicle Interface Testing	June 2022	BF-4 MVI Connection Patuxent River, Maryland	48 CTS

Acronyms: AA – Adversarial Assessment; AFB – Air Force Base; ALIS – Autonomic Logistics Information System; ALOU – Autonomic Logistics Operating Unit; CPE – Central Point of Entry; CTS – Cyberspace Test Squadron; CVPA – Cooperative Vulnerability and Penetration Assessment; ESU – Enterprise Support Unit; IAS – Information Aggressor Squadron; IFF – Identification Friend or Foe; ITF – Integrated Test Force; LM – Lockheed Martin; MCAS – Marine Corps Air Station; MCRT – Marine Corps Red Team; MVI – Maintainer Vehicle Interface; OBK – ODIN (Operational Data Integration Network) Base Kit; SQK – Squadron Kit

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(U) IFF Mode 5 Testing

(U) As part of a DOT&E-approved UOTT test plan, the JSF Integrated Test Force (ITF) Patuxent River Mission System team supported the IFF Mode 5 test on aircraft BF-4 in an anechoic chamber in November 2021 and in February 2022.

(U) ALIS Testing

(b)(1) [redacted]

(U) In 2023, the UOTT conducted a Cooperative Vulnerability and Penetration Assessment (CVPA) and an Adversarial Assessment (AA) on ALIS 35P21.Q4, in accordance with the DOT&E-approved plan. The 48 CTS supported CVPAs of the U.S. CPE and Enterprise Support Unit (ESU) at Eglin AFB from March 27 to April 7; the program's single Autonomic Logistics Operating Unit (ALOU) at Lockheed Martin, Ft. Worth, Texas from April 10 to 14; and the SQK in the OBK configuration at Eglin AFB from May 15 to 25. The 177th Information Aggressor Squadron (IAS) supported the AA of the U.S. CPE and ESU from July 10 to 21, and the ALOU from August 21 to September 1. The Marine Corps Red Team (MCRT) supported the AA of the SQK in the OBK configuration at Marine Corps Air Station (MCAS) Yuma from September 11 to 22.

(b)(1) [redacted]

(b)(1) [redacted]

(U) Maintainer Vehicle Interface Testing

(b)(1) [redacted]

(U) F-35 Post-IOT&E Cyber Survivability Assessments

(b)(1) [redacted]

(U) IFF Mode 5

(b)(1) [redacted]

(U) ALIS Testing

(b)(1) [redacted]

(b)(1)
[redacted]

(U) Maintainer Vehicle Interface Testing

(b)(1)
[redacted]

(U) Recommendations

(U) Effectiveness

(b)(1)
[redacted]

(b)(1) [redacted]

- (U) In coordination with the Services, the F-35 program office should ensure the OT squadrons are equipped with production-representative, fully-instrumented test aircraft for adequate OT. Aircraft are need in both the current Technical Refresh-2 suite of avionics and the upgraded Technical Refresh-3 suite of avionics.
- (U) The JPO should ensure development and integration of OABS capabilities are contracted and funded in accordance with the Test and Evaluation Master Plans.
- (U) The JPO and the U.S. Services should program and budget for advancements in threat models needed for JSE as well as threat surrogates for the open-air test ranges.

(U) Suitability

- (U) DOT&E recommends that the JPO ensures that the ODIN data environment minimizes inconsistent, inaccurate, or missing data across all areas of sustainment, from aircraft configuration and component remaining life to spare part records.
- (U) DOT&E recommends that the JPO improved methods for LO defect entry in ALIS and ODIN.
- (U) DOT&E recommends that the JPO deliver capabilities in ODIN required by maintainers, but missing in ALIS; in particular, an Identify and Locate documentation functionality.
- (U) DOT&E recommends that the UOTT complete testing of the ability of an F-35 unit to conduct operations with ALIS disconnected from their supporting infrastructure, as required by the TEMP.
- (U) DOT&E recommends that the UOTT conduct usability surveys of the most frequently used logistics information system applications for each major new information system version, comparing results with previous versions to assess whether usability improves.

(b)(1) [redacted]

(U) Cyber Survivability

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(b)(1) [redacted]

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[redacted]

(b)(1)

[redacted]

(U) Table 3-6. OCA/AI Open-Air Trial Outcomes by Critical Design Factors

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1) [redacted]

(U) The presence of target location error forced the F-35 pilots to execute the F-35 kill chain employing onboard sensors to locate the targets and develop imagery from which the F-35 system could derive precise coordinates. Coordinates were then transferred to weapons and the targets were attacked. AI targets were ground structures simulated to be typical interdiction objectives such as enemy force sustainment facilities or transportation resources. The test team was able to vary the clutter level in the target areas as was planned.

(U) Open-Air Trial Results

(b)(1) [redacted]

(b)(1)

[redacted]

3 (U) For the combined mission trials, the flight lead of the AI force was designated as the overall mission commander.

(b)(1) [redacted]

(b)(1)

[redacted]

There were times when the planned aircraft were not available on the day of a trial because required repairs had not been completed or because spare parts were not available. Other times, an aircraft had a system failure on the ground, prior to or after takeoff, but prior to the start of the trial runs.

(U) On a case-by-case basis, DOT&E gave permission to the test team to proceed with a trial when only three aircraft of a single variant were available, and fly with a 3-ship of a single variant, in lieu of the intended 4-ship. In other cases, DOT&E permitted the test team to fly with mixed 4-ships that included two different variants. A total of 9 of the 20 trials had at least one 3-ship of a single variant. Another 4 of the 20 trials featured at least one mixed 4-ship. Put another way, 13 of 20 open-air trials were unable to adhere to the original test plan to operate with 4-ships of a single variant, illustrating the maintenance-related aircraft availability challenges the test team faced in IOT&E.

(U) The test plan called for 24 valid trials. After five months of testing, DOT&E approved changes to the test plan that resulted in a reduction in the requirement to 20 total valid trials completed as combined OCA and AI missions. This change retained a focus on F-35 performance in the out-of-band surface-to-air threat environment but reduced the number of trials against in-band threats. In total, 25 test trials were attempted in order to achieve 20 valid trials.[2] Of these, 13 were conducted in out-of-band threat environments and 7 were in-band.

(U) The opposing red air forces were planned to consist of four aircraft and several SAMs. On five trials only three opposing aircraft were available. Surface threats were varied in accordance with the test plan to consist of the desired in-band and out-of-band, long and medium-range capabilities. Table 3-5 shows the F-35 variant and red threats presented by trial.

(U) Table 3-5. OCA and AI Open-Air Trials: Blue vs. Red Forces

[redacted]

[2] (U) Within a few days of completion, execution details and preliminary data for each trial were reviewed by the test team and DOT&E to ensure specific requirements were met. A trial determined to be not valid for use in evaluating measures of performance would be a candidate to be attempted again. This happened in several mission areas. Hence more trials were attempted than are required to be valid.

(b)(1) [redacted]

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Station	1	2	3	4	5	6	7	8*	9	10	11
Offensive Counter-Air - Direct Attack											
F-35A				GBU-31	AIM-120		AIM-120	GBU-31 or AIM-120			
F-35B				GBU-32	AIM-120		AIM-120	GBU-32 or AIM-120			
F-35C				GBU-31	AIM-120		AIM-120	GBU-31 or AIM-120			
Offensive Counter-Air - Standoff Weapons											
F-35A					AIM-120		AIM-120	4X GBU-39/B or AIM-120			
F-35B	N/A										
F-35C					AIM-120		AIM-120	AGM-154 or AIM-120			
* For OCA configurations, mission commanders had the discretion to load either 1 bomb and 3 missiles or 2 bombs and 2 missiles, depending on mission scenario.											
Air Interdiction											
F-35A				GBU-31	AIM-120		AIM-120	GBU-31			
F-35B				GBU-32	AIM-120		AIM-120	GBU-32			
F-35C				GBU-31	AIM-120		AIM-120	GBU-31			

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(U) Figure 3-1. Weapon Loads Used for the Combined OCA and AI Trials

(U) Open-Air Trial Execution

(U) As discussed earlier, two 4-ship formations of F-35s were used in these combined trials, one performing the OCA mission roles – sweep/escort and S/DEAD – to reduce or eliminate the enemy aircraft and SAM threats, while the other 4-ship conducted the AI mission. Because aircraft variant was a test design factor, the OCA and AI (Combined) trials were planned to be conducted with a 4-ship formation of one variant in the OCA roles and a 4-ship of another variant in the AI role. Launching F-35 4-ship formations of a single variant proved to be a challenge in the IOT&E open-air trials, due to maintenance-related aircraft availability issues.

(b)(1) [redacted]

(b)(1)

[redacted]

(U) The F-35B was not cleared to carry a standoff weapon during the IOT&E period, and therefore could only participate in direct attack trials in the OCA role. For direct attack trials, the F-35A and F-35C aircraft tasked with the OCA role were each configured with one or two GBU-31 Joint Direct Attack Munition (JDAM) bombs with 2,000-pound-class warheads, and the F-35B aircraft were configured with one or two GBU-32 JDAM bombs with 1,000-pound-class warheads. The weapons load for OCA direct attack aircraft also included two or three AIM-120 missiles. AI configurations for F-35A and F-35C aircraft included two AIM-120 missiles and two GBU-31 JDAM bombs. F-35B aircraft conducting AI carried two AIM-120 missiles and two GBU-32 JDAM bombs.

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) Weapons Loadout

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)
[redacted]

(U) Table 3-4. OCA/AI DEAD Target Objective SAM Threat Categories and Maximum Recommended Intercept Ranges

(b)(1)
[redacted]

Factor	Levels	Applicable Mission Areas		
		OCA		AI
		DEAD	Sweep/Escort	
Acronyms: AI – air interdiction; DEAD – destruction of enemy air defenses, DoE – design of experiments; EA – electronic attack; OCA – offensive counter-air				

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(U) Primary Factors

(U) Understanding three factors in particular (susceptibility of the DEAD target objective to F-35 electronic attack, maximum DEAD target objective missile range, and weapons loadout) in greater detail is key to understanding the execution and results of the OCA and AI trials.

(U) Susceptibility of the DEAD Target Objective Surface-to-Air Missile Systems to F-35 Electronic Attack

(b)(1) [redacted]

(U) Maximum Missile Range of the DEAD Target Objective SAM System

(b)(1) [redacted]

Mission	Dates	Ranges	Aircraft OFP	Sorties			
				F-35A	F-35B	F-35C	Total
DCA vs. Manned Aircraft	Dec 13, 2018 to May 14, 2019	NTTR, PMSR	30R02.04	8	8	14	30
DCA vs. Cruise Missiles	Aug 23, 2018 to May 2, 2019	Atlantic Ranges, PMSR	30R00 30R02.03 30R02.04	4	N/A	6	10

Acronyms: AI – air interdiction; DCA – defensive counter-air; DEAD – destruction of enemy air defenses; NTTR – Nevada Test and Training Range; OCA – offensive counter-air; OFP – operational flight program; PMSR – Point Mugu Sea Range

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(U) Combined Offensive Counter-Air and Air Interdiction

(U) As previously explained in Section 2 of this report, OCA and AI evaluations were combined in open-air and JSE trials. The test plan for these combined trials incorporated a test design based on formal design-of-experiments principles. The test factors were chosen by the test team in advance, based on expectations that they were likely to have meaningful impacts on the performance measures. Table 3-3 reiterates the design of experiments factors and levels described in Section 2 that are applicable specifically to the combined OCA and AI trials.

(U) Table 3-3. DoE Factors and Levels for the Combined OCA/AI Trials

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Factor	Levels	Applicable Mission Areas		
		OCA		AI
		DEAD	Sweep/Escort	
F-35 Variant	A, B, C	X	X	X
Time of Day	Day Night	X	X	X
DEAD Target Objective EA Susceptibility	In Band Out of Band	X	X	
DEAD Target Objective Maximum Missile Range	Medium Range Long Range	X	X	
Target Location Confidence	Level 1 (no error) Level 2 (< 300 ft) Level 3 (> 300 ft)			X
Target Clutter	High Low			X
Blue Force Support	EA-18 Growlers None	X	X	
Weapons Loadout	Standoff Direct Attack	X	X	

were flown over the Point Mugu Sea Range (PMSR). DCA missions against manned aircraft were flown over NTTR and PMSR; the DCA missions against cruise missiles were flown over PMSR.

(U) Table 3-1. Primary Mission Trials Planned and Completed

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Mission		Open-Air						JSE	
		F-35A		F-35B		F-35C			
		Planned	Completed	Planned	Completed	Planned	Completed	Planned	Completed
Combined	OCA	9	9	6	3	9	8	31	31
	AI	9	8	9	9	6	3	31	31
OCA: DEAD Only		4	4	0	0	4	4	N/A	N/A
DCA vs. Manned Aircraft		6	3	5	2	5	5	11	11
DCA vs. Cruise Missiles		2*	2	2*	0	2*	4	22	22

*The variant was not specified for the two total DCA missions against cruise missiles planned for open-air testing.

Acronyms: AI – air interdiction; DEAD – destruction of enemy air defenses; JSE – Joint Simulation Environment; OCA – offensive counter-air

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(b)(1) [redacted]

(U) Table 3-2. Primary Open-Air Mission Sorties

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Mission		Dates	Ranges	Aircraft OFP	Sorties			
					F-35A	F-35B	F-35C	Total
Combined	OCA	Dec 18, 2018 to Aug 28, 2019	NTTR	30R02.04	40	10	28	78
	AI	Dec 18, 2018 to Aug 28, 2019	NTTR	30R02.04	29	34	8	71
OCA: DEAD only		Jul 22 – 31, 2020	PMSR	30R04.52	15	0	16	31

1 (U) An aircraft sortie represents one flight from takeoff to landing of one aircraft. A test trial refers to the conduct of a test event required in the test plan.

Section Three
(U) Operational Effectiveness Trials - Execution and Results

(U) Operational Effectiveness

(U) The effectiveness evaluation was conducted using data from both live and simulated test events. Open-air testing included 89 mission trials across all of the Services' required missions, supported by 75 live, in-flight weapon demonstration events (WDE). The first subsection includes the primary missions of offensive counter-air (OCA), including the roles of sweep/escort and suppression/destruction of enemy air defenses (S/DEAD); air interdiction (AI); and defensive counter-air (DCA), against manned threat aircraft and against cruise missiles. The subsequent subsection provides analysis of the additional missions: close air support (CAS), forward air controller (airborne) (FAC(A)), combat search and rescue (CSAR), strike coordination and armed reconnaissance (SCAR), reconnaissance, and anti-surface warfare (ASuW). The next subsection provides the analysis of the full-scale weapons events conducted in the course of initial operational test and evaluation (IOT&E). The final subsection provides analyses of pilot-vehicle interfaces and human factors.

(U) The categorization of missions as primary or additional is based on the fact that success in the missions listed as primary is dependent on all of the F-35 design features intended to create unique, improved, 5th-generation military capability designed to meet key mission performance requirements. These missions leverage the inherent lethality and survivability characteristics of the F-35, such as fused sensors, low observability, electronic protection, and electronic attack. Success in the additional missions does not rely on improvements in capabilities beyond those that are available in existing 4th-generation systems. In fact, the F-35 evaluated in IOT&E actually lacks some of the key characteristics that make some 4th generations systems effective in these additional missions. Effectiveness in the additional missions relied on sensor performance, communication links and the overall ability to manage airspace deconfliction tasks, and less on low observable traits of the aircraft, threat geolocation and precision combat identification, which were important to the primary missions.

(U) DOT&E approved testing in increments as test infrastructure and F-35 operational aircraft test aircraft became available, beginning in January 2018 (see Table 2-1 for timeline and approvals of test activity). Testing of the additional missions in open-air trials and the WDEs, began first, after DOT&E approval in March 2018. Primary mission testing in open-air trials, which required the full extent of adversary force capabilities, range instrumentation, and full complement of operational test aircraft for each F-35 variant, was approved by DOT&E in December 2018. In September 2023, after the validation of the Joint Simulation Environment (JSE) was complete, DOT&E approved the remaining primary mission trials in that venue.

(U) Primary Missions

(U) Table 3-1 shows the number of planned and completed trials for the primary missions. All combined OCA and AI open-air trials were flown over the Nevada Test and Training Range (NTTR). Four additional OCA open-air trials assessing only the DEAD role

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(U) Suitability Limitations

(U) The IOT&E deployments were short duration, did not include a full afloat/deployment spares packages, or a full complement of aircraft, limiting assessment suitability of these spares packages to support operations without resupply.

(U) An F-35A short-notice deployment under a "Rapid Lightning" concept was not conducted since the U.S. Air Force did not have a mature concept of operations for this during the IOT&E period.

(U) The prognostic health management system does not automatically record pilot-initiated resets of mission-critical systems or other indications of software instability events; as a result, the effect on (reduction in) mission reliable due to software faults or instability could not be assessed.

(b)(1) [redacted]

(U) LFT&E Limitations

(U) The F-35 lethality assessment suffered from the inability of the F-35's gun to hit the targets because of design and installation issues. The F-35 lethality assessment also suffered from significant uncertainties in how the modeling and simulation were conducted, how the damage from the tests were collected (or not), and the inability of the modeling and simulation to represent sand, soil, or concrete.

(b)(1) [redacted]

(b)(1) [redacted]

- (U) Assessed Impact: *Significant.* These limitations effectively precluded the test team from assessing the end-to-end performance of the F-35 in CMD combat scenarios.

(U) Joint Simulation Environment Trial Limitations

(U) The Joint Strike Fighter Operational Test Team IOT&E final report for JSE includes an extensive section documenting limitations of the IOT&E trials conducted in JSE. The following list contains additional limitations of the JSE trials, some of which are common to the open-air trials. Some of the following are addressed in greater detail, above, in the discussions of threat representation.

(b)(1) [redacted]

- (U) Limitation: Same as for open-air.
- (U) Assessed Impact: *Significant.* Same as for open-air.

(U) DCA Cruise Missile Defense Trials Limited in Scope

- (b)(1) [redacted]
- (U) Assessed Impact: *Significant.* As was the case in the open-air trials, these limitations effectively precluded the test team from assessing the end-to-end performance of the F-35 in CMD combat scenarios.

(b)(1) [redacted]

(b)(1) [redacted]

(U) Overly Simplified Scenarios in the Close Air Support and Forward Air Controller (Airborne) Trials

- (U) Limitation: The open-air CAS and FAC(A) trials were over simplified, omitting key real-world aspects of these missions. In particular, there was no live, dynamic ground situation in play during the trials, no troop-level demand or feedback on results, and no time pressure to succeed.
- (U) Assessed Impact: *Significant*. The absence of the factors in question precluded the ability of the test team to fully assess the CAS and FAC(A) capabilities of the F-35 in combat-representative situations.

(U) Truth Data Shortfalls in the Anti-Surface Warfare Trials

- (U) Limitation: The ships playing the role of the surface targets in the ASuW missions were part of formations of warships similar to the kinds of formations that would be encountered in combat ASuW missions. Each ship had radars onboard that could have affected, and probably did affect, the performance of F-35 electronic support measures systems used to try to find and fix the target ships. No truth data was made available by the U.S. Navy on the positions of target ship or the positions of any other ships in the formations, nor on the status of each of their radars during the trial. This precluded the ability of test team analysts to precisely and accurately compare what happened, as perceived by the F-35s, to what actually happened, and to fully diagnose the causes of observed performance problems.
- (b)(1) [redacted]

(U) Open-Air Defensive Counter-Air Cruise Missile Defense Trials Limited in Scope

- (b)(1) [redacted]

(b)(1) [redacted]

(b)(1) [redacted]

(U) Inability of the Red Surface Threats to Engage F-35 Air-to-Surface Weapons

- (b)(1) [redacted]

(U) Unrealistic Aerial Refueling Plan for the Combined Offensive Counter-Air and Air Interdiction Trials

- (b)(1) [redacted]

(b)(1) [redacted]

(U) Open-Air Test Limitations

(U) The open-air IOT&E trials were subject to many limitations for a wide variety of reasons. Some of the following are addressed in greater detail above in the discussions of threat representation.

(U) Surface Threat Signal Density

(b)(1) [redacted]

(U) Inability of Blue Support Aircraft to Conduct Electronic Attack on the Radar Signal Emulators

- (b)(1) [redacted]

environments and to LHA-class carriers,[13] and the F-35C to a nuclear-power aircraft carrier. The logistics footprint of a standard operational unit is evaluated for each variant deployed to its intended environment. Cold and hot weather operations are evaluated. The postures of responding to a short-notice tasking or urgent need for sustained airpower are incorporated in alert launch and surge operations evaluations. Maintenance demonstrations are included to assess the efficiency and clarity of technical orders and time required to complete maintenance tasks.

(U) The suitability design relies on the ORD for thresholds of acceptable performance determined by the Services for each variant. Taken together, requirement thresholds are useful to gauge the degree of difficulty experienced in the deploy – fly – regenerate cycle of sustained operations. The Services arrived at these thresholds by a requirements process aimed at developing and characterizing an air system and sustainment architecture that would provide new, unique, advanced military capability without sacrificing aircraft availability to combatant commanders. Hence the suitability test design is structured to answer the question of whether or not the system performs as desired in many specific measures including logistic footprint, mission and component failure rates, repair times, and the manpower required. Sustainment of low-observable capability, historically difficult in early legacy stealth aircraft is evaluated. The suitability of support equipment and the Autonomic Logistics Information System are evaluated as is the training system.

(U) The suitability test design included a test plan that required initial open-air radar cross-section measurements of operational test aircraft prior to the start of IOT&E, followed by subsequent measurements at the end of, or soon after, IOT&E. Details on this testing are in the suitability section of this report.

(U) LFT&E Design

(U) The LFT&E test strategy involved a coordinated government and contractor effort to support the survivability evaluation of the F-35 against kinetic threats, a subset of directed energy weapons, and chemical, biological, nuclear and radiological threats. LFT&E included a combination of component, sub-system, and system-level testing including one flight test aircraft, two complete airframe structural test articles, and four F135 engines. LFT&E was adequate to enable comparisons of F-35A/B/C vulnerabilities with other aircraft, identify major F-35 vulnerabilities and their effect on residual mission capability. LFT&E began in July 2002 and concluded in September 2022 and was conducted in accordance with the DOT&E-approved alternative LFT&E strategy and plans.

(U) Cyber Survivability Test Design

[redacted]

[13] (U) "LHA" represents USN Amphibious Assault Ship 'Tarawa' Class.

(b)(1)

[redacted]

(U) IOT&E Design – Operational Suitability

(U) The suitability evaluation is designed to assess the capability to send F-35 units to intended operational environments and sustain combat operations for a period of time. To use F-35s in combat, the Services deploy operational units that then generate missions with the intention to sustain operations to meet the tasking of theater commands. As sorties are generated and flown, system failures inevitably occur requiring maintenance to return aircraft to service and continue combat operations. Accordingly, the suitability evaluation is designed to examine deployability, sortie generation, reliability, and maintainability. The F-35 program terms this entire process "Autonomic Logistics," both a term and a quality in that the intent of the investment in the F-35 was to advance combat capability, in a low-observable aircraft, with high reliability that can be sustained in a semi-autonomous way.

(U) Data for the evaluation come primarily from the demonstrated performance of F-35 aircraft assigned to U.S. operational test squadrons.[12] These squadrons conducted deployments and generated sorties to support the operational performance evaluation. The development and testing of the F-35 were largely concurrent with aircraft production and fielding. As a result, where applicable, the evaluation compares the observed performance of the operational test aircraft during IOT&E with that of the daily operations of the U.S. Service fleets. Modeling is used to evaluate certain measures to create reasonable estimates of suitability performance.

(U) Because the Services primarily deploy to circumstances unique to their concepts of operations, the characteristics of an operationally suitable system are modeled differently for each F-35 variant. The suitability design accounts for this by including deployments of the F-35A to "forward-deployed" land-based environments, the F-35B to both austere, land-based

[12] (U) In limited cases, as noted in the report, some data from F-35 aircraft assigned to the foreign partner OT squadrons were used to support the suitability evaluation.

and tools. Weapons were employed from both internal and external carriage stations. The events were conducted at test ranges with special capabilities for this type of testing, including high-fidelity tracking and recording of shooter, weapon, and target, as well as the ability to score final impact/intercept results. The operational test aircraft, weapons and targets were instrumented to enable these activities. Data collected via this instrumentation was available for analysis and trouble shooting. The ranges used for WDEs include China Lake Ranges, Eglin Gulf Test and Training Range, Hardwood Air-to-Ground Weapons Range, PMSR, Utah Test and Training Range, White Sands Missile Range, and YTRC. Full-scale and sub-scale drones were used as aerial targets for the missile demonstration events. No supersonic sub-scale drones were available to support weapon tests, limiting the ability to assess weapon and F-35 capabilities against those target types.

(U) Anti-Surface Warfare Resources.

[redacted]

(U) Table 2-10. Operational Test Aircraft

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Aircraft Variant	Tail Number	Production Lot [a]	Test Unit	Service
F-35A	AF-31	5	31st Test and Evaluation Squadron (31 TES)	U.S. Air Force
	AF-32	5		
	AF-79	7		
	AF-80	7		
	AF-109	9		
	AF-112	9		
	AN-01	3	323 Test Squadron (323 TES)	Royal Netherlands Air Force
	AN-02	4		
F-35B	BF-15	3	Marine Operational Test and Evaluation Squadron 1 (VMX-1)	U.S. Marine Corps
	BF-16	3		
	BF-17	3		
	BF-18	3		
	BF-19	4		
	BF-20	4		
	BK-01	3	17 Squadron (17 AS)	Royal Air Force, United Kingdom
	BK-02	3		
	BK-04	7		
F-35C	CF-06	4	Air Test and Evaluation Squadron 9 (VX-9)	U.S. Navy
	CF-07	4		
	CF-08	4		
	CF-09	4		
	CF-10	5		
	CF-11	5		

a. All aircraft were modified from their original production lot configuration to the production lot 9 configuration prior to the start of testing.

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(U) Aerial Refueling

(U) The combined OCA and AI open-air range trials were focused on evaluating performance on-station in hostile territory and hence simulated the final 20-60 minutes of the ingress phase for F-35 missions. Aerial refueling was arranged for some open-air range effectiveness trials, enabling the simulation of the ingress portion of the mission to have occurred several hundred miles from the F-35 point of origin. In JSE, air refueling was assumed complete when the F-35 cockpits were initialized for each trial, with a standardized fuel reduction to account for transitioning from the refueling area to the mission area.

(U) Weapon Demonstration Event Resources

(U) Aircraft from the operational test squadrons, flown by unit pilots, were used in all WDEs. Weapons were loaded by operational unit personnel using field technical data, equipment flight, and do not account for the real-time inner workings of the sensor hardware and software that can cause actual system performance to vary.

- (U) FSM/VTI simulates perfect sensor tracking in terms of track accuracy, which is not representative of installed system performance, but because of the safety constraints limiting validation testing, no reference data exist in order to configure FSM/VTI to represent installed system performance.

(U) F-35 Operational Test Squadrons.

(U) The U.S. Services created operational test squadrons, each with six F-35 aircraft of one variant, to fly the open-air trials. These squadrons functioned much like operational combat units. Operational test squadrons from the United Kingdom, with three F-35B aircraft, and from the Netherlands, with two F-35A aircraft, also participated in open-air trials. All of these units operated from Edwards AFB, California for the open-air trials. All aircraft were modified to represent the production lot 9 configuration prior to the start of formal IOT&E in December 2018. The aircraft included instrumentation that recorded data from sensors, threat warning information, and weapons messages. This instrumentation was contained in a purpose-built pod created for flight test that was loaded on the airplane at an internal weapons carriage point in the weapons bay (see Figure 2-2 for the location of the approved loading station for the pod).[11] The data from this pod were used to support analyses of trial conduct. The operational test squadrons were also equipped with the same support equipment used by combat squadrons (e.g., the Autonomic Logistics Information System, mission planning, maintenance support equipment). The aircraft baseline radar cross-section was evaluated prior to the start of formal operational testing and assessed by maintenance teams routinely during the course of IOT&E. Additional details on assessing the radar cross-section over time is found in the suitability section of this report. Table 2-10 shows the aircraft used for open-air trials, by variant, production lot, unit assignment, and Service or foreign partner representation.

[11] (U) The Data Analysis, Recording, and Telemetry (DART) pod is an F-35 unique flight test instrumentation package that was used throughout IOT&E.

(U) Virtual Threat Insertion and Fusion Simulation Model

(U) The process of generating and displaying simulated warning indications to the pilot, employed in the open-air trials, is referred to as Virtual Threat Insertion (VTI) and is managed by the Fusion Simulation Model (FSM). The VTI component of this modeling combination receives simulated missile position and state information via the battle-shaping infrastructure, generated by the missile fly-out models running inside a test range computer, and provides this information to the FSM. The FSM uses this information to determine whether or not one of the sensors can detect the target; if so, it creates a synthetic mission system track on the target. The synthetic track is presented to the pilot on the applicable display(s), and can also be used by mission systems functions that trigger automatic threat responses.

(U) The insertion of virtual threats in to the FSM ensured that the F-35 pilots in the open-air trials retained some of the key survivability functionality designed into the aircraft. However, FSM/VTI suffers modeling simplifications and limitations that very probably resulted in simulated threat warning capabilities in the open-air trials that significantly exceeded what the aircraft would be capable of in combat, sometimes skewing the outcomes of engagements in favor of the F-35. However, the extent to which this was the case cannot be quantified, because flight safety restrictions preclude the kinds of testing against live missiles that would be required to meaningfully validate the FSM/VTI modeling. Key examples of FSM/VTI modeling simplifications and limitations include the following, paraphrased from a November 2018 test team accreditation assessment of FSM and VTI for IOT&E.[10]

- (U) FSM processes synthetic tracks regardless of real sensor operating status. For example, synthetic radars tracks will be generated by FSM even if the radar is in standby or in an emissions control setting that would not allow it to detect and track targets.
- (U) FSM processes synthetic tracks over the entire maximum field-of-regard for all sensors, all the time, even if the pilot has narrowed the field-of-regard in a way that would prevent real detections and tracks.
- (b)(1) [redacted]
- (U) Detection ranges in FSM are based on predetermined mean and standard deviation values for each missile threat and each F-35 sensor that might detect it. These are programmed into the Operational Mission Support (OMS) system before

[10] (U) See JSF Operational Test Team document "Preliminary Accreditation Assessment of F-35 Fusion Simulation Model and Virtual Threat Insertion for F-35 IOT&E" dated November 29, 2018.

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9 (U) Embedded Training is a module within F-35 mission systems that enables the F-35 and pilot to interact with external messages from virtual or live players.

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(U) Models Supporting Test Infrastructure

(U) Models Supporting Air-to-Air Threat and Friendly Aircraft Presentations in Open-Air Trials.

(U) In addition to modeling weapon fly-out models and probability of successful weapons employment, there were several other important modeling efforts involved in execution and measurement of open-air trials. Of necessity, some key aspects of air-to-air combat having to do with weapons employment had to be implemented with digital simulation across the open-air trials, in a similar way that they were done in the JSE, since having the Blue Force and Red Force shoot actual missiles at each other cannot be done. Air-to-air missiles were simulated with digital models running in the test range's OABS systems.[7] The unavoidable use of these necessary models imposed certain limitations and compromises on test execution that, if not mitigated, could have significantly impacted trial outcomes in ways that are difficult, if not impossible, to quantify. The main limitations and compromises involved the following sensors, which in actual combat would be used to detect, track, and identify threat missiles in flight, providing this information to F-35 sensor fusion for display to the pilot and to activate defensive countermeasures.

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[7] (U) Both the Nevada Test and Training Range and the Point Mugu Sea Range had infrastructure that enabled weapon threat models to be integrated with the F-35 and other blue and red threat aircraft to conduct missile-to-aircraft pairing and flyout. See the modeling and simulation section of test resources for more details on battle-shaping

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- (U) The OFP software version was OFP 30R02, which was the version that was used at the start of formal IOT&E, in the open-air trials. This limited the capabilities of the F-35 in JSE to the capabilities associated with OFP version 30R02. Because very little in the way of additional capabilities had been added to the F-35 OFP by the time the JSE trials were approved and executed, this was considered an acceptable limitation. Some corrections to deficiencies in that version of OFP for the aircraft were added to the software as the F-35 model used in JSE was updated during development.
- (U) JSE trials were not subject to actual aircraft availability or degraded conditions that were observed in open-air trials.
- (U) Wind effects were not yet represented in the JSE environment.
- (b)(1) [redacted]

6 (U) See F-35 Block 3F Joint Simulation Environment Systems Performance & Mission Effectiveness Modeling and Simulation Verification and Validation Report, September 7, 2023.

NM by 50 NM airspace, which were sufficient for the CAS and RECCE-related trials executed there.

(U) Joint Simulation Environment Overview

(U) The IOT&E test design required 64 trials in the JSE. JSE is an operator-in-the-loop, virtual combat simulation created and operated by the Services. In the JSE, F-35 pilots operate cockpits with the full suite of F-35 controls and displays, equipped with high-visual-fidelity, out-the-window dome displays, to realistically represent a pilot's full visual field-of-regard. Using these "domed" cockpits, pilots conduct missions in a virtual operational environment that include digital simulations of surface and air defenses, friendly supporting aircraft, the physical environment, and the interactions between them. Pilots also operate virtual adversary aircraft from similarly domed cockpits, albeit with generic controls and displays, employing simulations of threat aircraft and missiles to attempt to defeat F-35 aircraft. The JSE used the same battle-shaping methods as open-air ranges to manage and score trials conducted there. Blue forces in the JSE can be augmented with command-and-control airborne battle managers and electronic attack operators manning workstations with live-play displays.

(U) Unlike the open-air trials, where F-35 pilots were assigned to and maintained currency with one of the operational test units, the F-35 pilots in the JSE trials were a mixture of operational pilots and contractor pilots, all with operational F-35 experience. The red threat aircraft were flown by either current or former military aviators. Most of the F-35 and red air pilots had experience with the JSE, having flown proficiency spin-up and/or simulation verification runs prior to conducting the runs-for-score trials. Three mission areas were planned in the JSE: DCA, OCA, and AI. OCA and AI were combined into one mission execution, just like the open-air trials. In addition to missions against manned threat aircraft, DCA missions included defending against cruise missile attacks.

[redacted]

(U) Joint Simulation Environment Accreditation and Identified Trial Limitations

[redacted]

opposing force simulating an enemy air defense system. Live weapons were released from the aircraft only during a few CAS and SCAR open-air trials, when permitted by range operations (i.e., safety and airspace restrictions did not prevent weapon releases). For the primary mission scenarios (i.e., OCA, AI and DCA), weapon engagements were simulated using instrumentation onboard the aircraft connected to a network of range systems. Flight paths of the weapons from shooter to target were simulated using models created and validated for this purpose within these networked range systems. Other models integrated into this network determined if the complete engagement was successful, and provided a "kill removal" indication to test control personnel. This process allowed the test control team to shape the progress of the battle in real time to provide outcomes representative of what would likely have occurred in combat with actual weapons.

- **Nevada Test and Training Range**. The Nevada Test and Training Range (NTTR) is operated by the U.S. Air Force and is located north of Las Vegas, Nevada. This battlespace, used for many F-35 open-air mission trials, is entirely over land, spanning 120 NM by 50 NM laterally, and from the surface to above 30,000 feet. Crewed and uncrewed threat simulators were emplaced throughout much of the range, including systems emulating both legacy and modern threat capabilities. Instrumentation integral to the range was used to observe these primary mission trials in real time. The instrumentation provided the ability to shape the battle in real time by incorporating weapons fly-out and probability of success models wherein aircraft or threats losing an engagement were kill-removed. Data recorded by the range was used to assess mission outcomes and understand F-35 performance.
- **China Lake Range**. The U.S. Navy operates the China Lake Range. It was used for additional missions, including CAS, FAC(A), CSAR, SCAR, and RECCE, in the F-35 IOT&E. This range provided weapons impact areas that were useful for the missions flown with full-scale inert and other munitions. Only a limited number of ground threat emulation were available for operational test scenarios, all of which were legacy systems without modern threat characteristics. The airspace around the target and threat emplacements is sufficient for small scenarios such as those needed for the additional missions.
- **Point Mugu Sea Range**. The PMSR is also operated by the U.S. Navy and is located off the Pacific coast of central California. This battlespace, used for some larger F-35 open-air mission trials is a maritime environment spanning laterally 200 NM by 220 NM, and vertically from the surface to above 30,000 feet. Crewed and uncrewed systems emulating modern threats were deployed among sites on the Channel Islands as well as on the shoreline of Point Mugu Naval Air Station and Vandenburg AFB. The same battle-shaping instrumentation used at NTTR was used at PMSR.
- **Yuma Training Range Complex**. The Yuma Training Range Complex (YTRC) is an over-land range operated by the U.S. Marine Corps in Arizona. The Service conducts training exercises there for air and combined forces. The range includes limited surface-to-air threat replications and weapons impact areas adjoined to a 100

(U) Pilot-Vehicle Interface and Human Factors Survey Plan

(U) Following open-air and JSE trials, pilots completed surveys to measure pilot-vehicle interface usability and for workload. Pilot-vehicle interface usability was collected using the Usability Metric for User Experience Lite scale and then converted via linear transformation to the System Usability Scale for ease of interpretation. System Usability Scale scores below 50 indicated unacceptable usability, at-or-above 50 but below 70 indicated marginally acceptable usability, and at-or-above 70 indicated acceptable usability.

(U) Pilots reported their average and peak mission workloads using the Air Force Flight Test Center Revised Workload Estimate Scale. Optimal workload levels occur at the midpoint of the scale (4; busy). Both extreme low (1; nothing to do) and high (7; overloaded) scores are associated with degraded performance and safety risk.

(U) After JSE trials, pilots additionally completed items concerning key effectiveness enablers: perceived situational awareness, lethality, survivability, and interoperability. Pilots were asked one to three questions about each effectiveness enabler and responded along a Likert scale ranging from 1 (completely unacceptable) to 6 (completely acceptable). The survey questions are shown in Table 2-9. The survey results are in Section 3.

(U) Table 2-9. Post-Mission F-35 Pilot Survey Questions

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Question Group	Question
Situational Awareness	• What is your assessment of the F-35's ability to maintain SA of F-35 flight members (within a single MADL group)? • For DCA TEM lines 6, 7, and 10 only. What is your assessment of the F-35's ability to maintain SA of other (non-F-35) blue air entities? • What is your assessment of the F-35's ability to maintain SA of red air and ground entities?
Lethality	• What is your assessment of Combat ID (CID) in support of mission objectives? • What is your assessment of the ability to sort targets in support of mission objectives?
Survivability	• What is your assessment of the TSD threat track lines/audio cues/DAS missile warnings/TWD accuracy, and their contribution to aircraft survivability? • Were you kill-removed?
Interoperability	• What is your assessment of the F-35's Link-16 interoperability on mission execution?
Acronyms: SA – situational awareness; MADL – Multi-ship Advanced Data Link; TEM – Test Evaluation Matrix; TSD – Tactical Situation Display; DAS – Distributed Aperture System; TWD – Threat Warning Display	

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(U) Test Resources for Effectiveness Trials

(U) Open-Air Ranges Overview

(U) Open-air ranges maintained by the Services were the venues for the IOT&E effectiveness trials. The ranges provide airspace set aside for military purposes, as well as restricted-use surface areas on which targets are placed and surface-based threats are operated by trained range personnel. This provided the opportunity to operate an F-35 force against an

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[redacted]

(U) GAU-22/A 25mm Cannon.

(U) The GAU-22/A 25mm cannon (hereafter the "gun") is integrated into the F-35 in two forms. The F-35A gun is internally mounted and includes a firing port on the left side of the airplane. A podded version of the GAU-22/A is available for the F-35B and F-35C, which is externally carried on the centerline station of these aircraft. Differences in the outer mold-line fairing mount make the gun pods unique to each variant (i.e., an F-35B gun pod cannot be mounted on an F-35C aircraft). F-35 gun employment capability is designed for air-to-surface targets and air-to-air engagements. Gun integration involves physical integration of the gun hardware to the aircraft to ensure safe and effective gun operations, as well as software-driven pilot interfaces to aim the gun and determine when the shooter is within range, given the engagement geometry.

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[redacted]

(b)(1) [redacted]

(U) AIM-120 Advanced Medium-Range Air-to-Air Missile

(b)(1) [redacted]

(U) AIM-9X Short-Range Air-to-Air Missile

(b)(1) [redacted]

(b)(1) [redacted]

(U) GBU-12 Paveway II Bomb

(b)(1) [redacted]

(U) GBU-31 Joint Direct Attack Munition

(b)(1) [redacted]

(U) GBU-32 Joint Direct Attack Munition

(b)(1) [redacted]

(U) GBU-49 Enhanced Paveway II Block 5

(b)(1) [redacted]

(b)(1) [redacted]

(U) The following list of weapons, with brief description and key factors involved in the design, constituted the WDE components of effectiveness testing.

(U) AGM-154C Joint Standoff Weapon (F-35C only)

(b)(1) [redacted]

(U) GBU-39 Small Diameter Bomb I (F-35A only)

(b)(1) [redacted]

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Station	1	2	3	4*	5	6	7	8	9	10	11
F-35A	AIM-9X	GBU-12 GBU-49	GBU-12 GBU-49	GBU-12 GBU-31 GBU-39/B (4) GBU-49 AIM-120	AIM-120		AIM-120	GBU-12 GBU-31 GBU-39/B (4) GBU-49 AIM-120	GBU-12 GBU-49	GBU-12 GBU-49	AIM-9X
F-35B	AIM-9X	GBU-12 GBU-49	GBU-12 GBU-49	GBU-12 GBU-32 GBU-49 AIM-120	AIM-120	Gun Pod	AIM-120	GBU-12 GBU-32 GBU-49 AIM-120	GBU-12 GBU-49	GBU-12 GBU-49	AIM-9X
F-35C	AIM-9X	GBU-12 GBU-49	GBU-12 GBU-49	GBU-12 GBU-31 GBU-32 GBU-49 AGM-154 AIM-120	AIM-120	Gun Pod	AIM-120	GBU-12 GBU-31 GBU-32 GBU-49 AGM-154 AIM-120	GBU-12 GBU-49	GBU-12 GBU-49	AIM-9X

*All OT aircraft were cleared to carry the Data Analysis, Recording, and Telemetry pod on station 4.

Weapons carried on stations 1, 2, 3, 6, 9, 10, and 11 are external, and negatively affect radar cross-section.
Weapons loaded in stations 4, 5, 7, and 8 are internal and only affect radar cross-section when doors are open for release.

Color	Weapon Type	Color	Weapon Type
Orange	AMRAAM (radar-guided missile)	Gold	Direct attack, shorter range bomb
Blue	Shorter range, air-to-air infrared missile	Green	Standoff, longer-range bomb

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(U) Figure 2-2. Authorized Weapons Loading by Variant

(U) Figure 2-2 below shows where specific weapons are authorized for carriage on each F-35 variant. The program maintains Stores Configuration Lists for each variant that control weapons loads and provide carriage and employment envelopes for pilots. During IOT&E, the majority of authorized configurations consisted of AIM-120 air-to-air missiles and one type of air-to-surface weapon, all loaded internally. Due to the flexibility it provides in certain dynamic combat situations, such as CAS, the Services would like the ability to employ mixed loads of multiple types of air-to-surface weapons. However, the initial set of weapons clearances for IOT&E included only symmetric loads of the same type of weapon. Enabling mixed weapons and asymmetric configurations required additional flight testing that was not in the scope of the Block 3F development contract. Thus, IOT&E WDEs focused on, and were limited to, weapon loads that were not mixed.

(U) Table 2-8. Weapon Demonstration Events Design Factors for Air-to-Surface and Air-to-Air Guns

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Design Factor	Factor Levels	
	Air-to-Surface Gun	Air-to-Air Gun
Cueing and aiming	Unaided, sensor-to-HMD	
Geometry		Lateral or vertical fight
Dive angle	Shallow (10 degrees) to high (35 degrees)	
Slant range	Maximum range cue to minimum safe range	Long- to short-range, aspect constant
Aspect		High to low, angle from target tail
Speed	Medium to high	Fighter and target, high to low
Type of track	Short to longer shots	Short "snapshot" to longer tracking shot
Time of day	Day, night	

Acronyms: EOTS: Electro-Optical Targeting System; ESM – electronic support measures; GPS – Global Positioning System; HMD – Helmet Mounted Display; OMS – Offboard Mission Systems; SAR – synthetic aperture radar

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(U) The WDE component of the IOT&E was essential to the evaluation of operational effectiveness because the preponderance of open-air mission trials were conducted on ranges where actual full-scale weapons deliveries on targets were not authorized. Therefore, the open-air trials simulated weapons deliveries using models of the weapons engaging targets in a virtual environment.[4] These models were capable of representing weapon performance (i.e. trajectory, time of flight, impact angle) previously determined in live testing from release to impact, but incapable of directly assessing aircraft-to-weapon integration due to inherent modeling limitations. For example, initialization and status monitoring of weapons by the pilot and the aircraft do not occur in simulated weapons use, nor is the aircraft performance affected by the difference in weight due to having weapons onboard. The WDEs component of IOT&E design addressed these gaps. The test team also conducted deliveries of full-scale inert weapons on a small number of open-air mission trials (CAS, SCAR) and during deployments supporting the sortie demonstration portions of the suitability evaluation. These weapon deliveries were conducted at ranges with ground impact zones designated for this purpose, which enabled scoring of weapon delivery accuracy. In addition to the WDEs, these activities realistically stressed the integration of these weapons and improved overall confidence in the analysis of weapons bay environment, weapons bay door functions, weapons carriage interfaces, and the Stores Management System.

4 (U) Open-air trials used AARI as the virtual environment for determining weapons effects in all of the primary missions of OCA, DCA, SEAD/DEAD and AI.

constraints imposed by the certified employment envelopes. Additionally, certain events called for multiple weapons releases in a single attack which is operationally realistic and a necessary stress on the system, particularly considering internally carried weapons and weapons bay enclosure mechanization. These events were completed as integrated test events. As the WDEs progressed, the remaining planned events were reviewed and updated to collect data missing from previous WDEs, account for updates in mission systems capabilities, or verify corrections of deficiencies discovered during previous developmental or operational testing. In some cases, test objectives from multiple planned WDEs were combined in the execution of a single event. The resulting series of WDEs account for the assessment described in this report.

(U) Table 2-7. Weapon Demonstration Events – Design Factors for Air-to-Surface Bombs and Air-to-Air Missiles

(b)(1) [redacted]

Mission	Measure	Definition
RECCE	Timeliness of delivering Intelligence	Amount of time from removal of data brick from aircraft post sortie to receipt of collected intelligence by qualified imagery analysts.
	Sensor Quality Image	National Image Interpretability Rating Scale Rating.
ASuW	F-35 Vessel Find Time	Time from E2-D point out to F-35 to finding red vessel formation.
Acronyms: ASuW – anti-surface warfare; CAS – close air support; CSAR – combat search and rescue; FAC(A) - forward air controller (airborne); RECCE – reconnaissance; SCAR/AR - strike coordination and reconnaissance/armed reconnaissance		

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(U) A-10 Comparison Testing

(U) Early in the design process IOT&E plan required the comparison testing in the combined OCA and AI mission and in CAS, FAC(A) and CSAR missions. The combined OCA and AI mission comparison would entail conducting open-air trials in matched pairs using legacy, 4th-generation aircraft and comparing results with the F-35. Although the initial IOT&E design included a full comparison of 18 trials between the F-35 – conducting both mission roles – with F-16s in the OCA role and F/A-18s in the AI role, the final IOT&E plan required two trial demonstrations. These demonstrations were completed and did not result in a reasonable set of data for comparison with the F-35. Comparison tests in CAS, FAC(A), and CSAR trials were conducted with A-10 aircraft. The comparative performance assessments between the F-35A and the A-10 are included in a separate report provided by DOT&E in February 2022. Only F-35 results in these missions are included in this report.

(U) Weapon Demonstration Event Design

(U) Similar to the mission areas, WDEs were designed to span the employment envelope of each weapon (release conditions, engagement modes, etc.) and vary the operational conditions that supported the engage and assess steps in the kill chain. F-35 operational test aircraft completed steps in the kill chain and delivered weapons on targets and, when applicable, used onboard sensors to conduct battle damage assessments. This enabled an evaluation of the end-to-end sequence of actions from weapon loading to target impact on a ground target or intercept of an airborne target. The evaluation strategy integrated operational test events in series with developmental test events to obtain a more complete characterization of system performance and efficient use of resources. The developmental test events were designed to assess the integration of the weapon with the F-35 mission systems and the operational test events to assess overall employment performance in the most current tactical delivery profiles. The test team shaped scenarios for these discrete WDEs to provide a spectrum of challenges to the F-35 system by varying the difficulty of the intercept geometry, target type, jamming environment and countermeasures. The team also varied the manner in which the target was identified and aimpoint data assigned to weapon.

(U) Table 2-7 and Table 2-8 show the general battlespace factors featured in WDE designs. WDEs were conducted within the certified weapons release envelopes that resulted from developmental testing. Certain events were designed at maximum levels of specific release parameters for either the F-35 or the weapon; however, no events were designed outside of the

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[redacted]

(U) Table 3-7. Summary of Mission-Level Open-Air OCA/AI Success

(b)(1) [redacted]

(U) Table 3-8. Blue Force and Red Force Loss Comparison – Open-Air Trials

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(b)(1) [redacted]

(U) JSE Trial Execution

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(U) JSE Red Surface-to-Air Missiles

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(U) Table 3-9. OCA and AI JSE Trials: Blue vs. Red Forces

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(U) JSE AI Targets

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(U) There were three levels of target location confidence, defined by the amount of target location error associated with the ground reference point provided to the pilots in the pre-flight briefing, to direct them to the general location of the AI target area. For confidence level 1, the reference point had zero error. For confidence level 2, the error could be up to 300 feet, and for level 3 it was greater than 300 feet. The types of targets for each JSE AI mission, and the levels applicable to the mission for each for the test design factors, are summarized in Table 3-10 below.

(U) Table 3-10. AI Targets and Test Design Factors – JSE

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(U) The aircraft storage area in Figure 3-4 falls in the high-clutter category because of the irregular, non-geometric pattern of the desired points of impact, and the fact that these points have indistinct edges that blend in, to some extent, with the background. The complex of adjacent buildings in Figure 3-5 is in the high-clutter category because of the large number of distinct desired points of impact, on a set of structures that had the possibility of blending together in imagery.

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(U) Figure 3-2. Example of a Low-Clutter Building Target in JSE

(b)(1) [redacted]

(U) Figure 3-3. Example of a Low-Clutter Bridge Target in JSE

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(b)(1) [redacted]

(U) Figure 3-4. Example of a High-Clutter Area Target in JSE

(b)(1) [redacted]

(U) Figure 3-5. Example of a High-Clutter Building Target in JSE

(b)(1) [redacted]

(U) JSE Trial Results

(b)(1) [redacted]

(U) OCA/AI Combined JSE Trials Results

(b)(1) [redacted]

(U) Table 3-11. Summary of Mission-Level JSE OCA/AI Success

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(b)(1)

[redacted]

(U) Table 3-12. Blue Force and Red Force Loss Comparison – JSE Trials

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(U) Sweep/Escort Role Specifics

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[redacted]

(b)(1) [redacted]

(U) Table 3-13. The Relative Impacts of Level 1 and Level 3 Noise Jamming

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(U) DEAD Role Specifics

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(b)(1) [redacted]

(U) Forensics of DEAD Mission Failure

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[redacted]

(b)(1) [redacted]

(U) DEAD Targeting Performance

(b)(1) [redacted]

(U) Table 3-14. F-35 Targeting of Key SAM Site Vehicles

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(b)(1) [redacted]

(U) Table 3-15. F-35 Weapon Employment: Priority vs. Non-Priority SAM Site Vehicles

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(U) Explaining DEAD Results

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(U) Figure 3-6. Ownship (Magenta) and Wingman (Blue) AEL Ellipses

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(U) Figure 3-15. SAM Site Vehicle Composition and Laydown

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(U) Air Interdiction Specifics

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(U) Table 3-16. AI Results in the Context of OCA Results

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(U) This mission scenario was only accomplished in open-air trials, no JSE equivalent took place in IOT&E.

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(U) Offensive Counter-Air: DEAD Only Execution and Results

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(U) Defensive Counter-Air against Manned Aircraft

(U) This portion of the report discusses test trial execution and results for open-air testing and JSE. Comparison of the results and overall assessment of the DCA mission against manned aircraft complete this portion.

(U) Open-Air Trial Execution

(U) The test plan called for sixteen DCA trials conducted on the open-air ranges at Nevada Test and Training Range (over land) and Point Mugu Sea Range (over water). The test team completed twelve trials, of which eight were determined to be valid and four invalid due to lack of sufficient numbers of F-35 aircraft. DOT&E agreed with a test team request to delete the four remaining planned trials, not re-fly the four invalid trials, and add three new trials – one per variant – consisting of two F-35s operating with four 4th generation technology blue aircraft in trials that included greater numbers of red aircraft. Two of the three added trials were deemed valid when completed, the third was invalid due to lack of sufficient numbers of 4th generation technology blue aircraft. DOT&E did not insist on re-attempting this third trial. This resulted in a total of ten valid trials for the evaluation. In total, fifteen DCA trials were completed, five of which were invalid due to lack of resources (four trials due to lack of sufficient number of F-35s, one due to lack of sufficient number of supplemental blue 4th generation aircraft). All F-35 variants participated in DCA trials.

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(U) Table 3-17. Open-Air DCA Trials Completed: Blue vs. Red Forces with Test Design Factors

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Date (Trial ID)	Blue Force	Weapons	Environment	Time of Day	Test Range	Red Threat Force (regens)[a]
13-Dec-18 (8)	4 x F-35B	Internal	Land	Day	NTTR	6 x F-16
21-Feb-19 (9)	2 x F-35C 3 x F/A-18	Internal	Land	Day	NTTR	10(5) x F/A-18
22-Feb-19 (13)	2 x F-35A 4 x F-15	Internal	Water	Night	PMSR	8(2) x F/A-18
25-Feb-19 (4)	4 x F-35A	Internal	Land	Night	NTTR	2 x F-16 6(1) x F/A-18
26-Feb-19 (16)	4 x F/A-18 2 x F-35C	Internal	Water	Night	PMSR	9(3) x F/A-18 2 x EA-18
27-Feb-19 (11)	4 x F-35C	External	Water	Night	PMSR	11(5) x F/A-18
1-Mar-19 (10)	4 x F-35B	External	Water	Day	PMSR	6 x F/A-18
1-Mar-19 (12)	4 x F-35C	Internal	Water	Day	PMSR	7(2) x F/A-18
13-May-19 (17)	4 x F/A-18 2 x F-35A	Internal	Water	Day	PMSR	4 x F-35 6 x F/A-18 3 x EA-18
14-May-19 (19)	2 x F-35C 4 x F/A-18	External	Land	Day	NTTR	4 x F-16 6 x F/A-18

a. The numbers in parentheses represent the times red force aircraft were regenerated after being kill removed. These regenerated aircraft enabled the full red threat force presentation over the course of the trial, since the full complement of red forces were not available.

Acronyms: ID – Identification; NTTR – Nevada Test and Training Range; PMSR – Point Mugu Sea Range

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(U) The attacking red forces were all emulated by manned aircraft representing manned enemy strike and escort platforms. No cruise missiles were used or simulated in these DCA open-air trials. Although the test plan called for varying the adversary threat across three categorical levels, differentiated by capabilities and numbers, execution of the trials did not comply with this requirement. All trials were designed to present at least six adversary aircraft, however, in two trials less than this number were available at trial start. When the trials were conducted with less than the number of adversary aircraft required by the plan, the test teams permitted red aircraft to be regenerated when the red force experienced the loss of an aircraft. The number of regenerated aircraft in each trial are represented by the number in parenthesis in

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the right column of Table 3-17. The highest threat level included the use of 5^{th} generation capabilities for four of the six threat aircraft; however, in only one trial was a 5^{th} generation adversary aircraft used. This limitation effectively restricted the ability to evaluate F-35 Defensive Counter-Air effectiveness to 4^{th} generation adversaries in the open-air trials. The effect of reducing the number of valid trials needed to complete the DCA evaluation from 16 to 10 caused this gap, and was caused by the lack of adequate 5^{th} generation surrogates for the red air threat.

(U) Open-Air Trial Results

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(U) Table 3-18. Mission-Level Measures: DCA Open-Air Trials

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(U) Table 3-19. Force-Level Measures: DCA Open-Air Trials

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(U) Figure 3-18. Red Aircraft Encroachment Range at Death in DCA Open-Air Trials

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(U) JSE Trial Execution

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(U) Table 3-20. JSE DCA Trials Completed: Blue vs. Red forces with Test Design Factors

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(U) JSE Trial Results

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(U) Table 3-21. Mission-Level Measures: DCA JSE Trials

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(U) Figure 3-19. Red Aircraft Encroachment Range at Death in DCA Mission-JSE

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(U) Table 3-22. Force-Level Measures: DCA JSE Trials

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(U) Understanding JSE DCA Results

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(U) Figure 3-20. Initial Engagement Set-Up

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(U) Figure 3-21. Shocker 14 Display at Engagement Set-Up

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(U) Figure 3-22. Shocker 14 Display at AIM-120D Launch

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(U) Figure 3-23. Tiger 34 Track Displays Presence of Noise Jamming

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(U) Figure 3-24. Shocker 14 and Tiger 34 in Dueling Missile Exchange

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(U) Figure 3-26. Shocker 14 Designates Lion 12 as Next-to-Shoot

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(U) Figure 3-27. Shocker 14 Shoots Lion 12 When Track Quality Improves

(U) DCA Against Manned Aircraft: Overall Assessment

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(U) Defensive Counter-Air against Cruise Missiles

(U) This portion of the report discusses test trial execution and results for defending against cruise missiles in open-air and in JSE. Comparison of the results and overall assessment of the DCA mission against cruise missiles complete this portion.

(U) Open-Air Trial Execution and Results

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(U) JSF Trial Execution and Results

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[4] (U) In the context of testing against cruise missiles, an "intercept" represents a maneuver against a cruise missile after a detection has been made with the intent of achieving weapons launch parameters in order to destroy the cruise missile.

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(U) Table 3-23. JSE Cruise Missile Defense Trials Completed

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(U) Table 3-24. Results from JSE Cruise Missile Defense Trials

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(U) DCA against Cruise Missiles: Overall Assessment

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[redacted]

(U) Assessment in the Advancing Threat Environment

(U) Current Threats

(U) The operational effectiveness results and the associated strengths and shortcomings demonstrated by the F-35 across all mission areas in IOT&E were driven by the challenges the aircraft had to confront in each of the test trials. The degree of difficulty presented by these challenges was, in turn, driven more than any other factor by the system-level capabilities, the tactics, and the overall numbers of the threats the aircraft faced, as represented and replicated both in the open-air trials and in the JSE trials.

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(U) Emerging Threats out to 2030

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(U) Additional Missions

(U) Overall Execution

(U) The test team generated 107 sorties totaling 221 flight hours conducting the open-air test trials for the additional missions of close air support (CAS), forward air controller (airborne) (FAC(A)), combat search and rescue (CSAR), strike coordination and reconnaissance (SCAR), reconnaissance, and anti-surface warfare (ASuW).[5] Table 3-25 shows the dates, locations, aircraft software version used, and sorties by variant for trials for each mission. The aircraft launched from Edwards Air Force Base, California and Nellis Air Force Base, Nevada, and the trials were conducted at Naval Air Weapons Station China Lake, California; at Yuma Proving Ground, Arizona; around San Diego, California; off the Southern California coast; and off the northern Florida coast. None of the additional mission trials occurred in the JSE.

[5] (U) An aircraft sortie represents one flight from takeoff to landing of one aircraft. A test trial refers to the conduct of a test event required in the test plan. On a few occasions, aircraft were able to complete multiple CAS and FAC(A) trials in a single sortie, by means of aerial refueling.

(U) Table 3-25. Additional Mission Trial Dates, Ranges and Sorties

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Mission	Dates	Locations	Aircraft OFP	Sorties			
				F-35A	F-35B	F-35C	Total
CAS	March 30 to July 18, 2018	Yuma, China Lake	30R00	14	8	8	30
FAC(A)	April 2 to July 18, 2018; March 26-28, 2019	Yuma, China Lake	30R00 and 30R02.04	12	0	0	12
CSAR	April 3 to July 11, 2018; March 25-27, 2019	Yuma, China Lake	30R00 and 30R02.04	18	6	4	28
SCAR	April 9 to May 31, 2018	Yuma, China Lake	30R00	3	5	4	12
Reconnaissance	May 4 to July 10, 2018	San Diego, China Lake	30R00	2	2	0	4
ASuW	August 27-28, 2018; July 8-19, 2019; September 4, 2019	Southern California and Northern Florida coasts	30R00 and 30R02.04	2	8	14	24

Acronyms: ASuW – anti-surface warfare; CAS – close air support; CSAR – combat search and rescue; FAC(A) – forward air controller (airborne); OFP – operational flight program; SCAR – strike coordination and armed reconnaissance

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(U) Table 3-26 compares the planned versus the completed trials for these missions. Although included in the test plan, no F-35B FAC(A) trials were conducted due to no F-35B pilots being qualified in that mission area at the time of testing. The test team constructed two categories of threat environments for the additional missions (aside from ASuW): a low-threat "permissive" and a medium-threat "contested" environment. The permissive threat environment included man-portable air defense systems, anti-aircraft artillery, or both. The contested threat environment added a limited number of short- and medium-range, radar-guided SAM systems. SAM launch simulators ("smoky SAMs") were used when available to enhance the threat representation by providing visual launch indications to pilots operating in target areas. In order to permit scorable and consistent trial execution, the threat force in both threat environments consisted only of surface threats; no threat aircraft were present. Surface threat systems were controlled by threat operators under the overall control of a Red Force commander. The FAC(A) and CSAR trials occurred in only the contested environment. Reconnaissance trials occurred only in the permissive environment. CAS and SCAR The reconnaissance related missions were conducted only in permissive threat environments. CAS and SCAR trials occurred in both. These additional missions did not include higher-threat scenarios with modern SAMs and air threats, since the F-35 capabilities to conduct missions with these higher-level threats were assessed in the primary mission areas.

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(U) Table 3-26. Additional Mission Test Trials Planned and Completed

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Mission	F-35A		F-35B		F-35C	
	Planned	Completed	Planned	Completed	Planned	Completed
CAS	5	8	5	5	2	2
FAC(A)	2	8	2	0	0	0
CSAR	2	2	2	2	2	2
SCAR	2	2	3	2	3	2
Reconnaissance	N/A	1	N/A	2	N/A	0
ASuW	0	1	0	2	2	4

1. Additional F-35A test missions flown exclusively to support the F-35A to A-10C comparison testing are included here and data contributed to the assessments in this report.
2. CAS and SCAR missions were not all flown variant specific, as directed by the test plan.
3. Variant was not a factor for RECCE data collections.

Acronyms: ASuW – anti-surface warfare; CAS – close air support; CSAR – combat search and rescue; FAC(A) – forward air controller (airborne); RECCE – reconnaissance; SCARR – strike coordination and armed reconnaissance

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(U) Most CAS, FAC(A), or CSAR trials did not include a realistic representation of either opposing or friendly ground forces. The participation of ground forces was either judged impractical by the test team or outright prohibited by range safety rules when employment of inert weapons was planned. Some trials that were conducted as part of a Marine Weapons and Tactics Instructors Course exercise included friendly and opposing ground forces. In the other cases, the joint terminal attack controller (JTAC) drove the trial using a script with targets derived from existing structures and vehicles on the range that the test team selected to simulate enemy components. Range personnel operated moving targets along precisely defined, planned routes. While this arrangement availed the test team of near complete control of the test conditions, it eschewed the complexity introduced by supporting friendly ground forces in proximity with enemy ground forces, i.e., from avoiding friendly fire or participating in a combined fires plan.

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Station	1	2	3	4	5	6	7	8	9	10	11
Permissive Environment											
F-35A	AIM-9X	GBU-49	GBU-49	GBU-12 or GBU-31	AIM-120		AIM-120	GBU-12 or GBU-31	GBU-49	GBU-49	AIM-9X
F-35B	AIM-9X	GBU-49	GBU-49	GBU-12 or GBU-31	AIM-120	Gun Pod	AIM-120	GBU-12 or GBU-31	GBU-49	GBU-49	AIM-9X
F-35C	AIM-9X	GBU-49	GBU-49	GBU-12 or GBU-31	AIM-120	Gun Pod	AIM-120	GBU-12 or GBU-31	GBU-49	GBU-49	AIM-9X
Contested Environment											
F-35A F-35C				GBU-12 or GBU-31 or GBU-49	AIM-120		AIM-120	GBU-12 or GBU-31 or GBU-49			
F-35B				GBU-12 or GBU-31 or GBU-49	AIM-120		AIM-120	GBU-12 or GBU-31 or GBU-49			

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(U) Figure 3-31. Typical Simulated Loadout for Additional Missions

(U) Overall Results

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[6] (U) The notation [*lower bound*, *upper bound*] indicates an 80 percent confidence interval.

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Figure 3-32. CAS Median Targeting and Engagement Times

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(U) Forward Air Controller (Airborne) Execution and Results

(U) FAC(A) pilots completed 39 9-line briefs over the course of eight trials, compared to 18 briefs over eight trials in the test plan. Only the F-35A variant participated in the FAC(A) test trials. While the U.S. Marine Corps F-35B operational concept includes the FAC(A) mission, the service did not train and qualify F-35B pilots in the mission to support the test. This resulted in two planned trials not being executed by the test team. The U.S. Navy does not have a FAC(A) mission for the F-35C.

(U) The FAC(A) trials were flown over the China Lake range. The scenarios directed the two-ship of FAC(A) aircraft to coordinate with the JTAC to conduct area control of CAS aircraft over permissive and contested threat environments. The CAS aircraft included F/A-18, F-16, F-35A, and rotary wing aircraft. The FAC(A) aircraft had to accomplish several tasks: deconflict multiple CAS aircraft as they arrived and departed the target area, locate and suppress or destroy ground threats, correlate targets with the CAS aircraft, designate targets as necessary, and provide battle damage assessment after the attacks. The FAC(A) targets were similar to those used in the CAS scenarios.

(U) The effectiveness of the F-35 in the FAC(A) mission depends more on its ability coordinate CAS mission than execute elements of the kill chain. The test team defined two measures to assess the coordination capability. Brief generation time is the time elapsed from when the FAC(A) receives the target from the JTAC and ends at the start of the 9-line brief from the FAC(A) to the CAS aircraft. Correlation time is the time elapsed from the initiation of the 9-line brief until the CAS pilot has correlated the target with the FAC(A) pilot.

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(U) Figure 3-33. FAC(A) Correlation Time by Coordination Method

(U) Combat Search and Rescue Execution and Results

(U) F-35 pilots completed six CSAR trials – one day trial and one night trial per variant – per the test plan. The F-35A and F-35B pilots conducted the missions as four-ship formations that operated primarily as separate two-ship elements to simultaneously locate the survivor and escort the recovery aircraft. The F-35C pilots conducted the missions as a two-ship formation with a two-ship of F/A-18s providing escort of the recovery aircraft. The six CSAR test trials were flown over the China Lake range in a contested threat environment.

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(U) Strike Coordination and Reconnaissance (SCAR) Test Execution and Results

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(U) Figure 3-34. SCAR Catalog and Coordination Times

(U) The F-35 does not have a mechanism suited for the cataloging of targets, which contributed to high pilot workload. Pilots can create a designated point of interest on a target or add a navigation marker on a target. Designated points of interest can then be added to the air-to-surface shootlist. None of these mechanisms provide a single, comprehensive list of all targets with editable pilot annotations. As a result, pilot frequently resorted to maintaining a handwritten catalog on their kneeboards.

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(U) Reconnaissance Execution and Results

(U) Per the test plan, F-35 pilots conducted three reconnaissance trials. The concept of operations for the reconnaissance mission was undeveloped at the time of execution. The pilots were tasked to image planned, fixed areas or points of interest in littoral and desert environments using the EOTS or the SAR mode of the radar. After each trial, test team analysts extracted still images from recordings of the cockpit displays retrieved from the aircraft portable memory device (PMD). Qualified imagery analysts from the National Air and Space Intelligence Center scored the extracted still images using the standardized National Imagery Interpretability Rating Scale (NIIRS). ELINT collection, i.e., the collection of threat radar signals, was not a part of the reconnaissance trials. The evaluation of that capability is based on the employment of the electronic warfare system in other IOT&E sorties.

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(U) Figure 3-35. Average NIIRS Ratings for EOTS Imagery by Field-of-View and SAR Imagery by Magnification

(U) The collected images do not support a rigorous evaluation of the effect of the EOTS digital magnification. The narrow field-of-view also three digital magnifications (2x, 3x, and 4x) that pilots can employ. The use of the magnified views was not a part of the test design nor controlled during the test, and pilots recorded only a few images at higher magnification, which happened to be at close ranges. The limited data preclude estimating the NIIRS rating of that imagery as a function of slant range. In the limited cases that pilots did collect such imagery they also collected a unmagnified image of the same scene. Direct comparison of those images indicated that the digital magnification did not significantly improve the interpretability in those few cases.

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(U) Anti-Surface Warfare Execution and Results

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(U) Weapon Demonstration Events

(U) The test teams completed a total of 182 weapon deliveries and 128 gun attacks. Table 3-27 shows the number of events and weapons, planned and completed, during IOT&E, along with the F-35 variant used. Weapons were either employed in discrete, controlled scenarios with instrumented aircraft per a specific scenario described in the test plan (these events are formally referred to as weapon demonstration events, or WDEs, in this report, and represented by the "events" columns in Table 3-27) or in additional open-air events at ranges accommodating actual weapons employment. Both air-to-surface and air-to-air weapons were employed during the WDEs under profiles initially approved in the test plan, or subsequent modifications to the plan driven by updated operational tactics with review and approval by DOT&E. The WDEs were integrated between the developmental and operational test teams to support adequate coverage of operational and employment conditions. Additional weapon events stressed the integration of these weapons and improved overall confidence in the analysis of such things as weapons bay environment, weapons bay door functions, weapons carriage interfaces, and the stores management system, and weapons delivery accuracy analyses.

(U) Table 3-27. Summary of Weapons Events Planned and Completed

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Weapon	Variant	Planned		Completed	
		Events	Weapons	Events	Weapons
AGM-154C	F-35C	4	5	4	5
GBU-39	F-35A	9	26	8	19
GBU-12	All	1	2	67	65
GBU-31	F-35A F-35C	2	2	24	23
GBU-32	F-35B F-35C	1	2	24	22
GBU-49	F-35A F-35B	16	20	19	20
AIM-120	All	13	13	12	18
AIM-9X	F-35A	9	9	9	8
Gun	All	25	N/A	25	128*

* Represents 128 gun attacks

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[redacted]

(U) Figure 3-38 depicts the scope of WDEs completed during IOT&E as a function of variant and station carriage. Color-filled cells represent stations from which weapons were released for each variant. To differentiate single from multiple weapon loads, single carriage weapons are shown on the right side of the aircraft in the figure, regardless of whether it was carried there or on symmetric station on the left side. For example, a single GBU-31 bomb may have been carried on either station 4 or 8, but is shown as being carried on station 8 if it was a single weapon event. Events with multiple weapons include carriage on the left side of the aircraft in the figure. For example, SDB I and JSOW each had multiple weapons carried in single WDEs, hence those weapons are showed as being carried from both sides of the aircraft.

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Station	1	2	3	4*	5	6	7	8	9	10	11
F-35A	AIM-9X	GBU-12 GBU-49	GBU-12 GBU-49	GBU-12 GBU-31 GBU-39/B (4) GBU-49 AIM-120	AIM-120		AIM-120	GBU-12 GBU-31 GBU-39/B (4) GBU-49 AIM-120	GBU-12 GBU-49	GBU-12 GBU-49	AIM-9X
F-35B	AIM-9X	GBU-12 GBU-49	GBU-12 GBU-49	GBU-12 GBU-32 GBU-49 AIM-120	AIM-120	Gun Pod	AIM-120	GBU-12 GBU-32 GBU-49 AIM-120	GBU-12 GBU-49	GBU-12 GBU-49	AIM-9X
F-35C	AIM-9X	GBU-12 GBU-49	GBU-12 GBU-49	GBU-12 GBU-31 GBU-32 GBU-49 AGM-154 AIM-120	AIM-120	Gun Pod	AIM-120	GBU-12 GBU-31 GBU-32 GBU-49 AGM-154 AIM-120	GBU-12 GBU-49	GBU-12 GBU-49	AIM-9X

*All OT aircraft were cleared to carry the Data Analysis, Recording, and Telemetry pod on station 4.

Weapons carried on stations 1, 2, 3, 6, 9, 10, and 11 are external, and negatively affect radar cross-section.
Weapons loaded in stations 4, 5, 7, and 8 are internal and only affect radar cross-section when doors are open for release.

Color	Weapon Type	Color	Weapon Type
	AMRAAM (radar-guided missile)		Direct attack, shorter-range bomb
	Shorter range, air-to-air infrared missile		Stand-off, longer-range bomb

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Figure 3-38. Weapons Used During Demonstration Events, By Variant and Type of Station (Internal or External). For simplicity only, all single loads are marked on right side.

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(U) The weapon summaries below include all weapon types that were baselined for fielding in the configuration evaluated for IOT&E.

(U) AGM-154C Joint Standoff Weapon (F-35C only)

(b)(1) [redacted]

(U) GBU-39 Small Diameter Bomb (F-35A only)

(b)(1) [redacted]

(b)(1)

[redacted]

(U) GBU-31 and -32 Joint Direct Attack Munition

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[redacted]

(U) GBU-49

(b)(1)

[redacted]

(b)(1) [redacted]

Table 3-28. (U) Bomb Miss Distance Results

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(U) AIM-120 Advanced Medium-Range Air-to-Air Missile

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[redacted]

(b)(1) [redacted]

(U) Table 3-29. AIM-120 Missile Events

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(U) AIM-9X Sidewinder

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(U) Table 3-30. AIM-9X Missile Events and Results

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(U) Gun

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(U) Pilot-Vehicle Interface and Human Factors Assessment

(U) The results of F-35 survey ratings are reported below depending on survey type. The first covers PVI usability and workload which were surveyed directly after test trials in all missions. The second covers key effectiveness enablers that were surveyed post-JSE missions. For a detailed discussion of the *Pilot-Vehicle Interface and Human Factors Survey Plan*, see Section 2.

(U) Survey data were adequate to analyze pilot self-reports of human factors during most F-35 mission areas. As shown in Table 3-31, survey response rates were generally high (84 -100 percent of pilots flying the test trials completed survey responses) except for the DEAD only OCA missions (52 percent). No survey data were available for open-air DCA trials against cruise missiles or to analyze PVI usability during ASuW missions. Along with the survey ratings, pilots offered comments which have been incorporated into the analyses.

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(U) Table 3-31. Post-Mission F-35 Pilot Survey Response Counts

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Mission		Venue	Number of Trials	Number of Pilots	Number of Survey Responses		
					Usability	Workload	Key Effectiveness Enablers
Combined	OCA	Open-Air	20	78	72	72	-
		JSE	31	124	111	112	119
	AI	Open-Air	20	71	67	67	-
		JSE	31	124	104	104	115
OCA: DEAD Only		Open-Air	4	31	16	16	-
DCA vs. Manned Aircraft		Open-Air	10	30	30	30	-
		JSE	11	38	33	34	36
DCA vs. Cruise Missiles		JSE	22	70	66	66	67
CAS		Open-Air	15	32	31	31	-
FAC(A)		Open-Air	8	15	14	14	-
CSAR		Open-Air	8	28	26	26	-
SCAR		Open-Air	6	6	6	6	-
RECCE		Open-Air	4	4	4	4	-
ASuW		Open-Air	7	24	0	20	-

Acronyms: AI – Air Interdiction; ASuW – Anti-surface Warfare; CAS – Close Air Support; CSAR – Combat Search and Rescue; DCA – Defensive Counter-Air; DEAD – Destruction of Enemy Air Defenses; FAC(A) – Forward Air Controller (Airborne); JSE – Joint Simulation Environment; OCA – Offensive Counter-Air; RECCE – Reconnaissance; SCAR – Strike Coordination and Armed Reconnaissance

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(U) Survey responses provide information on how pilots perceive the F-35's PVI and additional concepts such as workload. Survey results should not be interpreted as an assessment of F-35 performance. For instance, while pilot perceptions of PVI reflect how effective the aircraft's interface is in communicating task-relevant information, they do not directly reflect the F-35's ability to complete the task.

(U) Pilot Assessment of F-35 PVI Usability and Workload for Open-Air and JSE Trials

(b)(1) [redacted]

(U) Figure 3-39. F-35 Pilot-Vehicle Interface Usability Across Mission Types

(b)(1) [redacted]

(b)(1) [redacted]

(U) Figure 3-40. Average Pilot Workload Across F-35 Mission Types

(b)(1) [redacted]

(b)(1) [redacted]

(U) Figure 3-41. Peak Pilot Workload Across F-35 Mission Types

(U) Pilot Assessment of F-35 PVI to Support Key Effectiveness Enablers for JSE Trials

(b)(1) [redacted]

(b)(1) [redacted]

(U) Figure 3-42. Acceptability Ratings for Maintaining Situational Awareness of Flight Members Within a MADL Group

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Figure 3-43. Acceptability Ratings for Maintaining Situational Awareness of Non-F-35 Blue Air Entities

(b)(1) [redacted]

(U) Figure 3-44. Acceptability Ratings for Maintaining Situational Awareness of Red Air and Ground Entities

(b)(1)

[redacted]

(U) Figure 3-45. Acceptability Ratings for Combat ID (CID) in Supporting Mission Objectives

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Figure 3-46. Acceptability Ratings for the Ability to Sort Targets in Support of Mission Objectives

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Figure 3-47. Acceptability Ratings for the TSD Threat Track Lines, Audio Cues, DAS Missile Warnings, TWD Accuracy, and Their Contribution to Aircraft Survivability

(b)(1)
[redacted]

(U) Figure 3-48. Acceptability Ratings for Link-16 Interoperability

(b)(1)
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Section Four
(U) Operational Suitability

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(U) Operational Suitability Overview

(U) The F-35 operational suitability evaluation was designed to assess (1) the ability of a unit equipped with the F-35 to deploy, generate combat sorties, and sustain operations; and (2) the F-35 training system's ability to provide mission-ready pilots and maintainers. ALIS, which was designed as an overall enabler of system suitability is integral to all F-35 operations and maintenance activities, was assessed throughout the evaluation. The performance of all F-35 variants during initial operational test and evaluation (IOT&E) was measured against the suitability requirements stated in the Joint Strike Fighter (JSF) Operational Requirements Document (ORD). Details of the overall suitability test design are included in the Test Adequacy section of this report.

(U) Summary of Results

(U) During IOT&E deployments, fewer aircraft were deployed and fewer sorties flown than planned due to suitability shortfalls. ALIS supported deployment planning, deployed operations, and post-deployment retrograde, with limitations across all phases. The logistics footprint for land-based deployments exceeds the requirement by about two times the number of C-17 loads (mostly due to the size of support equipment). The F-35B did not meet the logistics footprint for LHD/LHA6-class ship-based deployments (it met the weight, but did not meet the volume requirements), while the F-35C did meet the logistics footprint for CVN-class ship-based deployments. Shipboard operations in the flight and hangar decks were complicated by the large size of the support equipment. The F-35A slightly exceeded, and the F-35B/C met, the requirement for direct manpower spaces per aircraft, based on the Services' staffing documents.

(b)(1) [redacted]

(b)(1) [redacted]

(U) The F-35 Joint Program Office (JPO) completed validation and verification of the IOT&E F-35 SGR models; and the JSF Operational Test Team (JOTT) recommended accreditation. The accreditation of these models for operational testing (OT) by the F-35 OT Executive Committee (EXCOM), the accreditation authority, could not be confirmed. With this exception, the use of the models was consistent with the DOT&E-approved test plan and provided credible results which support an assessment of the F-35 SGR performance.

(b)(1) [redacted]

(U) During IOT&E, all F-35 variants assigned to the operational test squadrons (OTS) experienced MC rates (operational availability) and FMC rates below and well below the Services' target values respectively.[1] These rates are representative of the entire U.S. F-35 fleet

[1] (U) In general, the Mission Capable rate indicates the proportion of aircraft not in depot that are capable of flying at least one mission of the F-35 mission set, while the FMC rate reports the proportion that can fly all defined F-35 missions.

(all variants) during the same period, although fleet FMC rates were notably better than those of the OTS aircraft, but still well below Service expectations. Failure to meet most of the threshold R&M requirements resulted in these shortfalls. Mission-critical avionics systems were important contributors to reliability shortfalls. Key maintainability factors included the long cure times for LO coatings and certain adhesives.

(b)(1) [redacted]

(U) ALIS is the backbone of maintenance support for the F-35 aircraft. Squadrons depend on it to support day-to-day flight operations and maintenance activities. During IOT&E, ALIS demonstrated poor usability and impeded, rather than facilitated, effective maintenance operations.

(b)(1) [redacted]

(U) Suitability Test Execution

(U) The performance of all F-35 variants during IOT&E was measured against the suitability requirements stated in the JSF ORD, both key performance parameters (KPPs)—MR, SGR, and logistics footprint—and non-KPP requirements.

(U) The test team observed OTSs, both during deployments to representative operating environments and during local operations at Edwards Air Force Base (AFB), California. Data were collected for SGR, alert launch timing, and maintenance support. Performance assessments for availability, reliability, and maintainability were based on formally adjudicated maintenance records from the U.S. Services' OTSs, supplemented with data from U.S. F-35 fleet operations. Data on ALIS usability and suitability were collected using surveys and interviews administered to maintenance personnel assigned to the OTSs. The test team evaluated data from dynamic RCS measurement events to assess the stability and durability of the F-35 aircraft's RCS over time. To evaluate training, the test team visited pilot and maintenance personnel training sites and interviewed students and instructors.

(U) Deployability Evaluation Activity

(U) Operational test units conducted deployments to collect data on how well the support structure of the F-35 enables movement to and from basing in intended operational environments. Table 4-1 lists the locations and dates for IOT&E suitability test events supporting the deployment analyses. An F-35B deployment to the USS *Essex* (LHD 2), was included in the test plan. Operational test teams observed and collected data during an F-35B deployment to the *Essex* during a naval integration exercise in 2017, before the IOT&E period. DOT&E approved the use of these suitability data to support an assessment of deployment to and from amphibious assault ships in support of the IOT&E. An F-35A deployment under a "Rapid Lightning" concept of operations was also included in the plan, but not completed because the U.S. Air Force did not have a mature concept of operations for Rapid Lightning during the IOT&E period.

(U) Table 4-1. Suitability Test Events

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Test Event	Location	Date	Variants
F-35B deployment[a] LHD/LHA6-class operations	USS *Essex* (LHD 2)	Oct 20 – 29, 2017[b]	F-35B
F-35 (all variants) deployment[a] cold weather deployment, alert launches	Eielson AFB, AK	Jan 18 - Feb 4, 2018	All
F-35 (all variant) home station operations maintenance demos, alert launches	Edwards AFB, CA	Mar 30 – Dec 2, 3018	All
F-35C deployment to CVN-class aircraft carrier[a] SGR demos, ship-based alert launches	USS Abraham Lincoln (CVN 72)	Aug 17 – 31, 2018	F-35C
F-35A deployment to Forward Ops Base[a] SGR demos, weapon events	Volk Field ANGB, WI	Sep 7 – 19, 2018	F-35A
F-35B deployment to Austere Location SGR demos[a]	MCAS Yuma, AZ	Mar 4 – 23, 2019	F-35B
F-35 maintenance demos; reliability, maintainability, and availability data[c]	Edwards AFB, CA	Dec 3, 2018 – Sep 30, 2019	All

Test Event	Location	Date	Variants

a. These deployments provided data to support the logistics footprint assessment.

b. This deployment was completed prior to the start of formal testing. Operational test teams observed, collect deployment data, and conduct interviews. The F-35B aircraft were not in the IOT&E test configuration.

c. During this time period, the majority of the primary mission area open-air trials were conducted. Test aircraft were in Lot 9 configuration with 30R02.04 software load. The OTSs had an elevated supply priority status compared to normal test units. Performance of F-35 aircraft assigned to the OTSs was used to evaluate the reliability, maintainability, and availability.

Acronyms: ANGB – Air National Guard Base; ALIS – Autonomic Logistics Information System; MCAGCC – Marine Corps Air Ground Combat Center; MCAS – Marine Corps Air Station; SGR – sortie generation rate

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(U) Logistics Footprint (KPP)

(U) The logistics footprint is a quantification, measured in weight and volume, of how much support equipment, spare parts, and consumables are required to deploy and sustain the F-35 for a specified period of time in a given operating environment. The test team collected logistics footprint data from five deployments from October 2017 through March 2019 (as noted in Table 4-1). These deployments involved a smaller number of F-35 aircraft and took place over shorter durations than the scenarios described in the requirements document. While these data were used to support the assessment of the logistics footprint, they were not extrapolated to the full primary aircraft authorization quantity or longer duration deployments called out in the requirements document. To assess the full primary aircraft authorization with respect to the threshold requirement, the test team used the Service's planning products developed for units deploying the F-35.

(U) Maintenance Manpower

(U) The test team collected data from the U.S. OTSs regarding the direct maintenance manpower levels used during IOT&E. These data were used to evaluate the F-35 aircraft's direct maintenance manpower staffing levels. In addition, the Service's staffing plans were used as inputs in the F-35 SGR models, and modeling and simulation (M&S) results were used to evaluate these direct maintenance manpower staffing levels for all phases of sortie generation operations for a unit with a representative quantity of aircraft over a 100-day period.

(U) Sortie Generation Evaluation Activity

(U) The ability for deployed or home-based units to generate aircraft sorties to support mission taskings depends on inherent characteristics of both the aircraft and its supporting infrastructure, including spare parts and supplies, support equipment, assigned maintenance personnel, and the intended operating environment.

(U) Sortie Generation Rate (KPP)

(U) SGR is a measure of the capability of the F-35 to support wartime operations for an extended period of time at a high operational tempo. SGR is defined as the number of sorties flown per day divided by the number of aircraft assigned to the unit, and is specified in the threshold requirements by phase of operations: initial surge (days 1 – 7), sustained surge (days 8 – 30), and wartime sustainment (days 31 and beyond). SGR was evaluated using live and simulation results. Small-scale SGR demonstrations were conducted during deployments to intended operating environments. These live data are reported in this section and were used to support validation of the F-35 SGR M&S, which were used to evaluate SGR performance for the larger-scale, threshold requirement-defined, quantity of aircraft over all SGR phases.

(U) IOT&E Live SGR Testing

(U) The F-35A OTS conducted a deployment to Volk Field Air National Guard Base, Wisconsin from September 7 to 19, 2018, to assess deployed operations at a "forward base" and conduct surge operations for seven days. Only four out of six F-35A aircraft actually deployed, due to maintenance issues. These aircraft completed 57 of 84 planned sorties. The majority of the lost scheduled sorties were due aircraft being in Not Mission Capable (NMC) status; three sorties were lost due to maintenance ground aborts, and one to weather.

(U) The F-35B test unit conducted a land-based deployment from Edwards AFB, California to Marine Corps Air Base Yuma, Arizona from March 4 to 23, 2019, to collect data on deployment measures and conduct surge operations for seven days. Due to maintenance issues, only five out of six F-35B aircraft deployed. These aircraft completed 98 of 118 planned sorties. Scheduled sorties were missed due to (1) aircraft in NMC status, and (2) the time required to service and turn aircraft between sorties. During the deployment, the surge operations were suspended for two days due to ALIS non-availability.

(U) The F-35C SGR deployment to the USS *Abraham Lincoln* (CVN 72) was conducted with six aircraft from Strike Fighter Squadron (VFA)-125 and VFA-101, from Lemoore Naval Air Station, California. The OTS aircraft assigned to the F-35C unit at Edwards AFB were not certified to operate from an aircraft carrier, so this deployment was conducted with aircraft from an operational (non-test) unit. Over the seven days, six F-35C aircraft completed 61 of 80 scheduled sorties. Most of the lost scheduled sorties were due to aircraft in NMC status.

(U) Modeling and Simulation of SGR

(U) M&S results were used to assess the SGR performance of the ORD-defined quantity of each F-35 variant. Separate simulations were developed by the test team and multiple runs were completed for each variant in their respective operating environment. The simulations were extended to include all phases of SGR operations included in a 100-day period.

(U) The test team developed these scenario-specific SGR models for each F-35 variant and operating environment using the Logistics Composite Model (LCOM) tool, a sustainment modeling software tool maintained by the U.S. Air Force that is widely used to evaluate availability, R&M, and supportability capabilities of weapon systems. The F-35 SGR models used R&M characteristics of the F-35 aircraft based on adjudicated U.S. fleet data. The models used Service-provided data for the support infrastructure, planned manpower, planned spares packages, the flight schedules, and the concept of operations. The accreditation status of these IOT&E F-35 SGR models by the F-35 Operational Test EXCOM, the accreditation authority, could not be confirmed. The F-35 JPO completed validation and verification of the IOT&E SGR model; and the JOTT recommended accreditation of the model for use in IOT&E in the model accreditation summary report prepared for the F-35 OT EXCOM. The IOT&E model was based on a SGR model that was accredited by the JPO in 2010 (used to support contract specification development) and in 2018 (used for analysis to support closure of the System Development and Demonstration contract). Notwithstanding the lack of formal accreditation status, the use of the IOT&E F-35 SGR models was consistent with the DOT&E-approved test plan and with the tool's capabilities, and provided credible results that can be used to support an assessment of the F-35 SGR performance.

(U) Alert Launch Trials

(U) The F-35 threshold timing requirements for all variants to conduct an alert launch, from a cocked, ready-to-launch condition to being airborne and fully mission-ready. To assess performance against these requirements, the F-35 test units conducted dedicated alert launch trials across the range of expected ambient temperature operating conditions (see Table 4-2). Alert launch performance was assessed based on 86 alert launch attempts that resulted in 76 alert launches. The alert launch capability of all variants was tested in a land-based operating environment in moderate and hot weather conditions at Edwards AFB, California and in cold weather conditions at Eielson AFB, Alaska. The F-35C test unit conducted alert launches with moderate weather conditions during the deployment of F-35C aircraft to USS *Abraham Lincoln* (CVN 72).

(U) Table 4-2. F-35 IOT&E Alert Launch Test Events

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Location and Dates	Environment (Ambient Temperature)	Variant and Software Version	Aircraft and Number of Scored Attempts
Eielson AFB, AK Jan 18 - Feb 2, 2018	Land-based, Cold Weather (-31 to -17 degrees Fahrenheit)	All Variants 3FR6.32	AF-79, AF-80, BF-15, BF-19, CF-7, and CF-32 27 scored attempts resulting in 23 alert launches
Edwards AFB, CA Apr 17 – Nov 20, 2018	Land-based, Moderate Weather (49 to 69 degrees Fahrenheit)	F-35A/B 3FR6.2 30R00 30R02.03	AF-3, AF-32, AF-80, AF-109, AF-112, AN-1, AN-2, and BK-4 18 scored attempts resulting in 17 alert launches
Edwards AFB, CA Jul 23 – Aug 15, 2018	Land-based, Hot Weather (98 to 110 degrees Fahrenheit)	All Variants 30R00.0 30R01.02	AF-31, AF-79, AF-80, AF-112, BF-16, BF-19 BF-20, CF-10, CF-6, and CF-9 33 scored attempts resulting in 28 alert launches
USS Abraham Lincoln (CVN 72) Aug 17 – Aug 31, 2018	CVN-based, Moderate Weather (84 to 88 degrees Fahrenheit)	F-35C 3FR6.33	CF-25, CF-29, CF-30, CF-31, and CF-32 8 scored attempts resulting in 8 alert launches

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(U) Sustainment of Operations Evaluation Activity

(U) Effective sustained operations rely on the inherent R&M characteristics of the aircraft and support systems. The F-35 was designed for high reliability – being able to complete missions once airborne – and with low maintenance burden – enabling rapid return to flight following a mission or completed maintenance. Availability is a measure of readiness to conduct flight operations. The LO traits of the aircraft must be tracked and maintained as well to support combat operations that depend on those traits.

(U) Availability, Reliability, and Maintainability

(U) Maintenance records collected during the IOT&E period were formally adjudicated for accuracy and provided data for evaluating availability, R&M. This assessment is based on the F-35 aircraft assigned to the U.S. OTSs during the IOT&E suitability evaluation period, from December 3, 2018 through September 30, 2019. During this time frame the OTSs conducted a majority of open-air trials (which replicated combat sorties) and all the OT aircraft were in an operationally representative Lot 9 configuration with the appropriate software load, and the OTSs had an elevated supply priority status, rising to the level just below aircraft deployed for operations.[2] The total number of flight hours, sorties and unscheduled maintenance events that occurred during this period are listed in Table 4-3.

(U) Table 4-3. U.S. OT F-35 Aircraft Flight Hours, Sorties and Maintenance Events

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U.S. Operational Test Squadrons and Assigned Aircraft (December 3, 2018 through September 30, 2019)	Flight Hours	Sorties	Unscheduled Maintenance Events
U.S. Air Force 31st Test and Evaluation Squadron F-35A: AF-31, AF-32, AF-79, AF-80, AF-109, and AF-112	838	457	417
U.S. Marine Corps Operational Test and Evaluation Squadron ONE F-35B: BF-15, BF-16, BF-17, BF-18, BF-19, and BF-20	685	350	626
U.S. Navy Air Test and Evaluation Squadron NINE F-35C: CF-6, CF-7, CF-8, CF-9, CF-10, and CF-11	1,119	575	1,048
Totals	2,641	1,383	2,091

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(U) Autonomic Logistics Information System

(U) ALIS is a large, distributed information system that supports F-35 operations and maintenance, supply, and training; composed of hardware and software components located at the squadron, Service and enterprise levels, and includes both government- and contractor-owned assets.

(U) The test team planned to evaluate ALIS suitability to support sortie generation activity and deployment, primarily via a series of structured interviews and surveys. The team developed interviews for different ALIS users (e.g., maintenance personnel, administrator, supervisor) which covered each deployment phase (planning, operations, and reconstitution), and

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2 (U) Services assign parts priority on a scale from I to V to F-35 units based on criticality of the unit's mission. Normally, test and training units have lower priority than operational and deployed or "underway" units. During the period of data collection for the analyses referenced here, the F-35 operational test units had an elevated priority status from level V to level III+, just lower than operationally deployed units.

reactively covered unplanned ALIS disruptions. The interviews were supplemented with two types of surveys. An ALIS task survey, administered at the completion of a maintenance task, asked line maintainers about the overall ALIS contribution to a maintenance action and if they experienced any ALIS disruptions, such as an ALIS application crash or failure, during the specific task. An ALIS application usability survey, administered on a calendar basis, asked personnel about the ease or difficulty of their regular interactions with the particular ALIS software applications that their job role required. The test team collected demographic information from each respondent on their level of experience in their Service, and their time with the F-35 in particular.

(U) The team conducted interviews during the cold weather deployment to Eielson AFB, Alaska, but had not yet developed surveys. During IOT&E, to collect data on overall ALIS performance and usability, the test team collected interview and survey data on ALIS during routine operations at Edwards AFB and from the variant-specific deployments to Volk Field, Marine Corps Air Station (MCAS) Yuma, and CVN 72. These deployments replicated expected operational deployed environments and included SGR demonstrations. The team administered the usability surveys for eight key ALIS applications. The test team did not administer surveys for the Training Management System, having determined that none of the OTSs use it, nor do operational units in the field, preferring to use their parent Service's systems, vice the ALIS application, to track training. Table 4-4 summarizes survey responses by test event location, survey type, and by the versions of ALIS then in use.

(U) Table 4-4. ALIS Survey Responses from IOT&E

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Test Event	Dates	ALIS Version	Service	Responses by Survey Type		
				Demographics	ALIS Apps	Maintainer Tasks
F-35C SGR Deployment (CVN 72)	Aug 2018	2.0.2.4	USN	30	48	30
F-35A SGR Deployment (Volk Field ANGB, WI)	Sep 2018	3.0.1.1	USAF	42	7	102
Operational Test Squadron home base Operations – All Variants (Edwards AFB, CA)[a]	Feb 2019 – June 2020	3.0.1 – 3.5	USAF	63	60	167
			USN	150	212	1,471
F-35B SGR Deployment (MCAS Yuma, AZ)	Mar 2019	3.0.1.2	USMC		34	38
Total				285	361	1,808

a. The test team collected surveys from the OT units during this period, during which time the majority of IOT&E flying activities occurred.

Acronyms: ANGB – Air National Guard Base; AFB – Air Force Base; MCAS – Marine Corps Air Station; USAF – U.S. Air Force; USMC – U.S. Marine Corps; USN – U.S. Navy; ALIS – Autonomic Logistics Information System; SGR – Sortie Generation Rate

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(b)(1) [redacted]

(U) There were sufficient survey responses to evaluate the effects of ALIS on overall maintainer task completion, and for rating the usability of seven of the eight surveyed applications. There did not appear to be major differences in user responses between ALIS versions or between Services.

(U) Low Observable Stability Over Time

(b)(1) [redacted]

(b)(1)

[redacted]

(U) LOSOT Test Objectives

(b)(1)

[redacted]

(U) LO Health Assessment System Evaluation

(b)(1)

[redacted]

(b)(1) [redacted]

(U) LO Maintenance Required for LO Signature Evaluation

(b)(1) [redacted]

(U) Pilot and Maintenance Personnel Training Evaluation Activity

(U) The test team observed F-35–specific pilot training activities and conducted interviews with students and instructors. The evaluation covered the full scope of training from initial pilot accession and pilot conversion to training conducted at operational units (see Table 4-6). The test team also conducted 24 pilot interviews with the U.S. OTSs to collect user feedback on the training system.

(U) Table 4-6. Number of F-35 Pilot Training Interviews at Training and Operational Units

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Description, Location, and Date	Service			Unit Type	
	USAF	USMC	USN	Training	Operational
F-35A and F-35C training units (58 FS and VFA-101) Eglin AFB, Florida, March/April 2019	6		15	21	
F-35B training unit (VMFAT-501) MCAS Beaufort, South Carolina, February/March 2019		22		22	
F-35A training units (61 FS, 62 FS, 63 FS, 308 FS, and 944 OG Det 2) Luke AFB, Arizona, April 2019	36			36	
F-35C training and operational units (VFA-147 and VFA-125) NAS Lemoore, California, February 2019			23	10	13
F-35B operational unit (VMFA-122) MCAS Yuma, Arizona, May 2019		14			14
F-35A operational unit (34 FS, 388th FW and 419 FW) Hill AFB, Utah, May 2019	5				5
Total number of pilot interviews:	47	36	38	89	32

Acronyms: Det – Detachment; FW – Fighter Wing; FS – Fighter Squadron; MCAS – Marine Corps Air Station; NAS – Naval Air Station; OG – Operations Group; USAF – U.S. Air Force; USMC – U.S. Marine Corps; USN – U.S. Navy; VFA – Strike Fighter Squadron; VMFAT – Marine Fighter Attack Training Squadron

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(U) In March 2019, the test team observed F-35–specific maintenance support personnel training activities at Eglin AFB, Florida. They conducted interviews with both students and

(b)(1) [redacted]

instructors at the Academic Training Center responsible for initial training of new maintenance support personnel (see Table 4-7). The test team also conducted interviews with Field Training Detachment instructors and supervisors responsible for providing F-35 qualification training for experienced maintainers.

(U) Table 4-7. F-35 Maintenance Support Personnel Training Interviews Conducted at Eglin AFB, Florida, March 2019

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Interview type	Service		
	USAF	USMC	USN
Student	16	15	5
Instructor	8	8	7
Instructor-supervisor	6	4	6
Field Training Detachment[a] Instructor	9	0	0
Field Training Detachment Instructor-supervisor	6	0	0

a. The Field Training Detachment provides follow-on training to maintenance support personnel. At the time of the IOT&E evaluation, this detachment included USAF personnel only.

Acronyms: AFB – Air Force Base; ATC – Academic Training Center; USAF – U.S. Air Force; USMC – U.S. Marine Corps; USN – U.S. Navy

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(U) Detailed Suitability Results

(U) The IOT&E suitability results are organized in terms of assessing the ability of an F-35 unit to deploy, generate sorties, and sustain operations. Assessments of aircraft specific pilot and maintainer training are included, along with ALIS usability ratings. None of the F-35 variants met all threshold KPP requirements. The F-35 did not meet most of the threshold suitability requirements. The results in this report compare observed performance of the OT aircraft during IOT&E with suitability requirements defined by the JSF ORD, the JPO, or individual Services. The ORD includes KPP requirements, as well as threshold requirements for R&M metrics. The Services maintained availability objectives for their respective variants before and during the period of this IOT&E.[4]

(U) Deployability

(U) The F-35 and its associated logistics support structure were designed to be readily deployable to each variant's intended operational environments. During IOT&E, the F-35 demonstrated the capability to deploy and conduct flight operations. However, fewer F-35 aircraft than planned were deployed due to the lack of aircraft operational availability. ALIS supported deployment planning, deployed operations (with limitations), and post-deployment retrograde.

4 (U) The Block 4 Capability Development Document defines availability requirements for the F-35B and F-35C.

(U) Logistics Footprint (KPP)

(U) The logistics footprint quantifies how much support equipment, spare parts, and consumables are required to deploy and sustain the F-35 in a given operating environment. Airlift is the primary means used to deploy to land-based operating environments and the logistic footprint is a measure of the number of C-17 equivalent loads required. For ship-based deployments, space is limited and at a premium, in particular the space used to store maintenance support equipment and to conduct maintenance activities, and the logistics footprint is measured in terms of total weight and volume required.

(b)(1) [redacted]

(U) Table 4-8. Estimated Logistics Footprints Compared to Requirements

(b)(1) [redacted]

(U) Shipboard operations will be adversely affected by the size of the heavy support equipment and the need to move it and aircraft around crowded flight and hangar decks to complete maintenance, generate sorties, and conduct shipboard operations such as resupply.

(b)(1) [redacted]

Personnel will have more difficulty completing maintenance activities quickly and launching aircraft on schedule compared to legacy carrier aircraft.

(U) The logistics footprint estimate includes a full engine spare as well as a spare for each engine module. The land-based logistics footprint assumes no pre-staged F-35 peculiar support equipment at the deployment location. The ship-based logistics footprint estimate excludes common support and material handling equipment shared with other airframes.

(U) Cold Weather Environment

(b)(1) [redacted]

(U) Operational testing during the deployment to Eielson AFB, Alaska identified the following problems specific to operating in the cold weather environment:

(b)(1) [redacted]

(U) Shipboard Environment

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Manpower

(U) The maintenance manpower level available during IOT&E was suitable to support OT, although day-to-day operations are reliant on contractor logistics support (CLS). Maintenance manpower positions are categorized as direct maintenance, indirect maintenance, and CLS. Direct maintenance, or touch labor, is all scheduled and unscheduled maintenance conducted at the unit-level, on and off the aircraft. Indirect maintenance includes scheduling maintenance work, ordering of spare parts, upkeep of aircraft usage history, and tracking remaining engine life. For the F-35, CLS includes ALIS administrators and field service engineers. While there are threshold requirements for direct maintenance manpower, there are no manpower requirements for either indirect maintenance or contractor support.

(U) Direct Maintenance Manpower Spaces per Aircraft

(U) The F-35B and F-35C meet, and the F-35A slightly exceeds, their direct maintenance manpower requirements, as summarized in Table 4-9. These manpower levels were used as inputs for the F-35 SGR models, the results from which indicated that these levels did not constrain the ability of the Services to maintain aircraft at the higher utilization rates.

(U) Table 4-9. Direct Maintenance Manpower Used for F-35 SGR Model Inputs

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Variant/ Environment	DMSpA Threshold Requirement	Direct Maintenance Manpower	Calculated DMSpA	Do Results Meet the Requirement?
F-35A Deployed Main Operating Base (24 PAA)	≤ 12	294	12.3	Slightly Exceeds
F-35B Land-Based (20 PAA)	≤ 12	154	7.7	Yes
F-35B Amphibious-Based (6 PAA)	≤ 12	62	10.3	Yes
F-35C CVN-Based (12 PAA)	≤ 12	112	9.3	Yes

Acronyms: DMSpA – direct manpower spaces per aircraft; PAA – primary aircraft authorized

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(U) Direct Maintenance Manpower During IOT&E

(U) The direct maintenance manpower levels during IOT&E were suitable to support operational testing. Direct maintenance personnel conduct scheduled and unscheduled maintenance, on and off the aircraft, such as removing and installing line-replaceable components. The reported staffing levels used during IOT&E were higher than the Services' planned levels (see Table 4-10), and were not necessarily operationally representative because each U.S. OTS supported only six aircraft. Field units would be expected to gain manpower efficiencies when supporting additional aircraft. Direct Manpower Spaces Per Aircraft measures the personnel needed to directly support the F-35 over the most demanding phases of campaigns or peacetime operations.

(U) Table 4-10. F-35 Maintenance Manpower during IOT&E (Number of Persons)

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Variant	Environment	Total	Indirect	Direct	No. of Aircraft	Calculated DMSpA
F-35A	Cold Weather deployment (Jan 2018)	100	43	57	2	28.5
	Edwards AFB (Dec 2018)	128	37	91	6	15.2
	Edwards AFB (July 2019)	117	28	89	6	14.8
	SGR deployment (Volk Sept 2018)	126	45	81	4	20.3
F-35B	Cold Weather deployment (Jan 2018)	84	28	56	2	28.0
	Edwards AFB (Dec 2018)	149	40	109	6	18.2
	Edwards AFB (July 2019)	149	40	109	6	18.2
	SGR deployment (Yuma)	120	58	62	5	12.4

Variant	Environment	Total	Indirect	Direct	No. of Aircraft	Calculated DMSpA
F-35C	Cold Weather deployment (Jan 2018)	96	27	69	2	34.5
	Edwards AFB (Dec 2018)	153	56	97	6	16.2
	Edwards AFB (July 2019)	153	56	97	6	16.2
	SGR deployment CVN 72	201	85	116	6	19.3
Acronyms: AFB – Air Force Base; DMSpA – direct manpower spaces per aircraft; SGR – sortie generation rate						

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(U) Contractor Logistics Support

(U) Day-to-day F-35 operations are dependent on CLS, particularly for ALIS administrators. There were 91 CLS supporting the 23 OT aircraft (three U.S. OTSs and two partner squadrons) in January 2019 at Edwards AFB. During the three SGR deployments, contractor logistic support personnel constituted between 10-14 percent of active duty direct and indirect support personnel combined. The effect of the reliance on CLS support, or the availability of CLS support, during combat operations when aircraft are forward deployed was not assessed. Maintainers generally lack access to routine technical data, such as more detailed schematics needed to identify replacement part numbers, that are readily available to CLS field service engineers.

(U) Sortie Generation

(U) The evaluation of the sortie generation performance of the F-35 during IOT&E is based on assessments from the small-scale SGR demonstrations, M&S of the SGR of an F-35 unit through 100-days of operations at the full ORD-defined quantity of aircraft, evaluation of the integrated combat turn times, and dedicated alert launch trials.

(U) The ability to generate sorties to support mission tasking is a function of the capabilities of the both the F-35 aircraft and its supporting infrastructure. To support the flight schedule, aircraft must be available in a MC status. This operational availability must be sustained and depends on – at a fundamental level – system reliability, maintainability, and the availability of spare parts. The target operational availability levels need to account for spare aircraft to provide flexibility if aircraft fall out. To complete multiple sorties in a given day, the F-35 was designed to minimize the aircraft turn-around time (the time needed to complete aircraft servicing, inspections, refueling and rearming). The ability to rapidly take-off and respond to mission requirements when the aircraft is on alert status require minimizing the time for aircraft start-up, take-off, and for mission systems to be ready quickly to support air-to-ground and/or air-to-air missions.

(U) Sortie Generation Rate (KPP)

(U) SGR, measured in terms of sorties per aircraft per day, is an assessment of the capability to support wartime operations for an extended period of time at a significantly higher operations tempo than peacetime operations. The JSF ORD establishes the SGR requirement, which decreases progressively through three defined phases of combat. The concept of "SGR

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phasing" used in the requirement is based on a combat deployment principle that the highest demand for sorties is at the start of combat operations and lowers as combat operations progress. The highest SGR requirement is for the first seven days of operations, referred to as the initial surge. The SGR requirement is lower for the next phase, referred to as the sustained surge period, which includes days 8 through 30. The SGR requirement decreases further for the final phase of wartime sustained operations, which is days 31 and beyond.

(U) The test plan to evaluate SGR involved a two-part analysis. First, the OTSs conducted small-scale SGR demonstrations during deployments to specified operating environments. Second, the data collected during these demonstrations supported the accreditation of a model used to generate SGR results for a representative quantity of aircraft.

(U) Live F-35 Sortie Generation Rate Demonstrations

(U) During IOT&E the OTSs conducted three small-unit deployments, one for each variant, away from their home station, to measure SGR capability in a forward-deployed operational environment, simulating combat conditions. The numbers of aircraft, personnel, and support materiel were scaled down from a full operational unit deployment, but served to represent the individual Services' concepts of employment. Table 4-11 summarizes the SGR demonstration results from the IOT&E deployments for all variants.

(b)(1) [redacted]

(U) Table 4-11. Summary of F-35 SGR Demonstrations during IOT&E

(b)(1) [redacted]

(b)(1) [redacted]

(U) F-35A

(U) The F-35A OTS conducted a deployment to Volk Field, Wisconsin from September 7 to 19, 2018 to assess deployed operations at a "forward base" and conduct surge operations for 7 days during the period. Although the test plan called for six aircraft for the deployment, maintenance issues that developed the day before, and the day of, the deployment prevented two of the planned aircraft from deploying. During the deployment, pilots conducted simulated close air support and reconnaissance missions that included air-to-ground weapon deliveries of inert bombs on a scorable range. The results of these events are included in the effectiveness section of this report.

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(U) F-35B

(U) Similar to the F-35A unit, the F-35B OTS conducted a land-based deployment from Edwards AFB, California to MCAS Yuma, Arizona from March 4 to 23, 2019, to collect data on deployment measures and conduct a demonstration of surge operations. Although the test plan called for six aircraft, one of the planned aircraft was NMC before and during the full deployment period and did not participate.

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(U) During the deployment, pilots conducted simulated close air support and reconnaissance missions that included air-to-ground weapon deliveries of inert bombs on a scorable range. The results of these events are included in the weapons assessment of this report.

(U) F-35C

(b)(1) [redacted]

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(U) Modeled Sortie Generation Rate Performance

(U) To evaluate the SGR capabilities of each F-35 variant, the test team developed scenario-specific SGR models for each F-35 variant and operating environment using LCOM, a sustainment modeling software tool maintained by the U.S. Air Force that is widely used to evaluate the availability, R&M, and supportability capabilities of weapon systems. The input data includes the R&M characteristics of the aircraft, its support infrastructure, planned manpower and spares packages, flight schedules, and the concept of operations. The SGR model's validation included actual R&M data from the U.S. F-35 fleet and data from the live IOT&E SGR deployments. The ASD requirement for each variant was a static input into the model, provided by the corresponding Service in the ORD.

(U) The model results showed that none of the F-35 variants met the SGR threshold requirement for either the initial surge phase (days 1–7) or the sustained surge phase (days 8–30). This was due to low operational availability, driven primarily by low reliability, long maintenance durations, and supply shortages. The F-35A in a main operating base environment, and the F-35B in a land-based environment, met the SGR threshold requirement during the wartime sustainment phase (days 31 and after). The amphibious-based F-35B met the requirement 59 percent of the time, and the carrier-based F-35C, which met the requirement 69 percent of the time, did not meet the overall requirement. Table 4-12 summarizes the results used by the F-35 SGR models to evaluate the SGR capabilities of the F-35 during high-tempo operations.

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(b)(1) [redacted]

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(U) Table 4-12. F-35 Sortie Generation Rate Model Results

(b)(1) [redacted]

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[redacted]

(U) Figure 4-1. IOT&E F-35 SGR Model Results Showing the Predicted Mean SGR and Operational Availability by Day for each Variant and Operating Environment

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[redacted]

(U) Integrated Combat Turn Times

(b)(1)

[redacted]

(U) Table 4-13. IOT&E Estimated Integrated Combat Turn Times

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[redacted]

(b)(1) [redacted]

(b)(1) [redacted]

(U) Alert Launch

(U) The alert launch requirements for the F-35 are based on the mission timing needed for close air support (air-to-ground) and defensive counter-air (air-to-air) missions. Aircraft in an alert status are in an enhanced state of readiness and have been prepared to rapidly take-off and respond to mission requirements. There are three different time requirements; this time begins when the pilot initiates the aircraft start sequence and continues until the F-35 aircraft has achieved (1) an alert launch (takes off), (2) air-to-air combat capabilities, and/or (3) air-to-ground combat capabilities. In addition, there are different time requirements for different ambient temperature conditions; these are independent of the basing environment.

(b)(1) [redacted]

(U) Table 4-14. Summary of F-35 Alert Launch Results during IOT&E

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(U) Figure 4-2 shows the results demonstrated during IOT&E with separate sub-plots for each applicable combination of ambient temperature and operating environment. The plots show the individual alert launch trial results (diamonds colored by variant), the threshold requirement (vertical magenta line) and the median demonstrated time (open triangle symbol). In most cases the same threshold requirement applies to all three variants, with the exception of cold temperature conditions, where the F-35B has a different time requirement for alert launch and the availability of air-to-air combat capabilities than the F-35A and the F-35C.

(b)(1) [redacted]

(b)(1) [redacted]

(U) Figure 4-2. F-35 IOT&E Results from the Scored Alert Launch Trials by ambient Temperature and Operating Environment

(U) Sustaining Operations

(U) As aircraft are generated and sorties are flown to conduct missions, scheduled and unscheduled maintenance will be required to ensure aircraft safety for flight and to restore aircraft to MC or FMC status after system failures. The number of failures will be influenced by a combination of the inherent reliability of aircraft's components, systems, and software; the nature of the aircraft's operational use, and the accumulated exposure to the operating environment. To sustain operations the F-35 aircraft was designed to achieve a high availability by being highly reliable and maintainable. To enable this, the aircraft was designed to monitor its own health to identify and log faults automatically based on data from various sensors and subsystems to both minimize and accelerate the manual troubleshooting of faults and reducing the overall maintenance time. This diagnostics data must then be processed in ALIS after the aircraft lands to be reviewed by maintainers.

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[redacted]

(U) Availability

(U) The demonstrated operational availability (or MC rate) of the F-35 is consistently below the Services' expectations for all variants (summarized in Table 4-15 with U.S. fleet data for comparison). Although the JSF ORD did not specify operational availability requirements for IOT&E, the JPO set targets in the sustainment contracts with Lockheed Martin based on each Services' needs.[5] Aircraft that are operationally available are either in a (PMC) status (capable of performing at least one tasked mission) or in an FMC status (capable of performing all missions). The operational availability rate is the number of mission-capable aircraft divided by number of possessed aircraft (this excludes the time when aircraft in a depot status and are not considered possessed by the unit).

(U) Table 4-15. F-35 Operational Availability and FMC Status during IOT&E

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Parameter	Derived Standard	OT Aircraft[a]	U.S. Fleet[b]
Operational Availability[c] (Mission Capable Rate)	≥ 70 percent	F-35A: 59 percent	F-35A: 61 percent
		F-35B: 40 percent	F-35B: 66 percent
		F-35C: 62 percent	F-35C: 60 percent
Fully Mission Capable	≥ 52.5 percent	F-35A: 18 percent	F-35A: 41 percent
		F-35B: 16 percent	F-35B: 24 percent
		F-35C: 0 percent	F-35C: 7 percent

a. From all U.S. F-35 OT aircraft using flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

b. From all U.S. F-35 (LRIP 2+) aircraft using flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

c. Mission Capable rate includes PMC time and FMC time. The data do not distinguish whether or which mission-essential functions may be available in FMC time.

Acronyms: FMC – Fully Mission Capable; LRIP – low-rate initial production; OT – operational test; PMC – Partially Mission Capable

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(U) Poor operational availability and FMC rates are the result of several causes, but primarily driven by R&M below requirements. Inadequate supply support is a major contributing factor, a problem whose root cause may be that components with lower than planned for reliability are often out of stock because they are in high demand.

5 (U) The Block 4 Capability Development Document defines availability requirements for the F-35B and F-35C.

[redacted]

(U) Maintenance Record Data

(U) Maintenance records are the primary data source for determining aircraft R&M metrics. These records document work conducted by maintenance personnel, both scheduled actions to ensure continued aircraft airworthiness and unscheduled actions to resolve failures or degradations. These records do not inherently capture reliability events that do not require maintenance actions, such as some types of software faults. These software faults may be resolved instead by pilot-initiated system resets, or by simply shutting down and restarting the aircraft. The design of the F-35 maintenance system and ALIS, provides some limited insight into these types of events via the maintenance records generated for reported failures or degradations.

(U) Failures or degradations within aircraft systems are recorded during flight via the on-aircraft portion of the Prognostic Health Management (PHM) system. These data are downloaded after the flight for off-aircraft processing in ALIS, maintenance review and assignment of troubleshooting or repair actions. In addition, pilots normally conduct a debrief with maintenance teams after each flight to report on any issues observed. Pilot-reported faults follow a similar process to system reported ones. Faults captured by the PHM system have unique health reporting codes that are intended to isolate the fault to a single component or to the applicable sub-system. Maintenance personnel use these codes and technical manuals to confirm that the fault has been correctly isolated or to manually isolate the fault to a specific component if only the sub-system was identified. Once a fault is correctly isolated, maintainers can then address the root cause. If maintainers can find and fix the root cause, they will document the work as complete and assign the fault to the specific component in the maintenance records. If maintainers cannot replicate the fault or find the root cause, they will assign the fault to "troubleshooting" instead of assigning it to a specific component.

(U) Reliability

(U) Aircraft maintenance records and flight hour data were used to calculate reliability metrics to assess specific aspects of the overall system reliability. Data from aircraft assigned to the OTSs was used to assess the IOT&E performance. Data from the U.S. fleet was consistent with the results from the OT aircraft and was used to evaluate the reliability drivers.

(U) The F-35 aircraft assigned to the U.S. OTSs during the IOT&E did not meet most of the threshold reliability requirements. To sustain aircraft at desired mission-capable rates, operational units will have to deploy with more spare parts and will have an increased supply system demand than planned. In-flight software faults frequently caused the loss or degradation of critical mission systems. Analyzing and troubleshooting these faults is challenging, because the aircraft's onboard diagnostic system – designed to capture these faults – failed to identify a large percentage of them as problems.

(U) Mission Reliability (KPP)

(U) Mission reliability is a measure, expressed as a percentage, of the likelihood of completing an operational mission of a specified duration without experiencing a mission-critical failure. These are referred to as operational mission failures (OMF) and may be caused by a hardware failure or software fault that results in a partial, temporary, or complete failure of a system that is critical for the conduct of *any* defined F-35 mission – which may not be the specific mission the aircraft was tasked with when the failure occurs.

(U) The results, summarized in Table 4-16, show that no variant from the OT aircraft fleet met the threshold MR requirement. For the U.S. fleet, the F-35B came very close to meeting its requirement, but the F-35A and F-35C fell short.

(U) Table 4-16. F-35 Mission Reliability during IOT&E

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Variant	Mission Reliability		
	Threshold Requirement[a]	OT Aircraft[b]	U.S. Fleet[c]
F-35A	≥ 93 percent (at an ASD of 2.5 hours)	84.6 percent	86.4 percent
F-35B	≥ 95 percent (at an ASD of 1.1 hours)	93.2 percent	94.5 percent
F-35C	≥ 95 percent (at an ASD of 1.8 hours)	94.1 percent	92.6 percent

a. Mission reliability is specified by the JSF ORD using the following equation: MR = $e^{-\left(\frac{ASD}{MFHBOMF}\right)}$. The threshold requirement specifies the applicable ASD.

b. All U.S. F-35 OT aircraft, using all flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

c. All U.S. F-35 (LRIP 2+) aircraft, using all flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

Acronyms: ASD – average sortie duration; JSF ORD – Joint Strike Fighter Operational Requirements Document; LRIP – low-rate initial production; MFHBOMF – mean flight hours between operational mission failures; MR – mission reliability; OT – operational test

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(U) Mission reliability is a function of OMFs, which are uniquely defined events identified either automatically by the aircraft's diagnostic system or manually by pilots or maintenance personnel. Table 4-17 shows the OMF rate for both the OT aircraft and the U.S. fleet during the defined IOT&E period. Key factors affecting OMFs, and hence, mission reliability, are discussed below.

(U) Table 4-17. Operational Mission Failure Rate during IOT&E

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Variant	Mean Flight Hours Between Operational Mission Failures		
	Threshold Requirement[a]	OT Aircraft[b]	U.S. Fleet[c]
F-35A	≥ 34.4 hours	15.0 hours	17.1 hours
F-35B	≥ 21.4 hours	15.6 hours	19.4 hours
F-35C	≥ 35.1 hours	29.4 hours	23.5 hours

Variant	Mean Flight Hours Between Operational Mission Failures		
	Threshold Requirement[a]	OT Aircraft[b]	U.S. Fleet[c]

a. Calculated based on the ORD specified mission reliability and average sortie duration. Mission reliability is defined by the JSF ORD using the following equation: $MR = e^{-\left(\frac{ASD}{MFHBOMF}\right)}$. The threshold requirement specifies the applicable ASD.

b. All U.S. F-35 OT aircraft using all flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

c. All U.S. F-35 (LRIP 2+) aircraft using all flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

Acronyms: ASD – average sortie duration; JSF ORD – Joint Strike Fighter Operational Requirements Document; LRIP – low-rate initial production; MFHBOMF – mean flight hours between operational mission failures; MR – mission reliability; OT – operational test

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(U) The top five OMF drivers by system account for more than half of those reported for the U.S. F-35 fleet (shown in Table 4-18). At the system-level, four of the five top drivers are common for all variants: the integrated air vehicle architecture (mission system); electronic warfare; power and thermal management; and the communications, navigation, and identification systems. Data from the U.S. fleet were used to evaluate the OMF drivers because there was not sufficient data from the OT aircraft to evaluate drivers at the system level.

(U) Table 4-18. U.S. F-35 Fleet Operational Mission Failure Drivers by System

(b)(1) [redacted]

(U) The OMF drivers are much more spread out across many individual hardware components. Improving the reliability of hardware components typically requires component redesigns followed by manufacturing and proliferation of the new components throughout the fleet. Improving F-35 reliability via redesign of hardware components is further complicated by the large size of the fleet that would require retrofit.

(U) Mission system software faults can degrade mission performance and may require a pilot-initiated reset of mission systems in-flight. The aircraft's PHM system, designed to automatically detect faults, does not track or report pilot-initiated resets of mission systems in-flight. These software faults, which represent an OMF, could have severe consequences during combat.

(U) Pilots can manually document these events in ALIS, but the process is cumbersome and there is wide variability in this practice. Table 4-19 shows the proportion of OMFs that were reported by pilots versus those automatically identified by the PHM system. While, the mission system software versions are fielded in common configurations for all variants, F-35A pilots reported over a third of all the recorded F-35A OMFs, while F-35B pilots reported 16 percent, and F-35C pilots report 3 percent.

(U) Table 4-19. U.S. F-35 Fleet Operational Mission Failures

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U.S. Fleet[a] Operational Mission Failures		
Variant	**Percent Automatically Reported by PMH**	**Percent Manually Reported by Pilots**
F-35A	64 percent	36 percent
F-35B	84 percent	16 percent
F-35C	97 percent	3 percent

a. All U.S. F-35 (LRIP 2+) aircraft using all flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

Acronyms: LRIP – low-rate initial production; OMF – operational mission failure; PHM – Prognostic Health Management

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(U) Reliability Metrics

(U) The reliability of the F-35 OT aircraft was below requirements for the majority of metrics. There are several reliability metrics, each characterizing a unique aspect of overall system reliability (see Table 4-20). Poor reliability will require operational units to deploy with larger stocks of critical components, and to make more frequent demands for critical components from the supply system in order to sustain their aircraft at desired combat capability, with associated increases in logistics and support burden.

(U) The threshold values for these metrics were based off the F-35 fleet achieving maturity, defined as 200,000 total U.S. fleet flights hours, comprised of 75,000 hours each for the F-35A and F-35B, and 50,000 hours for the F-35C. The program developed reliability growth goals to assess the progress as each F-35 variant matured. At the start of the IOT&E period, the F-35A fleet had achieved maturity, while the F-35B and F-35C fleets had not.

(U) Table 4-20. F-35 Reliability Metrics during IOT&E

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Parameter	Threshold Requirement	OT Aircraft[a]	U.S. Fleet[b]
MFHBCF[c]	F-35A: ≥ 20 hours	F-35A: 8.6 hours	F-35A: 10.1 hours
	F-35B: ≥ 12 hours	F-35B: 7.1 hours	F-35B: 7.2 hours
	F-35C: ≥ 14 hours	F-35C: 13.5 hours	F-35C: 10.8 hours
MFHBME(U)[c]	F-35A: ≥ 2.0 hours	F-35A: 2.0 hours	F-35A: 1.6 hours
	F-35B: ≥ 1.5 hours	F-35B: 1.1 hours	F-35B: 1.3 hours
	F-35C: ≥ 1.5 hours	F-35C: 1.1 hours	F-35C: 1.3 hours
MFHBR[d]	F-35A: ≥ 6.5 hours	F-35A: 3.7 hours	F-35A: 5.5 hours
	F-35B: ≥ 6.0 hours	F-35B: 2.4 hours	F-35B: 3.3 hours
	F-35C: ≥ 6.0 hours	F-35C: 4.7 hours	F-35C: 4.5 hours

a. All U.S. F-35 OT aircraft using all flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

b. All U.S. F-35 (LRIP 2+) aircraft using all flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

c. During the IOT&E period the F-35B and F-35C had not reached the cumulative flight hours defined by the reliability growth plan but have since reached 'maturity'. Interim reliability goals for the F-35B and F-35C were approximately 10 to 15 percent lower than the requirement at maturity.

d. Includes both scheduled and unscheduled maintenance events.

Acronyms: MFHBCF – mean flight hours between critical failures; MFHBME(U) – mean flight hours between maintenance events (unscheduled); MFHBR – mean flight hours between removals; OT – operational test

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(U) Mean flight hours between critical failures (MFHBCF) includes all failures that render the aircraft unsafe to fly, along with any failures that cause the loss of a mission-essential function that would prevent the completion of a defined F-35 mission. It includes failures discovered both in the air and on the ground. OMFs (discussed above) are the subset of critical failures that are discovered during a mission.

(U) All variants of the U.S. fleet were below both their MFHBCF requirement and their growth goal, with the F-35A achieving only 50 percent of its threshold value. The F-35B, with the most flight-safety critical components, such as the lift system that neither the F-35A nor F-35C have, was significantly less reliable than either the F-35A or F-35C. The overall U.S. F-35C fleet was below its growth goal. The OT F-35C fleet was above its growth goal, but it was still below its requirement for MFHBCF at maturity.

(U) The top five drivers by system account for around 40 to 50 percent of the reported critical failures for the U.S. F-35 fleet (shown in Table 4-21). Four of the five top drivers are common between all variants: integrated air vehicle architecture; electronic warfare; power and thermal management; and access doors and covers (this includes frequently used maintenance access and refueling panels).

(U) Table 4-21. U.S. F-35 Fleet Critical Failure Drivers by System

[redacted]

(U) The poor critical failure rate was a significant contributor to low availability and low FMC rates. Improving reliability will be difficult because the critical failures are relatively evenly spread out among many different components. Looking at critical failures of individual components across the whole U.S. F-35A fleet, the top 20 drivers by component accounted for only 24 percent of all critical failures and the top 72 drivers account for 50 percent.

(U) Mean flight hours between maintenance events – unscheduled (MFHBME(U)) is a reliability metric for evaluating maintenance workload caused by unplanned maintenance. Maintenance events are either scheduled (e.g., inspections or planned part replacements) or unscheduled (e.g., failure remedies, troubleshooting, replacing worn parts such as tires).

(U) Some F-35 fleets achieved MFHBME(U) requirements or growth goals. The OT F-35A fleet met its MFHBME(U) threshold requirement; however, the whole U.S. F-35A fleet was at only 80 percent of the requirement. The whole U.S. F-35B and F-35C fleets were at or near their reliability growth goals for MFHBME(U), but below their threshold requirements.

(U) The top five drivers by system accounted for between 55 and 66 percent of the reported unscheduled maintenance events for the U.S. F-35 fleet (shown in Table 4-22). Four of the top five system-level drivers are common between all variants: landing gear, access doors and covers, LO surfaces standard practices, structures (this includes LO system restoration), structures; and wings.

(U) Table 4-22. U.S. F-35 Fleet Unscheduled Maintenance Events Drivers by System

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(U) Notably frequent unscheduled maintenance events included repairs to the aircraft LO system, replacement of attaching hardware (which is not included in the MFHBR metric), and issues involving tires. Non-critical false alarms produced by the PHM system were also a large driver of maintenance events. Direct maintainers do not have to expend much effort on most of these false alarms. However, personnel who manage maintenance and preserve aircraft records do incur a significant administrative burden to confirm that these false alarms are not actionable, and then sign them off in ALIS. The program has deployed filters in ALIS to automatically remove the known false alarms; however, a large number still pass through these filters and need to be manually resolved.

(U) Mean flight hours between removals (MFHBR) indicates the degree of necessary logistical support. It includes the removal of all repairable items from the aircraft for replacement, whether scheduled or unscheduled. It does not include (1) replacement of consumable items such as nuts, bolts, washers, gaskets, and other piece parts; (2) removals to facilitate other maintenance; or (3) cannibalizations. Not all unscheduled removals are failures. For example, some removed items are later determined not to have failed when tested at the repair site, and other components, such as worn tires, may be removed because they display signs of excessive wear.

(U) All variants were below their MFHBR requirements or growth goals. The F-35B had the lowest MFHBR reliability. The whole U.S. F-35B fleet achieved only 55 percent of its threshold requirement for MFHBR, and was also well below its growth goal. Unscheduled replacements accounted for at least 80 percent of all replacements for each variant. Low MFHBR reliability, particularly for unscheduled replacements that maintenance cannot plan to, increases the number of spare parts the program has to purchase in order to achieve its availability and FMC rate goals compared to initial plans for spares purchases.

[redacted]

(U) Table 4-23. U.S. F-35 Fleet Removal Drivers by System

[redacted]

(U) Maintainability

(U) Aircraft maintenance actions are required to support flight operations, ensure aircraft safety for flight, and to restore aircraft to MC or FMC status after system failures. Maintenance events included scheduled maintenance such as inspections, servicing, and planned part replacements; and unscheduled maintenance to troubleshoot and remedy failures or replace worn parts, such as tires. The F-35 aircraft, enabled by ALIS, was designed to be highly maintainable with the ability to monitor its health status using sensor and subsystems data, and automatically identify faults to minimize manual troubleshooting and to reduce overall maintenance times. This process involves downloading the relevant data from the aircraft after flight for off-aircraft processing in ALIS. The F-35 was also designed to reduce maintenance required for the LO system by incorporating quick access panels to facilitate frequent maintenance actions without requiring LO system restoration.

(U) Maintainability Metrics

(U) The F-35 takes at least twice as long to repair as required by the JSF ORD threshold values. The maintainability measures include mean corrective maintenance time for critical

(b)(1) [redacted]

failures (MCMTCF), mean time to repair (MTTR) for all unscheduled maintenance, and maintenance man-hours per flight hour (MMH/FH) (see Table 4-24). 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 the average time needed for maintainers to return an aircraft from NMC to 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 the MCMTCF and MTTR measures include "active touch" labor time, as well as cure times for coatings, sealants, paints, and so on, but do not include logistics delay times, such as how long it takes to receive shipment of a replacement part. MMH/FH measures the active touch labor time required from each maintainer to perform scheduled and unscheduled maintenance actions averaged over the flight hours the aircraft has flown. It is a general indicator of the direct labor burden to maintain the aircraft.

(b)(1) [redacted]

(U) The program may be able to reduce the amount of aircraft downtime for critical maintenance by focusing on improving the reliability of select top drivers for MCMTCF. This is because maintenance downtime for critical failures was more concentrated in fewer components than the overall occurrence of critical failures. For example, for the whole U.S. F-35A fleet, the top 20 individual component drivers for critical maintenance downtime accounted for 43 percent of all critical maintenance downtime.

(b)(1) [redacted]

(b)(1) [redacted]

(U) During IOT&E, the MMH/FH requirement was met by the F-35A, but not met by the F-35B and F-35C.[6] The maintenance time and crew size for each maintenance task is manually documented in ALIS by maintenance personnel. Some maintenance tasks conducted shipboard may require additional time, and the MMH/FH for the F-35B and F-35C variants may increase with more frequent ship-based deployments. Some difference in the reported MMH/FH between variants may be due in part to Services' reporting practices.

(U) For the OT aircraft during IOT&E, MMH/FH values were closer to requirement than MCMTCF and MTTR values. This is because non-active touch labor time, such as cure time, contributed significantly to long MCMTCF and MTTR times.

(U) Table 4-24. F-35 Maintainability Metrics during IOT&E

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Parameter	Threshold Requirement	OT Aircraft[a]	U.S. Fleet[b]
MTTR	F-35A: ≤ 2.5 hours	F-35A: 7.0 hours	F-35A: 6.1 hours
	F-35B: ≤ 3.0 hours	F-35B: 6.0 hours	F-35B: 6.7 hours
	F-35C: ≤ 2.5 hours	F-35C: 6.4 hours	F-35C: 5.1 hours
MCMTCF	F-35A: ≤ 4.0 hours	F-35A: 8.3 hours	F-35A: 11.2 hours
	F-35B: ≤ 4.5 hours	F-35B: 8.9 hours	F-35B: 10.8 hours
	F-35C: ≤ 4.0 hours	F-35C: 14 hours	F-35C: 11.8 hours
MMH/FH[c]	≤ 9.0 hours	F-35A: 7.5 hours	F-35A: 5.0 hours
		F-35B: 11 hours	F-35B: 8.8 hours
		F-35C: 9.7 hours	F-35C: 6.6 hours

a. All U.S. F-35 OT aircraft using all flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019.

b. All U.S. F-35 (LRIP 2+) aircraft using all flight hours and maintenance events completed between Dec 3, 2018 – Sep 30, 2019

c. Includes both scheduled and unscheduled maintenance events.

Acronyms: MMH/FH – maintenance man-hours per flight hour; MTTR – mean time to repair; MCMTCF – mean corrective maintenance time for critical failures; OT – operational test

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(U) LO System Maintainability

(b)(1) [redacted]

[6] (U) All results are based on maintenance conducted ashore.

(b)(1) [redacted]

(b)(1) [redacted]

(U) Table 4-25. Lower-Bound Estimate of the LO System Cure Time Contribution to the Total Elapsed Maintenance Time

(b)(1) [redacted]

(U) Propulsion Removal and Installation

(b)(1) [redacted]

[redacted]

(U) Table 4-26. F-35 Propulsion System Maintenance Times

[redacted]

(U) Prognostic Health Management

(U) The PHM system is intended to enhance flight safety and reduce the maintenance burden by automatically diagnosing aircraft faults in mission- and safety-critical systems, or even predict their impending failure based on data from on-aircraft sensors to enable pre-emptive replacement. However, the PHM diagnostic and prognostic functions do not work as intended, because the system is immature, has important coverage gaps, and results in additional troubleshooting maintenance activities.

(U) PHM diagnostic functions were designed detect system failures and isolate them to the individual line-replaceable component. This is the smallest level component that a squadron-level unit can swap out of an aircraft. ALIS automatically generates maintenance work orders once the PHM data are downloaded from the aircraft after flight. Maintainers then use the Anomaly and Failure Resolution System (AFRS) application in ALIS to attempt to isolate and repair the failures.

[redacted]

(U) Diagnostic performance is evaluated by the fault detection rate, fault isolation rate, and two false alarm rates; one for all false alarms and the other for only flight-safety critical false alarms. During the IOT&E period the U.S. fleet experienced a very small number of flight-safety false alarms events where PHM falsely indicated a flight-safety critical failure during flight (there were three reported flight-safety false alarms in more than 46,000 flight hours). The majority of the remaining diagnostic measures failed to meet their threshold requirements, as summarized in Table 4-27 with U.S. fleet data for comparison.

(U) Table 4-27. F-35 PHM Diagnostic Metrics during IOT&E

[redacted]

(U) PHM diagnostics produce a large number of automatically generated work orders due to false alarms, leading to inefficient use of maintenance resources. The false alarm rates for all variants were less than 1 hour between false alarms, against a threshold requirement of 50 hours. The F-35B variant produced about twice as many false alarms per hour as the F-35A or F-35C. This creates a high burden on maintenance management personnel to administratively sign off on the known false alarm work orders that ALIS automatically generates. About 95 percent of false alarms are pre-emptively signed off by maintenance supervisors without leading to any troubleshooting or direct maintenance action on the aircraft. The other five percent of false alarms resulted in an average of one hour of elapsed maintenance time for direct maintainers to troubleshoot before they determined that the PHM indication of a failure was not valid.

(U) Efforts to tackle the high false alarm rates have so far not yielded major progress toward meeting threshold requirements. Before IOT&E began, the program introduced software-based filters within ALIS to screen PHM from generating work orders for false alarms. While it has been refining these filters ever since, a large number of false alarms still result in non-actionable maintenance work orders. One cause of high false alarm rates is that new aircraft software loads, or new versions of hardware, tend to produce new false alarms, and the PHM filters lag the pace of system updates.

(U) Fault detection rates were closer to their threshold requirements than false alarm rates, with the U.S. fleet F-35B and F-35C calculated to meet the requirement. However, significant differences in estimated detection rates between variants indicate that PHM does not detect some failures that affect mission capability, and that the calculated detection rates for the F-35B and F-35C may be optimistic. The effects of missed PHM detects can range from potentially flying aircraft with failed critical components unknown to the pilots, to a greater burden placed on maintenance ground crews and pilots to inspect for faults.

(U) The fault detection rate is determined by comparing the faults PHM automatically detected with all found faults that PHM should have detected. By definition, the faults that PHM should have detected, but did not, were instead first reported by a human and then investigated to determine whether PHM should have registered the failure condition. F-35A pilots reported faults at a much higher rate than F-35B and F-35C pilots. This contributed to the U.S. fleet F-35A's estimated fault detection rate of 87 percent being below the fault detection rates of U.S. fleet F-35B and F-35C aircraft, which were both calculated at the threshold requirement of 98 percent. Of the confirmed PHM missed detects within the U.S. F-35A fleet, 74 percent were critical failures, and 81 percent of those were OMFs. Unlike many manually reported OMFs, all of the confirmed PHM missed detects represented actionable hardware failures rather than software instabilities. PHM missed detects were spread over many components with few standout drivers, although there was a slight concentration in the throttle grip, cockpit displays, and data security processor.

(U) Fault isolation rates for PHM-detected failures were below requirement, requiring extended troubleshooting time to identify and correct the root causes of these failures. Results were relatively consistent across variants, especially in the overall U.S. fleet where fault isolation rates were around 80 percent for each variant, compared to a threshold of 90 percent. The AFRS attempts to isolate faults to group of line-replaceable components within which the root cause should reside. While the F-35 did not meet its threshold requirement for isolating to a single line-replaceable component, it was significantly more accurate at isolating faults in non-electronic components than it was for faults in avionics. It also met contract specifications for isolating to an ambiguity group of no more than three line-replaceable components. Maintainers regularly note the lack of troubleshooting manuals and documentation to enable them to perform their tasks or provide feedback to improve the accuracy of the AFRS.

(U) Prognostics is intended to track the remaining useful life in components to allow maintainers to predict failure ahead of time. The intended benefits of prognostics are to avoid failures and to reduce wait times for spare parts by ordering replacements well before impending failure. Prognostic algorithms, also known as Assess Material Condition algorithms, are deployed to ALIS and grow more mature in accuracy as failure and PHM sensor data accrue. Few prognostic algorithms have been delivered to date. As of ALIS version 3.5, there were 16 active aircraft prognostic algorithms and 63 propulsion algorithms, all in various states of maturity.

(U) Autonomic Logistics Information System

(U) ALIS had poor usability, required large amounts of maintainer time to complete application tasks, experienced frequent disruptions, did not provide maintainers with all desired information and capabilities, and did not present consistent information to maintainers. The failure of ALIS to provide needed information, combined with maintainer mistrust of the information ALIS did provide, drove all three OTSs to track key aspects of aircraft and support equipment configuration manually outside of ALIS, each with their own unique processes. Electronic Equipment Log supply data within ALIS were often missing or inaccurate as well. Maintainers reported that these ALIS shortfalls extended maintenance task timelines, increased maintainer workload, complicated maintenance planning, and delayed aircraft availability to support the flying schedule.

(U) Based on maintainer responses to the task surveys, ALIS frequently experienced disruptions that hindered efficient task execution. Maintainers reported that ALIS crashed or failed in 29 percent of survey responses. Maintainers reported compounding factors a significant amount of the time as well. Six percent of survey responses noted manpower shortages, 6 percent noted problems with support equipment, and 5 percent stated a need for contractor field service engineer support to complete the task. Only 65 percent of the survey responses reported that ALIS worked without any issues or compounding factors present. When maintainers experienced disruptions in ALIS operations, or there was a compounding factor present, they reported that ALIS made their job more difficult and they had to spend a larger percentage of task time interacting with, or waiting on, ALIS. When ALIS was working without issues and no compounding factors were present, maintainers rated ALIS usability at 64, corresponding to a C minus letter grade, and reported that they spent, on average, 43 percent of their time working with ALIS. In 9 percent of survey responses, maintainers reported at least two issues with a task, such as an ALIS crash and at least one additional compounding factor. In these survey responses, maintainers rated ALIS usability at 49, corresponding to an F letter grade, and reported that they spent, on average, 51 percent of their time working with ALIS. Issues revealed by interview data reinforced these maintainer perceptions of general ALIS usability revealed by the task surveys. Maintainers perceived that ALIS was slow, unwieldy to navigate, and burdensome to document maintenance. The time burden to document maintenance in ALIS, especially if ALIS has a disruption, could also exacerbate a compounding factor such as a lack of manpower, as more man-hours have to be spent interacting with ALIS.

(U) Based on interview data, maintainers noted that they did not have access to information required to perform their jobs, but that contractor field service engineers did have access to that information; additionally, these type of information are readily available on legacy platforms. This included more detailed schematics and, in particular, the Identify and Locate documentation to help maintainers ensure they have the correct part numbers for ordering replacements from supply, and aircraft locations for those parts to conduct maintenance. Field service engineers also had access to additional information to distinguish whether health reporting codes produced by the PHM system were actionable or non-actionable. This lack of information forces dependency on contractor field service engineers for daily operations, even in peacetime, with unknown implications for combat operations in a deployed environment against a peer threat.

(U) ALIS supported deployment planning and post-deployment retrograde, subject to the general performance issues cited within this report. Each of the units involved with the deployments during IOT&E that included the SGR demonstrations sent one of their ALIS Squadron Kit's SOU servers ahead of the aircraft to the deployment site. ALIS personnel and other support personnel went along with the unit's SOU, ahead of the aircraft and pilots, to set up maintenance operations and be ready to receive the aircraft, which is standard practice. During the MCAS Yuma SGR deployment event, an ALIS hardware reliability issue surfaced while setting up the Squadron Kit: An electrical fault damaged two hard drives beyond the ability of the unit to repair. It took two days for contractor personnel to arrive with replacement drives and bring the Squadron Kit online, during which time the unit did not fly their aircraft because of safety concerns. While there were no other notable ALIS hardware reliability issues during IOT&E, this incident shows a brittle reliance on a functional ALIS system with little to no graceful degradation in ability to maintain flight operations in case of key ALIS hardware failures.

(U) ALIS Applications Usability and Issues

(U) Based on data from the usability surveys, individual ALIS applications were rated at the equivalent of a C to F letter grade by maintainers. Each application had performance issues driving workarounds, or negatively impacting sortie generation and aircraft sustainment. Table 4-28 describes the typical use for each of the ALIS applications and summarizes the ALIS application usability survey numbers and ratings based on data collected across all IOT&E events. The test team collected 360 surveys across seven of the more widely used ALIS applications and conducted user interviews. As only a single response was received for the supply chain management application, a valid usability score could not be determined. There were some differences based on Service member experience levels; more experienced personnel generally rated ALIS applications worse in usability than less experienced personnel. There were no significant differences in responses by Service.

(U) Table 4-28 – ALIS Application Usability Survey Results

[redacted]

(b)(1) [redacted]

(U) Computerized Maintenance Management System

(U) Maintainers interact most with this ALIS application, which did not support rapid aircraft turn-around during the SGR deployments. The amount of time required for maintainers to document turn-around actions down to the level of task granularity required prevented F-35C aircraft onboard CVN 72 from executing a single cycle turn with a 90-minute deck cycle. This means that when the carrier is launching aircraft on 90-minute intervals, an F-35C that lands needing to turn around and fly again will not be ready to launch again within 90 minutes without workarounds, and will instead have to wait for the following launch opportunity, 180 minutes after landing. To execute the carrier's air plan, the F-35C unit elected to perform hot seating for 23 of 25 scheduled single cycle turns. With a hot seat, maintainers do not conduct the full standard series of between-flight inspections and servicing actions. Similarly, both the F-35A deployment at Volk Field and the F-35B deployment at MCAS Yuma performed hot seating and hot refueling to try to achieve higher SGR rates because of usability issues with this application, even though neither were beholden to deck cycle-driven launch opportunities and could fly when ready.

(U) The Computerized Maintenance Management System occasionally presented inconsistent or conflicting data. Interview respondents cited examples such as one page showing a panel as installed, with another page showing that same panel as off of the aircraft. These inconsistencies reduce maintainer's confidence in the accuracy of data within ALIS. They can also extend maintenance timelines, in this particular example by forcing maintainers to visually

(b)(1) [redacted]

ascertain the correct configuration of the aircraft. Some inconsistencies require additional tracking of the true information outside of ALIS, increasing workload due to double documentation. Maintainers reported particular difficulties in tracking aircraft modifications within this application, and often needed to manually track them outside of the application.

(U) The Computerized Maintenance Management System also did not accurately track weapons statuses or allow the creation of maintenance actions for installing weapons on certain stations. This forced ordnance personnel to track ordnance maintenance requirements outside of the application, and employ workarounds to configure the aircraft with the appropriate munitions within ALIS.

(U) ALIS Application Used for Maintenance and Troubleshooting

(U) The AFRS application often lacked solution sets for health reporting codes, or its solution sets did not adequately resolve faults. Similarly, the Joint Technical Data occasionally had insufficient information to enable maintainers to execute repair actions, or had inaccurate information. In these cases, maintainers had to request external assistance by submitting Action Requests using the Customer Relationship Management application. Maintainers frequently stated that action request response times were too long. The resilience of this maintenance construct in a conflict situation with lost or severely degraded communications outside of the unit is unknown.

(U) Maintenance Management Production Aircraft Inspection Requirement System

(U) This ALIS application either had missing or inconsistent information, such as one screen reporting that an inspection for a component was overdue while another page displayed that the component still had usage life on it before needing the maintenance. As a result, each OTS developed methods to track inspection requirements outside of ALIS.

(U) LO Defect Entry Module

[redacted]

(U) Supply Chain Management

(U) Interview respondents reported frequent difficulties ordering parts using this ALIS application. The most commonly cited issues were different Lockheed Martin and original equipment manufacturer part numbers for the same parts, causing confusion as to the correct part number to use, and that the supply chain management application allowed substitution of different versions of parts that were not actually compatible with the specific aircraft the part was being ordered for. Estimated delivery dates within this application were often missing or

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inaccurate, leading unit maintainers to directly interact with upstream supply personnel and manually track parts delivery status outside of ALIS.

(U) When parts did arrive, oftentimes their associated electronic equipment list records either were not delivered within ALIS or had obvious inaccuracies. Maintainers cannot install a component in the aircraft without an accurate electronic equipment list on hand. In these cases, they had to rely on ALIS administrator intervention, or submit an action request to remedy the situation, further delaying returning aircraft to mission-capable status.

(U) LO Signature

(b)(1) [redacted]

(U) LO Signature Stability Over Time

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Figure 4-3. Timeline of F-35 Dynamic RCS Measurements

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[redacted]

(U) Figure 4-4. RCS Measurements: Elevation Cuts (left) and Azimuth Sectors (right)

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[redacted]

(b)(1) [redacted]

(U) Table 4-29. Summary of Radar Signature Measurements during IOT&E

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(b)(1) [redacted]

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[redacted]

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(U) Figure 4-5. LOHAS Overview

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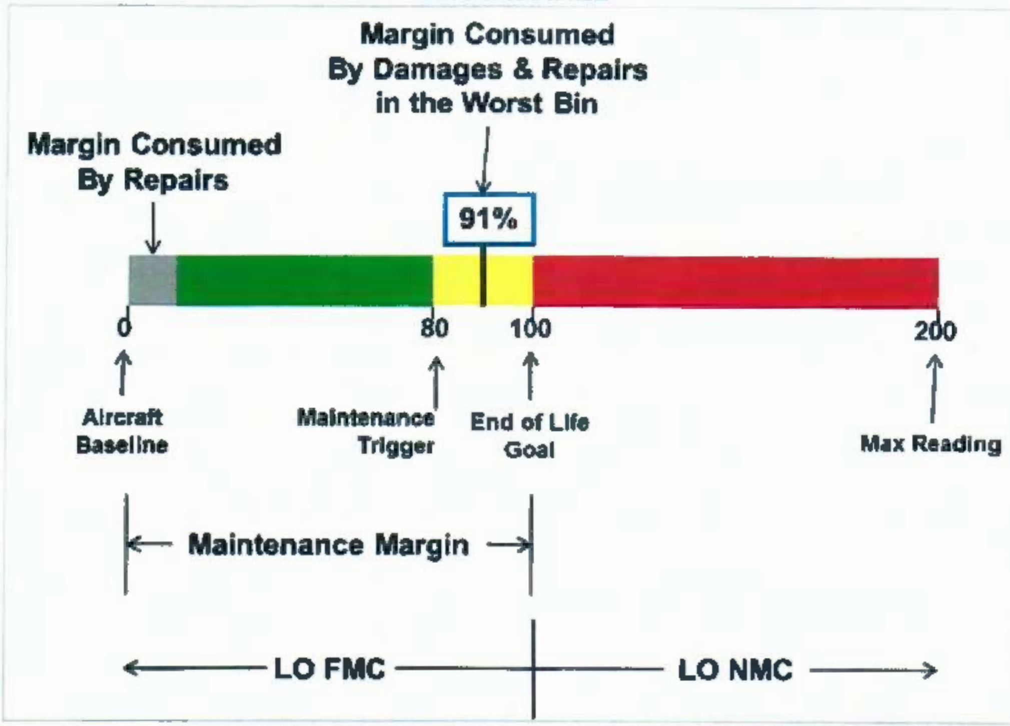

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(U) Figure 4-6. LOHAS 'Gas Gauge' Description

[redacted]

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7 (U) Only 22 of the IOT&E measurement missions had the needed data available from the corresponding LOHAS audit accomplished prior to dynamic measurement in order to provide an accurate comparison with LOHAS.

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(U) RCS Measurements

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[redacted]

(U) Table 4-30. F-35 Threshold Signature Requirements

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(U) Training

(U) The F-35 training system provides aircraft specific training and is intended to prepare mission-ready pilots and maintenance support personnel. It supports both new and experienced personnel and includes initial and continuing training.

(U) Pilot Training

[redacted]

(U) Initial F-35 pilot training consists of classroom training, computer-based courseware, flight training devices (full mission simulator and mission rehearsal trainers), and live training missions conducted with F-35 aircraft and surrogate and simulated threats and targets. Pilots receive continuing training at operational units in-flight training devices and during live training missions. The following areas for training improvement were noted by pilots at training and operational units:

- (U) Mismatches between software versions in the aircraft and on training devices;
- (U) Lag in updating courseware to reflect fielded hardware and software;
- (U) Unacceptable training device reliability, and
- (U) Off-board Mission System training was unacceptable, due to a combination of the Off-board Mission System's poor user interface and the lack of practical exercises.

(U) The Training Management System was not used as intended to maintain pilot training and records; most bases use legacy methods including paper.

(U) Maintainer Training

(U) The F-35 maintainer training program was suitable to provide mission-ready support personnel. Training includes computer-based courseware (instructor-led and self-paced), Aircraft Simulated Maintenance Trainers (a virtual maintenance training environment similar to a video game), and maintenance training devices (mock-ups used for hands-on training). Thirty of 36 (83 percent) of students agreed that the hands-on maintenance training with actual aircraft or mock-ups met the training objectives. Instructors largely agreed that the training achieved objectives and that course material generally served its purpose. Instructors noted that the students would require additional on-the-job training when they arrived at their gaining units because course materials lagged fielded software versions and the Aircraft Simulated Maintenance Trainers could be several years out of date from the fielded versions. The Training Management System was not used as intended for managing maintainer training and records; most bases use legacy methods including paper.

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Section Five
(U) Survivability

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(U) Live Fire T&E

(U) Testing assessed the F-35 aircraft and pilot's vulnerability to kinetic threats, chemical and biological threats, low-power lasers, and electromagnetic pulse and high-power microwave threats expected to be encountered in combat. DOT&E approved the use of an early flight test aircraft, void of mission systems components, along with two complete airframe structural test articles and four F135 engines as sufficient for the live fire testing. Models, based on data from live fire events, were used to assess the vulnerabilities to specific ballistic threats.

(b)(1) [redacted]

(b)(1) [redacted]

(U) Assessments for chemical and biological threat vulnerabilities included pilot protection, aircraft hardness (i.e., ability to maintain mission-ready status), and decontamination procedures. Results show that the aircraft and associated equipment can protect the pilot against the effects of chemical and biological agents. The inherent hardness of the aircraft to these agents, and the manner in which it is serviced and maintained, enable it to fight through a chemical or biological contamination event and retain Full Mission Capability, without decontamination, for at least 30 days after contamination, which meets the requirement. Tests demonstrated that both chemical and biological decontamination processes could reduce contamination levels sufficiently for operational service without the need for pilots or maintenance personnel to wear protective gear.

(b)(1) [redacted]

(U) Kinetic Threats

(U) To assess F-35 vulnerability to kinetic threats, testers identified potential vulnerability contributors and determined their significance based on the threats listed in the F-35 contract specification. An extensive live fire test program (summarized in Table 5-1) addressed the set of live fire test and evaluation (LFT&E) issues. The resulting vulnerability assessments compared all three variants of the F-35 to other aircraft, and identified the major contributors to the F-35 vulnerability and their relative significance.

(U) Table 5-1. JSF Program Live Fire Test Summary

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[redacted]

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[redacted]

(b)(1) [redacted]

(U) Kinetic Threat Vulnerability Assessment Methodology

(U) Figure 5-1 illustrates the F-35 kinetic threat vulnerability assessment process. It is based on and is a subset of the Lockheed Martin process for vulnerability-reduction design and vulnerability assessment. The process began with a computer-generated geometric target model of each F-35 variant for evaluating effects of threat impacts and penetrations on aircraft components. The contractor started with its computer-aided design (CAD) models of each F-35 variant and developed further simplified models that retained features important to the vulnerability assessments. These models were used with the computational vulnerability assessment tools, Fast-Shotline Generator (FASTGEN) and Computation of Vulnerable Area Tool (COVART), to determine vulnerability uncertainties, establish the Live Fire Test Plan, and assess the aircraft vulnerabilities. The following sections detail those parts of the assessment process.

(U) The target models for the F-35 vulnerability analyses also included internally mounted munitions: two AIM-120 missiles and two Joint Direct Attack Munitions (JDAM), the latter of which had a net explosive weight of 2,000 pounds for the F-35A and F-35C and 1,000 pounds for the F-35B. The fuel state was set at 60 percent of total capacity and distributed in each individual tank based on standard fuel feeding processes and burn curves.

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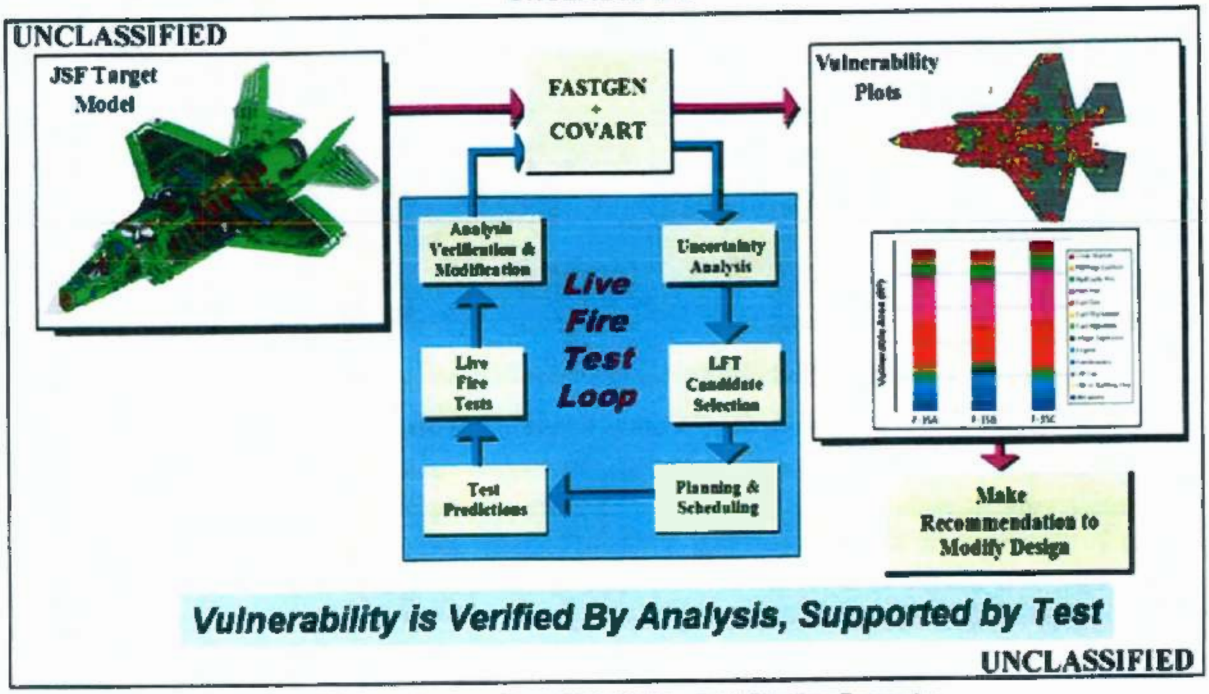

(U) COVART – Computation of Vulnerable Area Tool; FASTGEN – Fast-Shotline Generator

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(U) Figure 5-1. Vulnerability Assessment Process

(U) Computational Vulnerability Assessment Framework – FASTGEN/COVART

[redacted]

(U) COVART version 4.4.2 was then used to evaluate the vulnerability associated with each shotline by determining the probability of critical component kills as a threat traveled along the shotline and encountered target CAD model components. The target CAD model descriptions included component criticality and redundancy information; failure modes and their relationships to combat-caused damage derived from contractor Damage Mode and Effect Analyses; Failure Modes Effects and Criticality Analyses; and Failure Analysis Logic Trees.

(U) Early in the program, the contractor conducted a sensitivity analysis to consider how the uncertainty in each component dysfunction might drive the total aircraft vulnerability uncertainty, given a particular hit probability. This analysis provided the basis for defining a live fire test program to address significant knowledge shortfalls and associated vulnerability uncertainties, so as to drive the total vulnerability assessment uncertainty down to acceptable levels.

[redacted]

(U) Vulnerability Analysis Confidence and Uncertainty

(U) Uncertainty in the COVART analysis results is driven by (1) the quality of the aircraft design data (i.e., target CAD model validity), (2) uncertainties in the live fire test results, (3) analysis model limitations, and (4) analysis assumptions. The F-35 Joint Program Office worked to identify the constituent contributions to the uncertainty and mitigate where possible. For example, target-model–calculated weights of each component were compared to actual weights in the Lockheed Martin weight statements, and corrections were made if the calculated weights were not consistent. Live fire tests were conducted specifically for the purpose of reducing uncertainty with aspects of the analysis (as opposed to demonstrating damage effects). Lockheed Martin stated that much of their knowledge of COVART uncertainties came in developing the COVART F-35 Accreditation Support Package.[1] They also said that, wherever possible, they eliminated sources of uncertainty or established input values that minimized uncertainty effects. However, as they note, residual uncertainties exist with all empirical data. This is particularly true for live fire test data, where multiple iterations and examination of all possible combinations of variables become prohibitively expensive.

(U) The uncertainties center mainly on the fire prediction curves, which include fuel, PAO, and hydraulic fluid, and to a lesser extent component shielding effects. Error bars representing +9 percent and -6 percent root mean square variation are included in the results summaries for the RtF kill category discussed in the assessment against kinetic threats section below. Uncertainty for the PPE kill category does not include either of the fire-related uncertainties, so the total uncertainty is +/-2.5 percent.

[1] (U) "Accreditation Support Package for FASTGEN/COVART Modeling & Simulation Used to Verify F-35 Spec Requirements," Lockheed Martin document number 2YZA01187, Lockheed Martin Corporation, Fort Worth, Texas, May 14, 2012 (UNCLASSIFIED).

(b)(1) [redacted]

(U) Assessment Against Kinetic Threats

(U) F-35 vulnerabilities to kinetic threats were assessed based on a set of specification missions for each variant against threat capabilities at the RtF and PPE kill levels. The specification missions were developed based on expected F-35 mission sets for each of the Services and the capabilities of each variant. The mission profiles included launch from the operating base, cruise to the target or combat area, mission conduct at 20,000-foot altitude and Mach 0.8, and return to base.

(b)(1) [redacted]

(U) The assessed vulnerabilities were determined under the assumption that each hit is independent – there are no multiple hit interactions – and the increased vulnerability from the synergistic effect of multiple hits is not accounted for.

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2 (b)(1) [redacted]

(b)(1) [redacted]

(U) Figure 5-2. RtF Assessments of $P_{K|E}$ Given an Engagement Against Specification Threats

(b)(1) [redacted]

[3] (U) Vulnerable area is a physical approximation of relative contributors to aircraft kill modes based on the estimated probability of kill for that mode. Vulnerable area estimates are often used to make comparisons between the contributors based on a common reference area.

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[redacted]

(U) Figure 5-3. Vulnerable Area Contributors for the Return to FLOT Kill Level

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[redacted]

(b)(1)

[redacted]

(U) Figure 5-4. PPE Assessments of P_{KE} Given an Engagement

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[redacted]

(b)(1) [redacted]

(U) No live fire testing was conducted to specifically evaluate the ability to repair the F-35 after kinetic threat damage. Between live fire tests, experienced Battle Damage Repair (BDR) crews restored the full-scale test articles to usable condition to assess repair techniques. No unique procedures were developed to repair the F-35, because it is constructed with legacy building techniques and materials. LFT&E did not address capabilities for BDR to repair aircraft skin and low observable coatings to return the aircraft signature to its pre-damage condition.

(U) Chemical and Biological Threat Vulnerabilities.

(U) Chemical and biological threat vulnerabilities were assessed through an extensive developmental and live fire test program. The program determined the aircraft tolerance to the threats, developed and demonstrated the effectiveness of force protection measures for aircrew and maintainers, and developed and demonstrated effective aircraft decontamination techniques.

(U) Extensive testing evaluated F-35 capabilities against chemical and biological agent threats. The program developed and demonstrated capabilities for decontaminating the aircraft and returning it to operational status.

(U) Results indicated the aircraft and associated equipment could protect the pilot against the effects of chemical and biological agents. The inherent hardness of the aircraft to these agents and the manner in which it is serviced and maintained allow it to fight through a chemical or biological contamination event and retain Full Mission Capability, without decontamination, for at least 30 days after contamination.

(b)(1) [redacted]

(b)(1) [redacted]

(U) Electromagnetic Pulse and High-Power Microwave

(U) Electromagnetic environmental effects testing was completed on an F-35B from production lot 11, at the Patuxent River Naval Air Station, Maryland, from July 2019 through November 2020. Electromagnetic environmental effects testing evaluated the aircraft against MIL-STD-464 power levels defined in the aircraft contract specification for the following:

- Intra- and inter-system electromagnetic compatibility
- Hazards of electromagnetic radiation to personnel
- Direct Current bonding
- Hazards of electromagnetic radiation to ordnance
- High-altitude electromagnetic pulses
- Low level coupling
- Indirect lightning effects
- Emission control
- Precipitation static
- Telecommunications Electronics Material Protected from Emanating Spurious Transmissions (TEMPEST) requirements

(b)(1) [redacted]

(b)(1) [redacted]

(U) Cyber-Survivability Assessment

(b)(1) [redacted]

(U) Cybersecurity Testing

(U) The IOT&E cyber-survivability assessment of the F-35 Air System was conducted in accordance with the DOT&E-approved cyber test strategy for IOT&E. In total, the Joint Strike Fighter Operational Test Team (JOTT) evaluated 24 subsystems during the period. Table 5-2 shows which test events from which test plans were completed for each of the 24 subsystems. In cases where not all test objectives were completed (indicated by red text), subsequent testing ensured coverage was adequate to support the cyber-survivability assessments reported here. Because the program did not have a production-representative aircraft available for full-up cybersecurity testing, the knowledge of actual aircraft vulnerability is limited. During the test period, cybersecurity test teams[5] helped assess six system components of the F-35 aircraft:

---

[4] (U) An "insider" is a cyber attacker with both physical and logical (through a user account) access to a system who attempts to gain access through a connected network or by circumventing air-gap security measures; a "nearsider" has only physical access; and an "outsider" has neither.

[5] (U) Cybersecurity operational testing is supported by specially qualified test teams. The JOTT coordinated all cybersecurity testing with blue and red teams, aggregated the data, and provided reports.

(b)(1) [redacted]

(b)(1) [redacted]

Software Data Load (SDL), Weapons Controls and Stores (WC&S), Global Positioning System (GPS), Mode-S Identification Friend or Foe (IFF), Variable Message Format (VMF), and Link 16. In addition, four supporting systems—the Autonomic Logistics Information System (ALIS), Training Systems, the United States Reprogramming Laboratory (USRL), and the Mission Planning and Support Environment (MPSE) —all underwent cyber-survivability assessments. Additional cyber testing events, completed during Block 4 development, are included in a separate annex.

(b)(1) [redacted]

(b)(1) [redacted]

(U) This report uses the term "cyber vulnerability" to mean technical susceptibilities for which general threats may exist but adversary capabilities to exploit the susceptibilities are unknown. DOT&E based its mission effectiveness determinations on its assessment of the potential effects of identified cyber vulnerabilities on F-35 Air System performance.

(U) F-35 Aircraft Cyber-Survivability IOT&E Assessments

(b)(1) [redacted]

(b)(1)

[redacted]

(b)(1) [redacted]

(U) F-35 Supporting Systems Cyber-Survivability IOT&E Assessments

(U) For cyber-survivability assessment purposes, F-35 supporting systems fall into two categories: (1) unclassified systems that have connectivity to DoD-wide unclassified networks; (2) classified systems that have connectivity to classified DoD-wide networks or are air-gapped from other networks entirely.

(U) Autonomic Logistics Information System

(b)(1) [redacted]

(U) Training Systems

(b)(1) [redacted]

(b)(1) [redacted]

(U) United States Reprogramming Laboratory

(b)(1) [redacted]

(U) Mission Planning and Support Environment

(b)(1) [redacted]

(U) Other Assessments

(b)(1) [redacted]

(U) Summary of Vulnerability Findings and Deficiency Reports

(U) Table 5-3 summarizes the results from F-35 Air System cybersecurity testing. Defense Information Systems Agency (DISA) cyber vulnerability severity categories (CATs),[6] with CAT I the most severe, are shown for the cooperative vulnerability and penetration assessments (CVPAs) and adversarial assessments (AAs) conducted by the JOTT. For the CVPAs, the assignment of DISA CATs originated from supporting test team reports; for the AAs, DOT&E assigned DISA CATs based upon its independent review of JOTT and supporting test team reports.

(b)(1) [redacted]

6 (U) DISA CATs are defined as three levels of severity: CAT I - Any vulnerability, the exploitation of which will directly and immediately result in loss of Confidentiality, Availability, or Integrity; CAT II - Any vulnerability, the exploitation of which has a potential to result in loss of Confidentiality, Availability, or Integrity; and, CAT III - Any vulnerability, the existence of which degrades measures to protect against loss of Confidentiality, Availability, or Integrity.

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Table 5-3. Summary of Results from CPVA and AA Tests

(b)(1)

[redacted]

(U) Prevent, Mitigate, Recover, and Mission Effects

(U) F-35 Aircraft

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) F-35 Supporting Systems

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1) [redacted]

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(b)(1) [redacted]

(U) Section Six
(U) Recommendations

(U) The following recommendations are derived from DOT&E's observations of the execution and detailed review of results from the initial operational test and evaluation, examination of the causes of observed F-35 shortfalls in those trials, and consideration of improvement that could be made in the future to test methodologies.

(U) Effectiveness

(b)(1) [redacted]

(b)(1) [redacted]

- (U) The program should significantly increase the amount of ground-based F-35 testing in system integration laboratories and installed system test facilities (e.g., anechoic chambers), to more thoroughly characterize mission systems performance over wider ranges of operating conditions, including high-density signal environments, and capture all data from these tests in formats that facilitate the validation of F-35 performance in the Joint Simulation Environment (JSE).
- (U) The JPO should significantly increase the amount of F-35 developmental flight-testing and integrated developmental/operational flight-testing, to more thoroughly characterize mission systems performance over wider ranges of operating conditions, and capture all data from these tests in formats that facilitate the validation of F-35 performance in the JSE.

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Suitability

- (U) The U.S. Air Force should complete testing to demonstrate and evaluate the capability of F-35A equipped units to deploy on short notice by conducting a F-35A "Rapid Lighting" deployment.
- (U) The JPO should improve the reliability of the aircraft mission systems software and improve tracking of in-flight software faults (for example by automatically logging the number of faults caused by software anomalies and the number of pilot-initiated mission systems resets).
- (U) The JPO should focus on the development and implementation of maintenance system improvements that reduce the total time for low observable repairs and adhesive cure times, which are non-mission capable drivers.

(b)(1)

[redacted]

(U) Survivability

- (U) The JPO should re-analyze the trade-offs for incorporating PAO system and fueldraulics shut-offs in light of the vulnerability analysis results.

(b)(1)

[redacted]

- (U) The JPO should re-examine the On-Board Inert Gas Generating System (OBIGGS) test results to determine if the OBIGGS inerting shortfall can be better characterized in the F-35 vulnerability assessments.

(b)(1)

[redacted]

(b)(1) [redacted]

- (U) The JPO should use the results of the chemical and biological agent decontamination processes to optimize the techniques and procedures in order to determine threshold levels that balance personnel safety with mission readiness.

(b)(1) [redacted]

- (U) The Services should update the HPM and EMP test infrastructure to better approximate adversary capabilities.

(b)(1) [redacted]

- (U) The JPO should provide a test asset that allows for full, end-to-end testing of the air vehicle in a representative cyber threat environment.

(b)(1) [redacted]

(U) Appendix A
(U) Acronyms and Abbreviations

A

AA	adversarial assessment
AAA	anti-aircraft artillery
AARI	Air-to-Air Range Infrastructure
AEL	Advanced Emitter Location
AESA	active, electronically scanned array
[redacted]	[redacted]
AEW	airborne early warning
AFB	Air Force Base
AFRS	Anomaly and Failure Resolution System
AI	air interdiction
ALIS	Autonomic Logistics Information System
ALOU	Autonomic Logistics Operating Unit
AMRAAM	Advanced Medium-Range Air-to-Air Missile
ANGB	Air National Guard Base
API	armor piercing incendiary
APOC	assembly proof of concept
[redacted]	[redacted]
ASD	average sortie duration
ASuW	anti-surface warfare
ATC	Automatic Target Recognition by Class

B

BVR	beyond visual range

C

CAD	computer-aided design
CAS	close air support
CDA	concept development aircraft
CDD	Capability Development Document
CG	guided missile cruiser (naval ship class)
CLS	contractor logistics support
CM	countermeasures
CMD	cruise missile defense
COE	Classified Operational Environment

COVART	Computation of Vulnerable Area Tool
CPE	Central Point of Entry
CTOL	conventional takeoff and landing
cu ft	cubic feet
CV	carrier variant
CVPA	Cooperative Vulnerability and Penetration Assessment

D

DART	Data Analysis, Recording, and Telemetry
DAS	Distributed Aperture System
DBFSS	Dry Bay Fire Suppression System
dBsm	decibels relative to one square meter
DCA	defensive counter-air
DDG	guided missile destroyer (naval ship class)
DEAD	destruction of enemy air defenses
Det	Detachment
DEU	datalink enhanced update
DISA	Defense Information Systems Agency
DMSpA	direct manpower spaces per aircraft
DoE	design of experiments
DR	deficiency report
DRFM	digital radio frequency memory
DT	developmental testing
DTO	DEAD target objective

E

EA	electronic attack
EHA	electro-hydrostatic actuator
[redacted]	[redacted]
ELINT	Electronic Intelligence
EMP	electromagnetic pulse
EOTS	Electro-optical Targeting System
EP	electronic protection
ESA	electronically scanned array
ESM	electronic support measures
EW	electronic warfare
EXCOM	Executive Committee

F

FAC(A)	forward air controller (airborne)
FADEC	full-authority digital engine control
FASTGEN	Fast-Shotline Generator
FFR	final flight release
FLOT	forward line of own troops
FMC	Fully Mission Capable
FMS	Full Mission Simulator
FS	Fighter Squadron
FSM	Fusion Simulation Model
FSS	Fuel System Simulator
FW	Fighter Wing

G

GHz	gigahertz
GMTI	ground moving target indicator
GPS	Global Positioning System

H

HEI	high explosive incendiary
HG-ECM	High-Gain Electronic Countermeasures
HMD	Helmet Mounted Display
HOBS	High Off-Boresight
HPM	high-power microwave
HRAM	hydrodynamic ram
HSI	human-system integration

I

IADS	integrated air defense system
ICAW	Integrated Caution and Warning
ID	identification
[redacted]	[redacted]
IFF	identification, friend or foe
IFR	in-flight release
INS	inertial navigation system
IPP	internal power package
IOT&E	initial operational test and evaluation
IRST	Infrared Search and Track

J

JDAM	Joint Direct Attack Munition
JOTT	JSF Operational Test Team
JPALS	Joint Precision Approach Landing System
JPO	Joint Program Office
JSE	Joint Simulation Environment
JSF	Joint Strike Fighter
JSOW	Joint Standoff Weapon
JTAC	Joint Terminal Air Controller
JTD	Joint Technical Documentation

K

KPP	Key Performance Parameter

L

LCN	logistics control number
LCOM	Logistics Composite Model
LFP	logistics footprint
LFT	live fire test
LO	low observable
[redacted]	[redacted]
LOHAS	Low Observable Health Assessment System
LOSOT	Low Observable Stability Over Time
LPL	low-power laser
LRIP	low-rate initial production
LRU	line-replaceable unit

M

M&S	modeling and simulation
MADL	Multifunctional Advanced Datalink
MANPADS	man-portable air defense system
MAR	minimum abort range
MC	mission capable
MCAGCC	Marine Corps Air Ground Combat Center
MCAS	Marine Corps Air Station
MCMTCF	mean corrective maintenance time for critical failures

MDS-D	Mission Data System - Development
MDS-R	Mission Data System - Release
MFHBCF	mean flight hours between critical failures
MFHBOMF	mean flight hours between operational mission failures
MFHBME(U)	mean flight hours between maintenance events – unscheduled
MFHBR	mean flight hours between removals
MMH/FH	maintenance man-hours per flight hour
MPE	Mission Planning Environment
MPSE	Mission Planning and Support Environment
MR	mission reliability
MRT	Mission Rehearsal Trainer
MSIC	Missiles and Space Intelligence Center
MTTR	mean time to repair

N

NASIC	National Air and Space Intelligence Center
NAS	Naval Air Station
NIIRS	National Imagery Interpretability Rating Scale
NM	nautical miles
NMC	Not Mission Capable
NTTR	Nevada Test and Training Range
NTS	next-to-shoot

O

OABS	Open-air battle-shaping
OBIGGS	Onboard Inert Gas Generating System
OCA	offensive counter-air
OFP	operational flight program
OG	Operations Group
OMF	operational mission failure
OMS	Offboard Mission Support
ORD	operational requirements document
OT	operational test(ing)
OTS	operational test squadrons

P

PAA	primary aircraft authorization
PAO	polyalphaolefin

PHM	Prognostic Health Management
PKIE	Probability of Kill given an Engagement
(b)(1) [redacted]	(b)(1) [redacted]
PMA	Portable Maintenance Aid
PMC	Partially Mission Capable
PMD	Portable Memory Device
PMSR	Point Mugu Sea Range
PPE	Preventing Pilot Escape
PVI	pilot-vehicle interface(s)

Q

R

R&M	Reliability and Maintainability
R&I	removal and installation
RECCE	Reconnaissance
RF	radiofrequency
RCS	radar cross-section
RF	radiofrequency
RSE	Radar Signal Emulator

S

S/DEAD	suppression/destruction of enemy air defenses
SA	situational awareness
SAM	surface-to-air missile
SAPF	special access program facility
SAR	synthetic aperture radar
SCAR	strike coordination and armed reconnaissance
SDB I	Small-Diameter Bomb Increment One
SDD	System Development and Demonstration
SDL	Software Data Load
SE	support equipment
SGR	sortie generation rate
(b)(1) [redacted]	
SINS	Ship Inertial Navigation System
SMS	Stores Management System
SOU	Standard Operating Unit
SQL	Squadron Kit

(b)(1) [redacted]

ST	short ton
STOVL	short takeoff vertical landing

T

TEM	Test Evaluation Matrix
TEMPEST	Telecommunications Electronics Material Protected from Emanating Spurious Transmissions
TEL	tracked ejector and launcher
TER	target engagement radar
TLE	target location error
TSD	Tactical Situation Display
TWD	Threat Warning Display

U

UOE	Unclassified Operational Environment
UOTT	United States Operational Test Team
USAF	U.S. Air Force
USMC	U.S. Marine Corps
USN	U.S. Navy
USRL	United States Reprogramming Laboratory
UHF	ultra-high frequency

V

V&V	verification and validation
VV&A	verification, validation, and accreditation
VFA	Strike Fighter Squadron
VHF	very high frequency
VLO	very low observable
VMFAT	Marine Fighter Attack Training Squadron
VMF	Variable Message Format
VMS	Vehicle Management System
VIF	VSP/FCS (Vehicle System Processor/Flight Control System) Integration Facility
VSIF	Vehicle Systems Integration Facility
VTI	Virtual Threat Insertion

(b)(1) [redacted]

W

WC&S	Weapons Control and Stores
WDE	Weapon Demonstration Event(s)

X

Y

YRTC	Yuma Range Training Complex

Z

(U) Appendix B
(U) Selected DOT&E Approval Memoranda

(U) This appendix contains copies of the DOT&E approval memos associated with approval actions for specific portions of IOT&E, in order of issuance date:

- Approval of the F-35 Joint Strike Fighter Initial Operational Test and Evaluation Detailed Test Design, dated August 4, 2016.
- Approval of the F-35 Joint Strike Fighter (JSF) Pre-Initial Operational Test and Evaluation (IOT&E) Cold Weather Deployment Test Planning Documents, dated January 18, 2018.
- Approval of the F-35 Joint Strike Fighter (JSF) Pre-Initial Operational Test and Evaluation (IOT&E) Increment 2 Test Planning Documents, dated March 30, 2018.
- Changes to the F-35 Initial Operational Test and Evaluation (IOT&E) Comparison Test Design, dated May 11, 2018.
- Changes to F-35 IOTE Block 3F Air-to-Air Weapon Demonstration Event (WDE) Test Design, dated May 14, 2018.
- Approval of the F-35 Joint Strike Fighter Initial Operational Test & Evaluation, dated December 3, 2018.
- Approval of Changes to the F-35 Initial Operational Test and Evaluation Plan, dated August 23, 2019.
- Approval to Complete F-35 Electronic Attack Test Events, dated July 10, 2020.
- Data Collection from F-35 Joint Strike Fighter Test Events During Spin Up #2 Event in the Joint Simulation Environment, dated August 14, 2023.
- Approval of the Joint Strike Fighter Operational Test Team's Plan for Testing of the F-35 in the Joint Simulation Environment, dated September 8, 2023.

(b)(1)

[redacted]

(U) Figure B-1. Approval of the F-35 Joint Strike Fighter Initial Operational Test and Evaluation Detailed Test Design

(b)(1) [redacted]

(b)(1)

[redacted]

(b)(1) [redacted]

(b)(1)
[redacted]

(U) Figure B-2. Approval of the F-35 Joint Strike Fighter (JSF) Pre-Initial Operational Test and Evaluation (IOT&E) Cold Weather Deployment Test Planning Documents

(b)(1) [redacted]

OPERATIONAL TEST AND EVALUATION

OFFICE OF THE SECRETARY OF DEFENSE
1700 DEFENSE PENTAGON
WASHINGTON, DC 20301-1700

MAR 3 0 2011

MEMORANDUM FOR COMMANDER, AIR FORCE OPERATIONAL TEST AND EVALUATION CENTER
COMMANDER, OPERATIONAL TEST AND EVALUATION FORCE

SUBJECT: Approval of the F-35 Joint Strike Fighter (JSF) Pre-Initial Operational Test and Evaluation (IOT&E) Increment 2 Test Planning Documents

I have reviewed the JSF Operational Test Team (JOTT) planning documents submitted to my office for approval of Pre-IOT&E Increment 2 test events (attachments 1 through 12). I approve the JOTT conducting the planned Increment 2 test events as described in the Pre-IOT&E Increment 2 Test Event Matrices document (attachment 2) provided the following actions are completed:

- ACTION: Following the U.S. Marine Corps Weapons and Tactics Instructor (WTI) course, the JOTT will review the test event matrices with my staff to assess which events meet the test design and are adequate to count "for score" and which events remain.

  RATIONALE: The plan to conduct Strike Coordination and Reconnaissance/Armed Reconnaissance (SCAR/AR), Close Air Support (CAS), Forward Air Controller (Airborne) (FAC(A)), and Combat Search and Rescue (CSAR) test missions during the upcoming WTI course exercise, may not be sufficient to complete those test event matrices required per the approved test design; however, the JOTT should still use these events for collecting as much data as possible. Specifically, external weapons and the gun pod must be carried on a portion of the low threat missions (per the test design), but will likely not be available for the April WTI course.

- ACTION: The JOTT will provide a detailed plan for execution of the approved "matched pair" comparison test design prior to conducting F-35A vs A-10 comparison trials.

  RATIONALE: The CAS, CSAR and FAC(A) test designs were created to maximize efficiency for conducting both the F-35 evaluation and the F-35A versus A-10 comparison test. The planning documents do not include adequate detail on the plan for conducting the comparison test, including how the matched-pair trials will be accomplished.

- ACTION: The JOTT will provide the detailed Weapons Demonstration Events (WDE) plan under separate cover no later than 30 days prior to the first weapons event.

(b)(1) [redacted]

RATIONALE: The planning documents do not include detailed WDE scenarios. (NOTE: The WDEs listed in attachment 2 must be completed in an envelope with weapons certifications that are representative of the final Block 3F capability, accompanied by the updated flight series data codified with any relevant work-arounds.)

Preparations for formal entry into IOT&E must remain the primary focus across the program. While these early events will reduce the amount of testing remaining during formal IOT&E, they must not supersede the necessary actions to meet the remaining readiness criteria, including testing of the Air-to-Air Range Infrastructure system.

Approval of these Pre-IOT&E Increment 2 events does not constitute approval of the overall F-35 IOT&E test plan (attachment 4). The JOTT and the headquarters staffs should continue to work with my DOT&E staff and Institute for Defense Analyses subject matter experts to update the Data Management and Analysis Plans and Detailed Test Procedures in preparation for formal entry into IOT&E later this year. The DOT&E point of contact for this program is [redacted] He can be reached at [redacted] or at [redacted] (b)(1)

Robert F. Behler
Director

Attachments:
1. (FOUO REL US UK NL AU) Pre-IOT&E Increment 2 Cover Memo - Signed
2. (FOUO REL US UK NL AU) Pre-IOT&E Increment 2 Trial Matrices_Signed
3. (FOUO REL US UK NL AU) Pre-IOT&E Increment 2 TEMP Entry Criteria_Signed
4. (FOUO REL US UK NL AU) F-35 IOTE Test Plan v18_2
5. (FOUO REL US UK NL AU) Effectiveness DTP 7 Mar 2018
6. (FOUO REL US UK NL AU) Suitability DTP 21 Mar 2018
7. (FOUO REL US UK NL AU) Effectiveness DMAP 14 Mar 2018
8. (FOUO REL US UK NL AU) Suitability DMAP 22 Feb 18
9. (FOUO REL US UK NL AU) Cybersecurity DMAP 31 Oct 2017
10. (FOUO REL US UK NL AU) Effectiveness Interviews Surveys and DCFs 21 Mar 2018
11. (FOUO REL US UK NL AU) Suitability Interviews Surveys and DCFs
12. (FOUO) Cybersecurity Interviews Surveys and DCFs

cc:
USD (A&S)
USD (R&E)
ASN (RDA)
ASAF (Acquisition)
PEO (JSF)

2

UNCLASSIFIED

(U) Figure B-3. Approval of the F-35 Joint Strike Fighter (JSF) Pre-Initial Operational Test and Evaluation (IOT&E) Increment 2 Test Planning Documents

OFFICE OF THE SECRETARY OF DEFENSE
1700 DEFENSE PENTAGON
WASHINGTON, DC 20301-1700

OPERATIONAL TEST AND EVALUATION

MAY 1 1 2018

MEMORANDUM FOR COMMANDER, AIR FORCE OPERATIONAL TEST AND EVALUATION CENTER
COMMANDER, OPERATIONAL TEST AND EVALUATION FORCE

SUBJECT: Changes to the F-35 Initial Operational Test and Evaluation (IOT&E) Comparison Test Design

After considering the cost, schedule and operational impacts, along with inputs from Department stakeholders, I have decided to reduce the F-16 and F/A-18 portion of the F-35 IOT&E comparison testing. Changes are directed as follows:

- Reduce the F-16 and F/A-18 comparison testing from the current design of 18 valid test trials to two Nevada Test and Training Range periods, with a minimum of two completed valid trials.
- The Services are allowed to use their best available F-16 and F/A-18E/F/G capabilities, vice only the aircraft and configuration cited in the F-35 Operational Requirements Document (ORD) designated for replacement.
- The mission scenarios will be consistent with those in the currently-approved test design associated with the new Radar Signal Emulator (RSE) threat laydown. The F-35s will fly the same scenarios in a "matched pair" construct, but this no longer is required to occur during the same time period.
- Air-to-Air Range Infrastructure (AARI) instrumentation will be required for all red and blue aircraft to enable the required interactions, real-time battle shaping and data collection with the RSE threats.
- The Services and Operational Test Agencies should make available any additional relevant data from legacy aircraft testing, exercises, or simulators to supplement the open air data.

We will conduct the A-10 comparison testing in accordance with the approved F-35 IOT&E test design. There will be no changes or reductions to that portion of the design without my approval.

The DOT&E point of contact for this program is [redacted] He can be reached at [redacted]

Robert F. Behler
Director

cc:
USD (A&S)
USD (R&E)
ASN (RDA)
ASAF (Acquisition)
PEO (JSF)

2

UNCLASSIFIED

(U) Figure B-4. Changes to the F-35 Initial Operational Test and Evaluation (IOT&E) Comparison Test Design

(b)(1)

[redacted]

(U) Figure B-5. Changes to F-35 IOTE Block 3F Air-to-Air Weapon Demonstration Event (WDE) Test Design

(b)(1) [redacted]

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) Figure B-6. Approval of the F-35 Joint Strike Fighter Initial Operational Test & Evaluation

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) Figure B-7. Approval of Changes to the F-35 Initial Operational Test and Evaluation Plan

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Figure B-8. Approval to Complete F-35 Electronic Attack Test Events

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) Figure B-9. Data Collection from F-35 Joint Strike Fighter Test Events During Spin Up #2 Event in the Joint Simulation Environment

(b)(1)

[redacted]

UNCLASSIFIED upon removal of CUI attachments

OFFICE OF THE SECRETARY OF DEFENSE
1700 DEFENSE PENTAGON
WASHINGTON, DC 20301-1700

OPERATIONAL TEST AND EVALUATION

September 8, 2023

MEMORANDUM FOR F-35 PROGRAM EXECUTIVE OFFICER
COMMANDER, AIR FORCE OPERATIONAL TEST AND EVALUATION CENTER
DIRECTOR, OPERATIONAL TEST AND EVALUATION FORCE

SUBJECT: Approval of the Joint Strike Fighter Operational Test Team's Plan for Testing of the F-35 in the Joint Simulation Environment

I approve the attached Joint Strike Fighter Operational Test Team (JOTT) Plan for testing of the F-35 in the Joint Simulation Environment (JSE). This testing will complete F-35 Initial Operational Test and Evaluation (IOT&E). I urge the JSE stakeholders to expedite preparations for required F-35 follow-on operational testing in the JSE beginning with the 30R08 release.

My point of contact for this action is [redacted] He may be reached at [redacted] or at [redacted]

Nickolas H. Guertin
Director

Attachments:
As stated

cc:
Undersecretary of Defense for Acquisition and Sustainment
Assistant Secretary of the Air Force for Acquisition
Assistant Secretary of the Navy for Research, Development and Acquisition
Director, Test & Evaluation, HQ, U.S. Air Force
Deputy, Department of Navy Test and Evaluation Executive

UNCLASSIFIED upon removal of CUI attachments

UNCLASSIFIED

(U) Figure B-10. Approval of the Joint Strike Fighter Operational Test Team's Plan for Testing of the F-35 in the Joint Simulation Environment

(b)(1) [redacted]

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(b)(1) [redacted]

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(b)(1) [redacted]

(b)(1) [redacted]

(b)(1) [redacted]

Director, Operational Test and Evaluation

(U) F-35 Combined Initial Operational Test and Evaluation (IOT&E) and Live Fire Test and Evaluation (LFT&E) Report

February 2024

(U) This report on the F-35 Joint Strike Fighter fulfills the provisions of Title 10, United States Code, Sections 4171 and 4172. It assesses the adequacy of testing and the operational effectiveness, operational suitability, and survivability of the F-35 in order to inform Milestone C and Full Rate Production decisions.

Dr. Raymond D. O'Toole, Jr.
Acting Director

(b)(1) [redacted]

(b)(1) [redacted]

UNCLASSIFIED

UNCLASSIFIED

(U) F-35C operational test aircraft firing AIM-120 air-to-air missile.

(b)(1) [redacted]

(U) Executive Summary

(U) This report summarizes the results of the initial operational test and evaluation (IOT&E) of the overall mission capability of the F-35 weapon system, as delivered to the U.S. Services and International Partners[1] in the Block 3F configuration.[2] This mission capability assessment included the aircraft's operational effectiveness – in terms of combat lethality and survivability – and its operational suitability. The IOT&E included test activity from DOT&E-approved test plans from January 2018 through September 2023, conducted by operational test teams that involved participants from the U.S. and three F-35 partner nations: the United Kingdom, the Netherlands, and Australia. The results of tests conducted according to the separate live fire test and evaluation plan from July 2002 through November 2022, required by Title 10, are also included within this report.

(U) The testing conducted in IOT&E was adequate to evaluate the effectiveness and suitability of the F-35 in all Service-specified mission areas *in the operational conditions delineated in the test plans*. The effectiveness evaluation was conducted using data from both live and simulated test events. Open-air testing included 89 mission trials across all of the Services' required missions, supported by 75 live, in-flight Weapon Demonstration Events (WDE). The Joint Simulation Environment (JSE), accredited for the operational testing (OT) of the F-35 in the Block 3F configuration, included 64 mission trials and provided data to support the evaluation in the Service-designated mission areas of offensive counter-air (OCA), suppression or destruction of enemy air defenses (S/DEAD), defensive counter-air (DCA), and cruise missile defense (CMD).

(U) Suitability data were collected from test events and operational unit deployments to planned operating environments. These included a cold weather deployment, ship-borne deployments, and forward-basing and austere operations. Test teams collected reliability, maintainability and availability data on the operational test aircraft throughout the course of testing, to support the overall suitability evaluation. Digital models, supported with data collected from live test events and operational units, augmented live results to support evaluation of key performance parameters.

[redacted]

1 (U) The System Development and Demonstration program included partner nations from Australia, Canada, Denmark, Italy, the Netherlands, Norway, and the United Kingdom. Partners invested in the development of the program which distinguishes them from foreign military sales customer nations.

2 (U) The Block 3F configuration includes the Block 3F hardware and the associated software versions. See Table 2-2 for a full list of software versions used during IOT&E.

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[redacted]

3 (U) An "insider" is a cyber attacker with both physical and logical (through a user account) access to a system who attempts to gain access through a connected network or by circumventing air-gap security measures; a "nearsider" has only physical access; and an "outsider" has neither.

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(U) Defensive Counter-Air

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(U) Table 5. Mission-Level Measures: DCA Open-Air Trials vs. JSE Trials

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(U) Table 6. Force Level Measures: DCA Open-Air Trials vs. JSE Trials

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(U) Causal Factors Underlying the Results and Ramifications for Real-World Combat

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(U) Operational Effectiveness – Additional Missions

(b)(1) [redacted]

(b)(1) [redacted]

(U) Operational Suitability

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(U) During IOT&E deployments, fewer aircraft were deployed and fewer sorties flown than planned due to suitability shortfalls. ALIS supported deployment planning, deployed operations, and post-deployment retrograde, with limitations across all phases. The logistics footprint for land-based deployments exceeds the requirement by about two times the number of C-17 loads (mostly due to the size of support equipment). The F-35B did not meet the logistics footprint for LHD/LHA6-class ship-based deployments (it met the weight but did not meet the volume requirements), while the F-35C did meet the logistics footprint for ship-based deployments. Shipboard operations in the flight and hangar decks were complicated by the large size of the support equipment. The F-35A slightly exceeded, and the F-35B/C met, the requirement for direct manpower spaces per aircraft, based on the Services' staffing documents.

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(U) During the IOT&E sortie generation rate (SGR) deployments events, maximization of sortie generation was prioritized over Mission Capable status; consequently, maintenance (such as low observable [LO] system restoration) that would have affected the Fully Mission Capable (FMC) status was frequently deferred to allow aircraft to continue to fly sorties (results summarized in Table 7). In fact, none of the F-35A or F-35C aircraft either achieved or maintained FMC status during any period of these deployments, a condition that would be necessary for combat operations. For the F-35B deployment, the FMC rate was at 20 percent or less for the entire demonstration. All F-35A sorties were flown with aircraft that had a non-compliant LO signature. Four out of the five F-35B aircraft, and 80 percent of individual sorties, were LO non-compliant. None of the F-35C aircraft were reported as LO non-compliant.

(U) Table 7. IOT&E Results: Sortie Generation Rate Deployments

[redacted]

(U) Modeling was used to evaluate the SGR capabilities of an F-35 equipped unit over the course of a 100-day period using scenario-specific models for each F-35 variant and operating environment. The model results, summarized in Table 8, showed that none of the F-35 variants met the threshold SGR requirement for either the initial surge phase (days 1–7) or the sustained surge phase (days 8–30). The F-35A, in a main operating base environment, and the F-35B, in a land-based environment, met the threshold requirement during the wartime sustainment

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phase (days 31 and after). The amphibious-based F-35B met the requirement 59 percent of the time, and the carrier-based F-35C, which met the requirement 69 percent of the time, did not meet the overall requirement.

(U) Table 8. IOT&E F-35 Sortie Generation Rate Model Results

(b)(1) [redacted]

(U) The F-35 Joint Program Office (JPO) completed validation and verification of the IOT&E F-35 SGR models; and the JSF Operational Test Team (JOTT) recommended accreditation. The accreditation of these models for OT by the F-35 OT Executive Committee, the accreditation authority, could not be confirmed. With this exception, the use of the models was consistent with the DOT&E-approved test plan and provided credible results which support an assessment of the F-35 SGR performance.

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(U) During IOT&E, all F-35 variants assigned to the operational test squadrons experienced Mission Capable rates (operational availability) and Fully Mission Capable rates below and well below the Services' target values respectively.[4] These rates are representative of the entire U.S. F-35 fleet (all variants) during the same period, although fleet Fully Mission Capable rates were notably better than those of the operational test aircraft, but still well below service expectations. Failure to meet most of the threshold reliability and maintainability requirements resulted in these shortfalls (see Table 9). Mission-critical avionics systems were important contributors to reliability shortfalls. Key maintainability factors included the long cure times for low observable coatings and certain adhesives.

(U) Table 9. IOT&E F-35 Availability, Reliability, and Maintainability Metrics

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Parameter	Threshold Requirement [or Derived Standard]	Operational Test Aircraft[a]	U.S. Fleet[b]
Operational Availability[c] (Mission Capable Rate)	[≥ 70 percent]	F-35A: 59 percent	F-35A: 61 percent
		F-35B: 40 percent	F-35B: 66 percent
		F-35C: 62 percent	F-35C: 60 percent
Fully Mission Capable	[≥ 52.5 percent]	F-35A: 18 percent	F-35A: 41 percent
		F-35B: 16 percent	F-35B: 24 percent
		F-35C: 0 percent	F-35C: 7 percent
MFHBCF[d]	F-35A: ≥ 20 hours	F-35A: 8.6 hours	F-35A: 10.1 hours
	F-35B: ≥ 12 hours	F-35B: 7.1 hours	F-35B: 7.2 hours
	F-35C: ≥ 14 hours	F-35C: 13.5 hours	F-35C: 10.8 hours
MFHBME(U)[d]	F-35A: ≥ 2.0 hours	F-35A: 2.0 hours	F-35A: 1.6 hours
	F-35B: ≥ 1.5 hours	F-35B: 1.1 hours	F-35B: 1.3 hours
	F-35C: ≥ 1.5 hours	F-35C: 1.1 hours	F-35C: 1.3 hours
MFHBR[d]	F-35A: ≥ 6.5 hours	F-35A: 3.7 hours	F-35A: 5.5 hours
	F-35B: ≥ 6.0 hours	F-35B: 2.4 hours	F-35B: 3.3 hours
	F-35C: ≥ 6.0 hours	F-35C: 4.7 hours	F-35C: 4.5 hours
MTTR	F-35A: ≤ 2.5 hours	F-35A: 7.0 hours	F-35A: 6.1 hours
	F-35B: ≤ 3.0 hours	F-35B: 6.0 hours	F-35B: 6.7 hours
	F-35C: ≤ 2.5 hours	F-35C: 6.4 hours	F-35C: 5.1 hours
MCMTCF	F-35A: ≤ 4.0 hours	F-35A: 8.3 hours	F-35A: 11.2 hours
	F-35B: ≤ 4.5 hours	F-35B: 8.9 hours	F-35B: 10.8 hours
	F-35C: ≤ 4.0 hours	F-35C: 14 hours	F-35C: 11.8 hours

4 (U) In general, the Mission Capable rate indicates the proportion of aircraft not in depot that are capable of flying at least one mission of the F-35 mission set, while the Fully Mission Capable rate reports the proportion that can fly all defined F-35 missions.

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MMH/FH[e]	≤ 9.0 hours	F-35A: 7.5 hours	F-35A: 5.0 hours
		F-35B: 11 hours	F-35B: 8.8 hours
		F-35C: 9.7 hours	F-35C: 6.6 hours

a. From all U.S. F-35 operational test aircraft using flight hours and maintenance events completed between December 3, 2018 – September 30, 2019.

b. From all U.S. F-35 (LRIP 2+) aircraft using flight hours and maintenance events completed between December 3, 2018 – September 30, 2019.

c. Mission Capable rate includes Partially Mission Capable time and Fully Mission Capable time. The data do not distinguish whether or which mission-essential functions may be available in Partially Mission Capable time

d. During the IOT&E period the F-35B and F-35C had not reached the cumulative flight hours defined by the reliability growth plan but have since reached 'maturity'. Interim reliability goals for the F-35B and F-35C were approximately 10 to 15 percent lower than the requirement at maturity.

e. Includes both scheduled and unscheduled maintenance events.

Acronyms: ASD – average sortie duration; MMH/FH – maintenance man-hours per flight hour; MFHBME(U) – mean flight hours between maintenance events (unscheduled); MFHBCF – mean flight hours between critical failure; MFHBR – mean flight hours between removals; MTTR – mean time to repair; MCMTCF – mean corrective maintenance time for critical failures

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(U) The likelihood of an F-35 to maintain its full combat capabilities after take-off for the entire duration of a combat sortie is a measure referred to as Mission Reliability. Analyses of both the U.S. operational test squadron aircraft and the U.S. fleet aircraft during the IOT&E period showed that only the U.S. fleet F-35B was close to meeting this key performance parameter (see Table 10). In-flight software faults frequently caused the loss or degradation of critical mission systems. Analyzing and troubleshooting these faults is challenging, because the aircraft's onboard diagnostic system – designed to capture these faults – failed to identify a large percentage of them as problems.

(U) Table 10. F-35 Mission Reliability during IOT&E

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Variant	Mission Reliability Threshold Requirement[a]	Operational Test Aircraft[b]	U.S. Fleet[c]
F-35A	≥ 93 percent (at an ASD of 2.5 hours)	84.6 percent	86.4 percent
F-35B	≥ 95 percent (at an ASD of 1.1 hours)	93.2 percent	94.5 percent
F-35C	≥ 95 percent (at an ASD of 1.8 hours)	94.1 percent	92.6 percent

a. Mission reliability (MR) is specified by the F-35 ORD using the following equation: $MR = e^{-\left(\frac{ASD}{MFHBOMF}\right)}$, where ASD is the average sortie duration and MFHBOMF is the mean flight hours between operational mission failures. The threshold requirement specifies the applicable ASD.

b. All U.S. F-35 operational test aircraft using all flight hours and maintenance events completed between December 3, 2018 – September 30, 2019.

c. All U.S. F-35 (LRIP 2+) aircraft using all flight hours and maintenance events completed between December 3, 2018 – September 30, 2019.

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(U) ALIS is the backbone of maintenance support for the F-35 aircraft. Squadrons depend on it to support day-to-day flight operations and maintenance activities. During IOT&E, ALIS demonstrated poor usability and impeded, rather than facilitated, effective maintenance operations.

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(U) Cyber-Survivability

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(U) In total, the JOTT evaluated 24 subsystems during the period. Table 11 shows which test events from which test plans were completed for each of the 24 subsystems. In cases where not all test objectives were completed (indicated by red text), subsequent testing ensured coverage was adequate to support the cyber-survivability assessments reported here. Because the program did not have a production-representative aircraft available for full-up cybersecurity testing, the knowledge of actual aircraft vulnerability is limited.

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(U) Live Fire Test and Evaluation

(U) Testing assessed the F-35 aircraft and pilot vulnerability to kinetic threats, chemical and biological threats, low-power lasers, and electromagnetic pulse and high-power microwave threats expected to be encountered in combat. DOT&E approved the use of an early flight test aircraft, void of mission systems components, along with two complete airframe structural test articles and four F135 engines as sufficient for the live fire testing. Models, based on data from live fire events, were used to assess the vulnerabilities to specific ballistic threats.

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(U) Assessments for chemical and biological threat vulnerabilities included pilot protection, aircraft hardness (i.e., ability to maintain mission-ready status), and decontamination procedures. Results show that the aircraft and associated equipment can protect the pilot against the effects of chemical and biological agents. The inherent hardness of the aircraft to these agents, and the manner in which it is serviced and maintained, enable it to fight through a chemical or biological contamination event and retain full mission capability, without decontamination, for at least 30 days after contamination, which meets the requirement. Tests demonstrated that both chemical and biological decontamination processes could reduce contamination levels sufficiently for operational service without the need for pilots or maintenance personnel to wear protective gear.

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Director, Operational Test and Evaluation
Contents

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Section One
(U) System Description

(U) This section describes the system, missions, and threat environment.

(U) F-35 Joint Strike Fighter System

(U) The F-35 Joint Strike Fighter (JSF) program is a tri-Service, multinational program producing a weapon system consisting of the following key components:

- F-35 Block 3F aircraft
- Autonomic Logistics Information System (ALIS)
- Training Systems
- Mission Data

(U) Following the Milestone B Defense Acquisition Board, DoD awarded Lockheed Martin Aeronautics Company the System Development and Demonstration (SDD) contract in October 2001 to develop the JSF Air System, and awarded Pratt & Whitney and the General Electric Rolls-Royce Fighter Engine Team contracts to develop interchangeable propulsion systems. DoD terminated the contract with the General Electric Rolls-Royce Fighter Engine Team in 2011, eliminating the alternative engine source for the program. The SDD contract was planned as a 126-month effort. It included a comprehensive logistics support system, featuring an integrated training system for aircrew, maintenance, and support personnel, along with a mission planning system compatible with existing and planned joint systems. First flight occurred with an F-35A in December 2006, and the first production aircraft, designated AF-07, was delivered to the U.S. Air Force in May 2011. Because production of the aircraft occurred concurrently with the ongoing development of mission capabilities, aircraft already accepted by the Services had to be upgraded incrementally as the contractor delivered new blocks of mission capability. The Block 3F hardware was the configuration represented in low-rate production lot 9, the baseline configuration for evaluation during initial operational test and evaluation (IOT&E), and the final configuration under the SDD contract. The program has delivered over 600 aircraft to the U.S. Services through the end of FY23.

(U) F-35 Aircraft

(U) The F-35 aircraft is a single-seat strike fighter aircraft produced in three variants:

- F-35A Conventional Take-off and Landing
- F-35B Short Take-Off and Vertical Landing
- F-35C Aircraft Carrier Variant

(U) Figure 1-1 shows general characteristics of each F-35 variant. In this report, citing "F-35" refers to all variants while a specific variant will include the applicable designation: A, B or C.

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	F-35A (CTOL)	F-35B (STOVL)	F-35C (CV)
Radar Signature	Stealth	Stealth	Stealth
Height (ft)	14.2	14.1	14.9
Length (ft)	51.4	51.2	51.5
Span (ft)	35	35	43
Wing Area (sq. ft)	460	460	668
Weight Empty (approx)	29,500 lb	32,500 lb	35,000 lb
Internal Fuel (approx)	18,500 lb	14,000 lb	20,000 lb class
Weapons Payload	18,000 lb	15,000 lb	18,000 lb
Maximum Weight	70,000 lb class	60,000 lb class	70,000 lb class
Engine (one per A/C)	F135-PW-F100	F135-PW-600	F135-PW-100
Engine Thrust (Mil/Max)*	24,000 lb / 40,000 lb	26,000 lb / 38,000 lb	24,000 lb / 40,000 lb
Vertical Thrust*	N/A	40,600 lb	N/A
Speed	Mach 1.6	Mach 1.6	Mach 1.6
Approach Speed	N/A	N/A	< 145 knots
Mission Radius (KPP)	590 nm (USAF profile)	450 nm (USMC profile)	600 nm (USN profile)
Max G-Rating	9.0	7.0	7.5
Internal Weapons (Stealth)	2 A/A missiles, 2-2,000 lb-class A/G precision weapons, internal gun (Total: ~5,700 lb)	2 A/A missiles, 2 - 1,000 lb-class A/G precision weapons (Total: ~3,700 lb)	2 A/A missiles, 2 - 2,000 lb-class A/G precision weapons (Total: ~5,700 lb)
External Weapons Non-Stealth)	Variety, ~ 13,000 lb, 6 under-wing hard-points, 4 A/G / A/A and 2 IR missiles	Variety, ~ 12,000 lb, 6 under-wing hard-points, 4 A/G / A/A and 2 IR missiles, gun pod	Variety, ~ 13,000 lb, 6 under-wing hard-points, 4 A/G / A/A and 2 IR missiles, gun pod
Cannon	25 mm internal	25 mm missionized pod	25 mm missionized pod

(U) Source: F-35 Lightning II Test and Evaluation Master Plan (TEMP), Fourth Revision (V10.12), August 31, 2012.

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(U) Figure 1-1. Aircraft Variants

(U) The air system is composed of the aircraft—the air vehicle, embedded mission systems, and the propulsion system—and supporting ground systems within the Autonomic Logistics and Global Sustainment system.

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(U) Figure 1-2. F-35 5th-Generation Design Traits

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(U) Table 1-1. F-35 Aircraft Capabilities

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(U) Capability	(U) Description
(U) Air-to-Ground Munitions	o (U) GAU-22/A 25-millimeter (mm) rotary cannon[8] with 181 rounds of 25 mm ammunition on F-35A or 220 rounds on F-35B and F-35C o (U) GBU-12 Paveway II laser-guided bomb (500-pound class) o (U) GBU-31 Joint Direct Attack Munition (JDAM) Global Positioning System (GPS)-aided bomb (2,000-pound class) F-35A and F-35C only o (U) GBU-32 Joint Direct Attack Munition (JDAM) Global Positioning System (GPS)-aided bomb (1,000-pound class) F-35B and F-35C only o (U) GBU-49/58 Enhanced Paveway II laser-guided and GPS-aided bomb (500-pound class) o (U) GBU-39 Small Diameter Bomb (250-pound class) F-35A only o (U) AGM-154 Joint Stand-Off Weapon F-35C only
(U) Air-to-Air Weapons	o (U) AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM) o (U) AIM-9X air-to-air missile o (U) GAU-22/A 25-millimeter (mm) rotary cannon with 181 rounds of 25 mm ammunition on F-35A or 220 rounds on F-35B and F-35C
(U) Electronic Attack	(b)(1) [redacted]
(U) Situational Awareness and Targeting Sensors	o (U) AN/AAQ-40 Mid-wave infrared Electro-Optical Targeting System (EOTS) o (U) AN/AAQ-37 Mid-wave infrared Distributed Aperture System (DAS) o (U) AN/APG-81 active electronically scanned array (AESA) radar (b)(1) [redacted]

(U) Communications Suite	o (U) Ultra-high frequency (UHF) and very high frequency (VHF) radios, featuring
	  o (U) Secure voice communications via KY-58 encryption
	  o (U) Single Channel Ground and Airborne Radio System (SINCGARS)
	  o (U) Variable Message Format (VMF) messaging
	o (U) Link-16
	o (U) Multifunction Advanced Data Link (MADL)
	(b)(1) [redacted]

(b)(1) [redacted]

(U) Capability	(U) Description
(U) Self-Protection Systems	o (U) AN/ASQ-239 electronic warfare and countermeasures system (b)(1) [redacted] o (U) Radar warning and emitter location capabilities (b)(1) [redacted]

(b)(1) [redacted]

(b)(1) [redacted]

(b)(1) [redacted]

(b)(1) [redacted]

(U) Figure 1-3. F-35 Radar Frequency and Bandwidth

(U) F-35 Low Observable Characteristics

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(U) Autonomic Logistics Information System

(U) ALIS is a large, distributed information system that supports F-35 operations and maintenance, supply, and training. ALIS is composed of hardware and software components located at the F-35 squadron, country and enterprise level, and includes both government- and contractor-owned assets. As shown in Figure 1-4, ALIS uses a tiered architecture of networked computer resources.

(U) The F-35 program uses ALIS as the primary logistics tool to support unit and enterprise operations. At the unit level, ALIS was developed to support sortie generation, aircraft mission capability status determination and reporting, aircraft health management and diagnostics processing, maintenance planning and documentation, LO signature assessment and maintenance prioritization, supply chain management, support equipment and tool accounting, external assistance coordination, and training administration. At the enterprise level, ALIS is intended to integrate data from operational units, maintenance depots, the supporting logistics infrastructure, and relevant contractor information systems, and use its integrated data picture to support fleet readiness, spare parts provisioning and distribution, maintenance resource allocation and utilization, and product support and improvement engineering.

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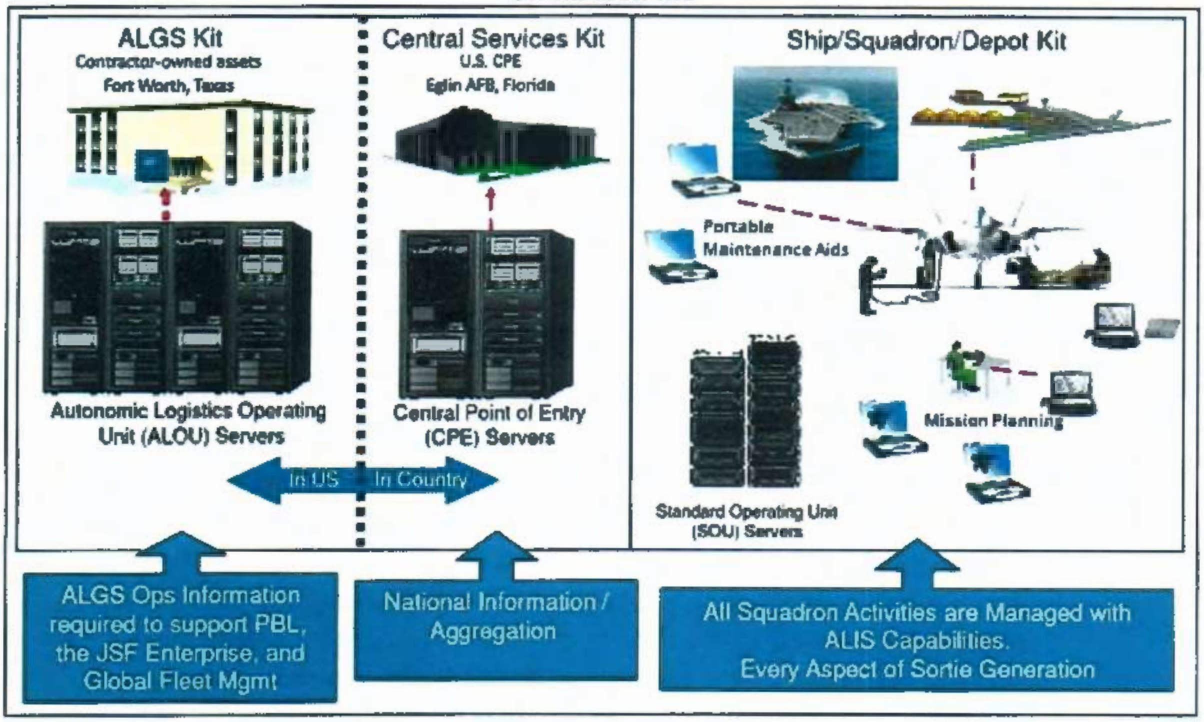

(U) Acronyms: ALGS – Autonomic Logistics and Global Sustainment; ALIS – Autonomic Logistics Information System; PBL – performance-based logistics

(U) Source: Adapted from "F-35 Lighting II Initial Operational Test and Evaluation Plan," JOTT, dated May 14, 2018

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(U) Figure 1-4. ALIS Uses a Tiered Architecture

(U) ALIS is composed of three tiers: the Squadron Kit, the Central Point of Entry (CPE), and the Autonomic Logistics Operating Unit (ALOU). The Squadron Kit is a suite of software applications that provides an individual unit the capabilities it needs to perform F-35 mission support roles. The CPE is a national-level collection and staging area both for data distributed to field-level systems and for data routed back from the field to the ALOU. Each F-35 partner nation has its own CPE through which its Squadron Kit communicates with the ALOU.

(U) The ALOU is the single collection point for global F-35 logistics and sustainment data, and the connection point to the government and contractor support information systems that comprise the Autonomic Logistics Global Sustainment concept. The ALOU supports enterprise logistical activities for the F-35 program, including the distribution of updated software for the aircraft and ALIS. The ALOU also provides for distribution of: (1) supply requisition status, (2) electronic log files for spare parts delivered to units, (3) parts catalog refreshes, (4) new maintenance technical data and urgent directives, (5) updates to reference databases stored within ALIS, (6) updates to algorithms used by ALIS to process downloads from the aircraft, (7) service tickets from the field and responses from engineering support, (8) records related to aircraft transfers between operating units, and (9) many other logistical details needed for overall enterprise management.

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(U) At a squadron, support personnel and pilots regularly use several key ALIS software applications to generate sorties and sustain the aircraft:

- Maintainers access the **Anomaly and Failure Resolution System** application to troubleshoot for solutions to faults that are detected by the **Prognostic Health Management** system, or for some fault types that are manually reported, based on the fault's Health Reporting Code.
- Pilots or maintainers use the **Squadron Health Management** application to manually input faults. Maintainers resolve faults and conduct routine inspections and servicing by viewing maintenance instructions housed in the **Joint Technical Data** application.
- Maintenance managers use the **Computerized Maintenance Management System** application to direct activity and certify aircraft safe to fly, and maintainers use it to record task execution. Pilots also review this application to familiarize themselves with the material condition of the jet they are about to fly.
- If solutions to faults are not available within the Anomaly and Failure Resolution System, or the provided solutions did not resolve the fault, or if there are discrepancies or unclear instructions in the Joint Technical Data, maintainers can request external support by submitting an Action Request in the **Customer Relationship Management** application.
- Maintainers use the **Low Observable Defect Entry Module** to track damages and repairs to the aircraft's outer mold line and LO system components to locally assess the radar signature of the aircraft in its as-maintained configuration.
- Supervisory personnel review upcoming required inspection and component end-of-life replacements in the **Maintenance Management Production Aircraft Inspection Requirement System** application.
- Supply personnel use the **Supply Chain Management** application to interact with the supply system and order parts. If parts are received without their necessary Electronic Equipment Logs in a complete and fully accurate form, supply personnel can request assistance by submitting an Action Request in the **Customer Relationship Management** application.
- Training can be assigned and tracked in the **Training Management System** application.

(U) The program developed and fielded multiple versions of ALIS throughout the system design and development period leading up to IOT&E. During IOT&E, the program continued to update ALIS software, primarily to address deficiencies and mitigate security concerns. As a result, the operational test units used several different iterations of ALIS, to include versions 2.0.2 through 3.5 during the course of testing. Testers had to conduct multiple cyber test events to cover the multiple versions.

(U) Training Systems

(U) F-35 training consists of aircraft-specific training for both new and experienced pilots and maintenance support personnel. Training activities range from classroom lectures and interactive computer-based courseware to hands-on training in and on the F-35 aircraft (see Figure 1-5). The contractor-operated Training System Support Center, located at Eglin Air Force Base (AFB), Florida, is responsible for developing, managing, and supporting F-35 training, from courseware to training devices. In addition, the Training Management System, an ALIS application, was designed to be used to schedule training and to be the official source of training records for pilots and support personnel.

(U) For F-35 pilots, formal training begins for new pilots with initial accession and for experienced pilots with conversion training. F-35A pilot accession occurs at the Academic Training Center located at Eglin AFB, Florida and Luke AFB, Arizona. F-35B pilot accession occurs at Marine Corp Air Station (MCAS) Beaufort, South Carolina and MCAS Miramar, California. F-35C accession occurs at Naval Air Station Lemoore, California. Classroom training consists of self-paced computer-based coursework and electronically mediated instructor lectures. Pilots practice interfacing with the F-35 aircraft using a representative touch panel display, control stick, and throttle with the desktop training aid. Training events are conducted in high-fidelity flight training devices (full mission simulators, mission rehearsal trainers, and deployable mission rehearsal trainers), and with live training missions in F-35 aircraft with surrogate and simulated threats and targets. Training also covers the use of the off-board mission system for F-35 mission planning. After a pilot's initial training, continuation and operational training occurs in their operational units, using both flight training devices and live training missions.

(U) For new maintenance support personnel, F-35-specific training begins with initial training conducted at the Academic Training Center at Eglin AFB, Florida. This involves instructor-led and self-paced coursework, interactive computer-based training (using aircraft simulated maintenance trainers), as well as hands-on training, both on-aircraft and with maintenance simulators (mock-ups). Formal conversion and continuation training for experienced maintainers are conducted at their assigned units, with contractor subject-matter experts and instructors teaching from formal test plans.

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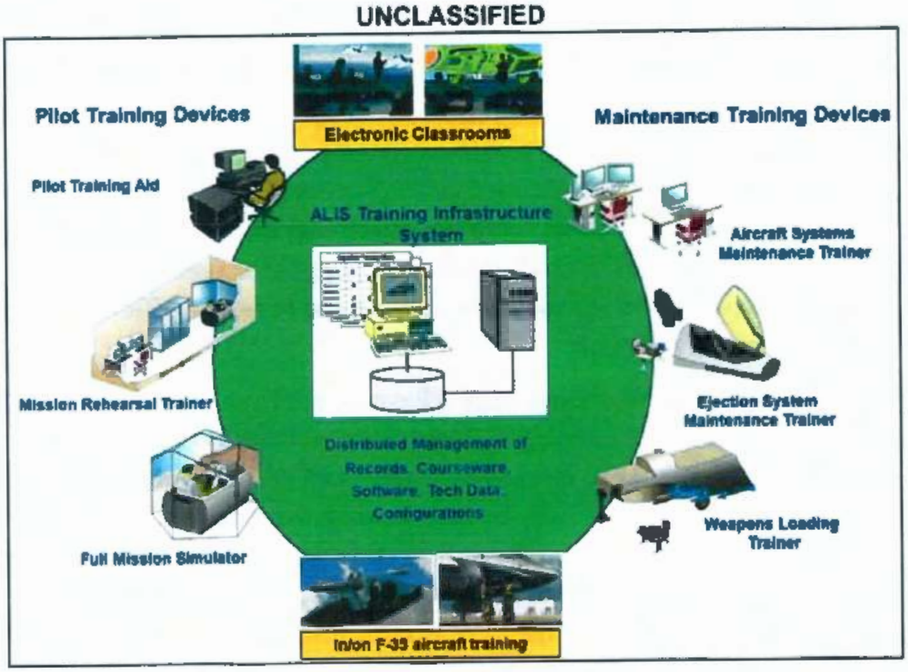

(U) Acronyms: ALIS – Autonomic Logistics Information System

(U) Source: adapted from "F-35 Ready for Training Operational Utility Evaluation Test Plan Briefing," JOTT, dated July 29, 2011

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(U) Figure 1-5. Core Components of F-35 Training for Pilots and Maintenance Support Personnel

(U) Mission Data

(b)(1) [redacted]

(U) Mission Descriptions

(b)(1) [redacted]

[redacted]

(U) The F-35 was also designed to have improved lethality in this environment compared to legacy multi-role aircraft. Combatant Commanders will employ units equipped with F-35 aircraft and associated support systems in joint and coalition operations to strike targets during day or night operations, in all weather conditions, and in threat environments ranging from permissive to anti-access/area denial. The F-35 will be used to attack fixed and mobile land targets, surface threats at sea, and air threats, including advanced adversary aircraft and cruise missiles. The F-35 will interoperate with joint and coalition forces to support air tasking orders.

(U) F-35 operational capability was evaluated in this IOT&E by tasking the F-35 operational test unit[1] to fly specific, doctrinally accepted mission roles. Table 1-2 shows how the IOT&E test design's mission areas were mapped to those designated by the three Services, which use different names for what are essentially the same mission tasks and capabilities, as listed in the ORD. Missions can be associated with how the steps in the "kill chain" of Find, Fix, Track, Target, Engage and Assess are applied during planning and execution. Analysis of common kill chain applications and common mission objectives led to consolidating the Service-titled mission roles for the purpose of efficient operational testing.

(U) In this report, these mission areas are separated into two categories: primary missions and additional missions, as shown in Table 1-2. Primary missions are: (1) air interdiction (AI), (2) offensive counter-air (OCA), which includes sweep/escort and suppression/destruction of enemy air defenses (S/DEAD), and (3) defensive counter-air (DCA). Additional missions are: (1) close air support (CAS), (2) forward air controller (airborne) (FAC(A)), (3) combat search and rescue (CSAR) (similar to tactical recovery of aircraft and personnel (TRAP)), (4) reconnaissance (RECCE) (and variations thereof), and (5) anti-surface warfare (ASuW). Successfully accomplishing primary missions requires the use of 5[th]-generation design features while successfully accomplishing additional missions does not.

1 (U) The overall conduct of F-35 IOT&E is the responsibility of the JSF Operational Test Team (JOTT), which includes five operational test units (one each from the U.S. Air Force, U.S. Navy, U.S. Marine Corps, the United Kingdom, and the Netherlands) and observers and test personnel from Australia.

[redacted]

(U) Table 1-2. IOT&E Mission Areas Mapped to Service-Defined Mission Areas

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Mission Category	IOT&E Test Design Mission Area	USAF (F-35A) Mission Area	USMC (F-35B) Mission Area	USN (F-35C) Mission Area
Primary	Air Interdiction	Attack Operations / Air Interdiction	Air Interdiction	Air Interdiction
		Strategic Attack		
	Offensive Counter-Air	Offensive Counter-Air	Anti-Air Warfare	Offensive Counter-Air
		Suppression of Enemy Air Defenses	Suppression of Enemy Air Defenses	Suppression of Enemy Air Defenses
		Destruction of Enemy Air Defenses	Destruction of Enemy Air Defenses	Destruction of Enemy Air Defenses
			Inherent Electronic Protection	Inherent Electronic Protection
			Electronic Attack and Electronic Warfare Support	Electronic Attack and Electronic Warfare Support
	Defensive Counter-Air	Defensive Counter-Air	Anti-Air Warfare	Defensive Counter-Air
Additional	Close Air Support	Close Air Support	Close Air Support	Close Air Support
	Forward Air Controller (Airborne)	Forward Air Controller (Airborne)	Tactical Air Controller (Airborne) / Forward Air Controller (Airborne)	Forward Air Controller (Airborne)
	Combat Search and Rescue	Combat Search and Rescue	Support of Tactical Recovery of Aircraft and Personnel	Combat Search and Rescue
			Combat Search and Rescue	
			Assault Support Escort	
	Reconnaissance	Armed Reconnaissance	Armed Reconnaissance	Armed Reconnaissance
			Aerial Reconnaissance	
			Strike Coordination and Reconnaissance	Strike Coordination and Reconnaissance
				Mining and Reconnaissance
	Anti-Surface Warfare	N/A	N/A	Attack of Maritime Surface Targets

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(U) The missions evaluated during IOT&E are described below.

(U) Offensive Counter-Air

(U) The objective of OCA is to project air power into an enemy's territory, typically in large force combinations and conceivably from long ranges that require air-to-air refueling. The OCA missions are tasked to gain localized and temporary air superiority over a given amount of airspace for a limited time by destroying or otherwise neutralizing enemy anti-air defenses, both aircraft and surface-based, so that other missions, such as AI, can be successfully and efficiently performed. Two specific types of this mission role were conducted to measure F-35 performance:

(U) Suppression / Destruction of Enemy Air Defenses (SEAD/DEAD)

- (U) This type of OCA mission role requires the F-35 to engage enemy surface-based threats to friendly air operations. The overarching objective of this role is to reduce the effectiveness of enemy surface defenses enough for the other friendly operations to be successful. F-35s must precisely locate and accurately identify the threats, prioritize them, and then determine whether they can best be handled by suppression methods, such as jamming the threat radar, or by destruction through attack with air-to-surface kinetic weapons. The mission targets are surface-based radar systems that surveil the airspace either to inform enemy command and control or to support enemy missile or gun fire defenses.

(U) Escort / Sweep

- (U) This OCA mission requires the F-35 to engage enemy aircraft that are threatening friendly air operations, typically in enemy-controlled ground and airspace. The F-35 may engage enemy aircraft while serving as an escort for friendly aircraft attacking enemy defenses or other targets; or in a sweep role, in which its mission is to draw and engage enemy air forces into battle in front of other friendly air operations, but as an independent action. F-35s must positively identify which aircraft are threats and which are hostile, neutral or friendly among all air traffic that could affect the given air operation. The F-35s must maintain high situational awareness of these aircraft throughout the timeframe that air superiority is required for friendly air operations. In the case of the escort role, engaging and destroying enemy aircraft early in the mission timeline is preferable, because the overarching objective is to prevent enemy aircraft from disrupting attacks by the escorted friendly forces.

(U) Air Interdiction

(U) AI missions are tasked to destroy enemy military capabilities or disrupt support to enemy military forces in order to prevent them from executing operations against friendly forces. Targets may include supplies, transportation resources, lines of communication, enemy troops, and warfighting equipment. A key aspect of AI is that friendly ground forces are not present, nor are they close enough to require coordination of friendly air attacks with ground components. F-35s in this role are required to use the F-35 systems to precisely locate pre-selected enemy targets and destroy them with air-to-surface weapons. AI forces may be escorted by other aircraft assigned to reduce enemy surface and air threats. Such integration of AI aircraft into large force combinations typically involves a long traverse to enemy territory, often requiring air-to-air refueling.

(U) Defensive Counter-Air

(U) DCA missions are tasked to prevent enemy aircraft or cruise missiles approaching friendly airspace from conducting operations against friendly forces. A defined region of airspace is assigned for "coverage" by the DCA mission. The F-35s in this mission role begin the mission in combat air patrols over or near the friendly airspace they are defending. Air-to-air refueling resources may also be available to extend the time these aircraft can cover the assigned airspace, and 4th-generation aircraft may be integrated as well.

(U) Close Air Support

(U) CAS missions are conducted to protect and support friendly ground forces against hostile action. The mission requires detailed integration with the fire control and movement of those forces and close coordination with the agencies controlling the airspace above the ground forces. This coordination is standardized with specific communication protocols. A single CAS event, or "control," is initiated with a "game plan" tasking from either a FAC(A) or ground-based Joint Terminal Attack Controller, who serves as the tasking authority to the CAS aircraft on behalf of the ground force commander. The tasking consists of a standardized, Joint Doctrine-approved "9-line" format brief describing nine specific details of the immediate task in short, clear terminology. This information can be transmitted verbally on the radio, or digitally between compatibly configured participants.

(U) Forward Air Controller (Airborne)

(U) The FAC(A) role exercises control, from the air, of aircraft engaged in CAS of ground troops. It involves airspace management over the target area, assigning 9-line taskings to CAS aircraft and coordinating engagements in support of ground forces.

(U) Combat Search and Rescue / Tactical Recovery of Aircraft and Personnel

(U) The U.S. Air Force and U.S. Navy's CSAR mission and the U.S. Marine Corps' TRAP mission are similar: operations are conducted to recover distressed friendly personnel, normally downed aircrew, during war or military operations other than war. The role executed by the F-35 is fundamentally the same for both missions. The scope, scale, and complexity of an operation varies broadly based on threats, environmental conditions, and available recovery assets. Initial tasks include escorting the recovery aircraft, locating and positively identifying the downed aircrew, and securing the rescue area of operations. Once these tasks are complete, the designated mission commander directs the recovery aircraft to "Execute" the rescue operation. The support rescue forces continue to coordinate security of the rescue area of operations until the distressed personnel have been extracted and the recovery aircraft has returned to friendly territory. The following sections of this report call this mission CSAR.

(b)(1) [redacted]

(U) Reconnaissance

(U) The F-35 is required to perform RECCE missions in accordance with specific joint and independent military service doctrines. All types of RECCE missions require the same F-35 capabilities to perform the necessary mission tasks. Two RECCE mission types were flown in IOT&E: Strike Coordination and Reconnaissance (SCAR), and (just) RECCE. The purpose of each is to detect targets, collect information including precise coordinates of target locations, and provide that information to other platforms or to the intelligence network used by command and control. Both mission types can be conducted by armed aircraft that also attack the targets they find. Aircraft may be dedicated to these missions by force allotment tasking or diverted from other missions if original tasking becomes lower priority than the RECCE missions.

(U) Differences exist in how quickly the RECCE information is to be used, and in how much processing and filtering takes place and by whom. SCAR missions are used in relatively fluid circumstances in which aircraft cannot determine where targets are available and need to be attacked until they arrive in the search area. Target priorities may change as the mission progresses. SCAR requires the F-35 pilots to identify target types, separate higher from lower priority objectives, and coordinate attacks with other armed aircraft by passing target information (type, location, priority) needed to prosecute an attack. Information can be passed verbally on the radio, via laser hand-off or via data links if the participating aircraft have compatible equipment.

(U) F-35s performing RECCE missions are intended to collect data on enemy locations or activities and then make the information available to other users. Depending on the type of data collected (coordinates, radar electronic signal characteristics, imagery), downstream users may continue processing the data or use it in its existing form to warn other systems of threats or to task targets for destruction.

(U) Anti-Surface Warfare

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[redacted]

(U) Threat Environment

(U) Air Defenses and Opposing Air Forces in the Open-Air and Joint Simulation Environment IOT&E Trials

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(U) Air-to-Air Threat Representation in F-35 IOT&E

(U) Opposing air forces, called "red air," were organized by the test team for use in trials, as required by the test design. Not all trials required red air. These red air forces were U.S. military aircraft flown by U.S. military pilots in the open-air trials and digital modeling replications of threat aircraft flown by a combination of current and former U.S. military pilots, in the JSE trials, performing tactics representative of the U.S. intelligence assessments of enemy capabilities and tactics. The test design controlled the ratio of blue-to-red aircraft, as well as the capabilities of red aircraft sensors and weapons. Actions by the red forces were in accordance with plans developed by the pilots flying the mission, but initialized and constrained by the test control team's coordination of the start of each trial. Ground or airborne controllers were available to coordinate and support the red air tactics and provide operationally representative command and control, when required by the test design. When models of the actual radar and data link equipment normally employed by ground and airborne controllers were not available, controllers used aircraft location information provided by range tracking systems (open-air) and by the simulation infrastructure (JSE).

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(U) Table 1-3. Air-to-Air Threat Representation in IOT&E

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[redacted]

(U) Real-World Air-to-Air Threat Attributes

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[redacted]

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) Air-to-Air Threat Representation in Open-Air Trials

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[redacted]

(b)(1)

[redacted]

[4] (U) "F-35 Lightning II Block 3F Open Air Initial Operational Test and Evaluation Report," dated 21 March 2022.

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[redacted]

(U) Air-to-Air Threat Representation in JSE Trials

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(b)(1) [redacted]

(U) Air-to-Air Threat Modeling Limitations in JSE Trials

(U) As a digital simulation in all respects – weapons system modeling, environment modeling, target modeling, etc. – the JSE was subject to a wide array of modeling limitations, with a variety of potential impacts on trial outcomes. The limitations and their predicted effects on the JSE trials are addressed in detail in the JSE verification and validation documentation supporting the accreditation of the simulation for IOT&E, and are not addressed in detail in this report. However, it is essential to understand that the simulation was verified, validated, and accredited for the relatively narrow range of threats and operational conditions evaluated in the IOT&E trials. Accordingly, the performance of the F-35 against these threats and under these conditions cannot be reliably extrapolated to draw valid conclusions about performance against more advanced threats or under more challenging operational conditions.

(U) Air Defenses and Surface-to-Air Systems: Open-Air Trials and JSE

(U) Table 1-4 and Table 1-5 list the current long-range and medium-range surface-to-air threats, and specifies how each was – or was not – represented in the open-air and JSE trials. The color coding for these tables is the same as described for the air-to-air systems and capabilities

(b)(1) [redacted]

captured in Table 1-3. The remainder of this section provides a detailed explanation of the differences and some of the associated test ramifications.

(U) Table 1-4. Long-Range Surface-to-Air Threat Representation

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(U) Table 1-5. Medium-Range Surface-To-Air Threat Representation

(b)(1) [redacted]

(b)(1)

[redacted]

(U) SAM Maximum Shot Range Limitations

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[redacted]

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) SAM Networked Advanced Engagement Techniques (AET)

(b)(1)

[redacted]

(U) Counter-Precision-Guided Munitions Representation

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) Camouflage, Concealment, and Deception

(b)(1)

[redacted]

(b)(1)
[redacted]

(U) Scene Complexity and RF Signal Congestion

(b)(1)
[redacted]

(b)(1)

[redacted]

Section Two
(U) Test Adequacy

(U) Initial operational test and evaluation (IOT&E) was adequate to evaluate the mission capability, including operational effectiveness – in terms of combat lethality and survivability – and the operational suitability, of the F-35 Block 3F aircraft in all Service-specified mission areas and under the operational conditions delineated in the test plans. The operational effectiveness evaluation was conducted using data from both live and simulated test events. Live or open-air testing included 89 mission trials across all of the Services' required missions, supported by 75 in-flight weapon demonstration events (WDE). Simulated test events, using the Joint Simulation Environment (JSE), accredited for the operational testing of the F-35 in the Block 3F configuration, provided data to support the evaluation in the Service-designated mission areas of offensive counter-air (OCA) including the roles of sweep/escort and suppression/destruction of enemy air defenses (S/DEAD), air interdiction (AI), and defensive counter-air (DCA), against threat aircraft and cruise missiles. Operational suitability data were collected from live test events and operational unit deployments to planned operating environments. Test teams collected reliability, maintainability, and availability data on the operational test aircraft.

(U) Cyber testing and evaluation conducted on aircraft system components and support systems was adequate to support the survivability evaluation of the F-35 in contested cyberspace. Similarly, the live fire test and evaluation (LFT&E) strategy and plans were adequate to support the survivability evaluation of the F-35 to kinetic and non-kinetic threat effects. Digital models, supported with data collected from live test events and operational units, augmented live results to support evaluation of key performance parameters.

(U) Test Adequacy Overview

(U) The IOT&E test concept organized the evaluation of F-35 effectiveness and suitability using the missions listed by the Services in the Operational Requirements Document (ORD) (e.g., OCA, AI, close air support (CAS)). All three F-35 variants were evaluated. The test team developed scenarios for each mission and staged discreet force-against-force trials (i.e., F-35 versus enemy opposition) to be flown in open-air ranges and in the JSE. In addition to determining the success of accomplishing a given overall mission objective, the test team predetermined many other measures (e.g., time required to find a target, kill exchange ratios) to assist in understanding the F-35 lethality and survivability. Open-air and JSE trial assessments were complemented by WDEs where F-35 pilots attacked air and surface targets with actual weapons.

(U) The IOT&E test concept also supported the evaluation of the reliability and maintainability performance described in the ORD for each variant. Suitability performance data were collected on the F-35 aircraft assigned to the Services' operational test squadrons throughout all flight operations over the course of the test (e.g., training, trial preparations, and trials). Data on maintenance actions, supporting the reliability, maintainability and availability evaluation were collected from the start of formal open-air test trails in December 2018 through

September 2019. The test design also included demonstrations of specific capabilities pertinent to evaluating suitability, such as small deployments to operational environments away from home bases. The design included the use of models, informed by data collected by the test teams, to evaluate key performance parameters called out in the ORD.

(U) Survivability testing by its very nature requires engaging the weapons system under test with live kinetic ordnance (e.g., missiles, guns), or with non-kinetic weapons (e.g., cyber and directed energy), nuclear environmental effects like high-power electromagnetic pulses, or chemical/biological threats. Issues of human safety required that F-35 vulnerability testing be conducted separately from the mission-level testing. The LFT&E assessed the vulnerability of the F-35 to kinetic weapons effects, chemical and biological agents, low-power laser, and electromagnetic radiation effects while dedicated cyber testing assessed the F-35 vulnerabilities to cyberattacks. Cyber survivability testing was designed to determine if attempts to attack the F-35 air system cyber boundaries (attack surfaces) could be detected, prevented, defended, and, if compromised, could integrity be restored following an attack. The results of survivability testing were used to inform the overall assessment of mission effectiveness.

(U) Timelines of Test Planning, Approvals, and Execution

(U) Test events supporting IOT&E began in January 2018 with a cold weather deployment of all three variants of the operational test aircraft to Eielson Air Force Base (AFB), Alaska. IOT&E concluded in September 2023 with the completion of mission trials in the JSE. Because all of the readiness requirements to enter IOT&E were not completed at once, DOT&E-approved portions of the IOT&E test plan for execution as soon as the program, test infrastructure, aircraft modifications, and necessary software updates were ready, while withholding additional approval until necessary requirements were met. Transient opportunities – such as cold weather conditions and ship availability – drove the need to conduct specific portions of the test plan when these environments were available. Table 2-1 lists the dates and approval actions for specific portions of IOT&E. The associated DOT&E approval memos are included in Appendix B.

(U) Table 2-1. Timeline and Approvals of Test Activity

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Date	DOT&E Approval Action	Purpose and Scope of Approval
4-Aug-16	Approval of F-35 IOT&E Detailed Test Design	Defined the scope of test and provided basis for detailed test planning. Enabled cyber survivability testing to proceed per strategy included in the design with separate approvals per event.
16-Jan-18	Approval to conduct cold weather testing	Enabled testing in cold weather environment at Eielson AFB, Alaska.
30-Mar-18	Approval of Pre-IOT&E Increment 2 Testing	Approved portions of the overall test plan for conducting test activity that met readiness requirements. These included weapons events and 2-ship CAS, FAC(A), CSAR, SCAR, and RECCE missions.

Date	DOT&E Approval Action	Purpose and Scope of Approval
11-May-18	Reduction of comparison test requirements for IOT&E	Reduced F-16 and F/A-18 comparison testing from the approved design of 18 valid test trials to 2 trials due to cost, schedule and operational impacts.
14-May-18	Changes to air-to-air WDE test design	Updated air-to-air weapons events.
3-Dec-18	Approval of (formal) IOT&E test events	Approved most of the remaining open-air trials in the overall test plan for execution, including 4-ship missions, with the exception of four OCA missions on PMSR and the JSE test trials.
23-Aug-19	Changes to the formal test plan requirements for the primary missions	Adjusted number of required valid trials for DCA and the combined OCA and AI missions.
10-Jul-20	Approval of dedicated electronic attack test events at PMSR	Approval of four open-air test events in overall test plan – this portion of the test plan was on hold until radar emulators were in place off the west coast.
14-Aug-23	Approval to use spin-up trials as for-score events at risk	DOT&E approved the test team to conduct spin-up trials as "for-score" trials at risk, pending post-trial analyses and validation.
8-Sep-23	Approval to conduct for-score test trials in JSE	Approval to conduct the JSE for-score test trials.
AI – air interdiction; CAS – close air support; CSAR – combat search and rescue; DCA – defensive counter-air; FAC(A) – forward air controller (airborne); IOT&E – initial operational test and evaluation; JSE – Joint Simulation Environment; OCA – offensive counter-air; PMSR – Point Mugu Sea Range; RECCE – reconnaissance; SCAR – strike coordination and reconnaissance; WDE – weapon demonstration event		

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(U) IOT&E of the F-35 Block 3F hardware configuration was conducted using a series of software configuration, called Operational Flight Program (OFP) versions. During the course of IOT&E, the program continued to upgrade the software to enable functionality, such as open-air battle-shaping (OABS), and address deficiencies in the initial version that prevented completion of testing. As shown in Table 2-2, a total of five OFP versions were used during IOT&E, covering various time spans and test events.

(U) Table 2-2. Software Configurations Used for Evaluating F-35 Block 3F Hardware

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Aircraft Software Configuration	Time Period	Test Events
3FR06	Beginning Jan 2018	Cold weather deployment, alert launches
30R00	Beginning Mar 2018	Additional mission areas, WDEs, deployments
30R02.04	Beginning Dec 2018	Formal IOT&E, included primary mission areas
30R04.52	Jul 2020	OCA trials over water (final mission trials)
30R06.42	Jun 2021	AIM-120 event (final WDE)
Acronyms: IOT&E – initial operational test and evaluation; OCA – offensive counter-air; WDE – weapon demonstration event		

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(b)(1) [redacted]

(U) IOT&E Design – Operational Effectiveness

(U) The test team designed the overall F-35 IOT&E test plan to be able to detect, with statistical confidence, differences in critical measures of performance across a collection of operational conditions decomposed into factors and levels to support a design-of-experiments construct. The factors or attributes of the various missions that were expected to have significant and important effects on mission outcomes in the IOT&E test design were grouped into: (1) attributes of the F-35 and its associated weapons, (2) attributes and numbers of threat weapons systems and targets, (3) attributes of the physical environment, and (4) attributes of the missions pertaining to tactics, available intelligence information, and command and control. Each factor was further decomposed into different levels expected to drive operationally relevant differences in mission outcomes for that factor. The measures used in the test design were used to quantify the impacts of the different factors on mission outcomes, as a function of levels. Some measures, such as times to complete mission tasks or encroachment ranges, were continuous in nature. Other operationally relevant measures of performance were discrete responses, such as targets designated, proportion of red or blue aircraft removed, and proportion of missions meeting commander's intent.[1]

(U) The statistical test design specifies the necessary number of measurement samples of the critical measures in each mission area and the particular combination of factor levels under which each of those measurements must occur. An important principle of the test design is that each mission trial be conducted under the specific combinations of factors described in the test event matrix. This ensured the resulting measures of the response variables could determine which factors, if any, significantly affected performance. For example, controlling the test missions between day and night environments enables comparison of the ability of the F-35 pilots to detect and isolate moving targets during day and night missions. For all mission areas except reconnaissance (RECCE), cruise missile defense (CMD) (a subset of the DCA mission) and anti-surface warfare (ASuW), the F-35 variant was designated as a factor, and the test was designed to determine if there were measurable performance differences between variants.

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[1] (U) Each test scenario for the primary missions included an overall mission objective referred to as "commander's intent," which included specific expectations as a function of the mission area and level of opposing threat.

[2] (U) Electronic attack (jamming) is the process of directing interference signals at enemy air or surface radars to suppress or deny detection or threat weapon guidance.

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(U) Figure 2-1. F-35 Kill Chain Design

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(U) Primary Missions Trial Design

(U) Primary missions were conducted in both open-air trials and in the JSE. The JSE trial design framework was based on the open-air trial design, but the scenarios and threat representation (types and densities) varied. Only primary missions were conducted in the JSE.

(U) To ensure the IOT&E plan adequately covered the operational environment, the trial design varied important factors, which are listed in Table 2-3. Critical measures, listed in Table 2-4, were also selected to support the evaluation of the operational performance of the F-35.

[3] (U) Test plans for IOT&E considered a 4-ship of the same variant to be the basic fighting element of F-35 aircraft. Exceptions included using 2-ship elements for CAS, FAC(A), SCAR, Recce, and scenarios where F-35s were augmented with other blue fighters.

(U) Table 2-3. IOT&E Design Factors: Primary Missions

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Factors	Levels	Applicable Mission Areas				
		OCA		Air Interdiction/ Attack	DCA	
		S/DEAD	Sweep/ Escort		Red Manned Aircraft	Cruise Missiles
F-35 Variant	A, B, C	X	X	X	X	
Time of Day	Day, Night	X	X	X	X	
DEAD Target Objective EA Susceptibility	In-Band Out-of-Band	X	X			
DEAD Target Objective Range	Medium Long	X	X			
Target Location Confidence	Level 1, 2, 3			X		
Target Clutter	High, Low			X		
Blue Force Support	EA-18 Growlers none	X	X			
Weapons Loadout	Standoff, Direct Attack (Air-to-Surface role)	X	X			
Weapons Loadout	Internal Only Internal & External (additional 2X A-9X)				X	
Red Air Threat Force Mix	Level 1, Level 2, Level 3				X[a]	X[b]
Ground Environment	Land, Sea				X	X

a. Red air threat force varied between two levels for the open-air test trials; the third, most challenging level or red threat force – which included one 4-ship of 5th-generation aircraft plus one 2-ship of 4th-generation aircraft –only occurred in the JSE test trials.

[redacted] Due to limited surrogates for open-air testing, only single-ship attacks were evaluated on the open-air ranges using subsonic surrogates. JSE testing added a greater number of cruise missiles and included supersonic targets.

Acronyms: DCA – defensive counter-air; DEAD – destruction of enemy air defenses; EA – electronic attack; JSE – Joint Simulation Environment; OCA – offensive counter-air; S/DEAD – suppression/destruction of enemy air defenses

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(U) The F-35 *Variant* was chosen as a factor for IOT&E because of the known significant differences between variants in terms of weapons loads, speed, maneuverability, and total available fuel.

(U) Time of Day was chosen as a factor because of the ways daytime and nighttime flying can differ with regard to employing the aircraft, especially pilot-vehicle interface issues, overall pilot situational awareness, and the performance of infrared sensors. These factors applied to all component mission areas.

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[redacted]

(U) *Target Location Confidence* was chosen as a factor in recognition that in different circumstances in combat, the accuracy of targeting information available to the pilots prior to commencing ground attacks will vary. Because this factor applies only to ground attacks where target coordinates are provided to the pilots prior to takeoff, it was applicable only to the AI mission areas. Target location confidence was defined in terms of the maximum error present in any target coordinates provided to the pilots in the pre-mission briefing, and three levels were used. Level 1 might be thought of as corresponding to targets that have been long-studied by the intelligence and weaponeering communities, giving them time to have developed essentially perfect coordinates. Levels 2 and 3 would correspond to buildings and other facilities that have

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only more recently been identified as targets of interest, for which there has been less time to refine the coordinates.

(U) The *Target Clutter* factor applied only to the AI mission area. Central to success in AI is the ability of a pilot to discern his assigned targets among the other objects that will generally be present in the F-35 sensor imagery. The degree of difficulty in doing so is predominantly a function of the distinctness of a target's shape and of its assigned designated points of weapons impact, and the number of other targets that are present in the imagery. The target clutter factor was broken out into two levels, "High" and "Low," and the interdiction target set for each trial was classified as high- or low-clutter based on a subjective determination of the aforementioned attributes of the target scene.

(b)(1) [redacted]

(b)(1) [redacted]

(U) Table 2-6. Test Design Critical Measures: Additional Missions

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Mission	Measure	Definition
CAS	Targeting Time	From the initiation of the 9-line brief *until* the first target is correlated.
	Engagement Time	From the correlation of the first target *until* the first weapon release or gun employment on that target.
FAC(A)	Brief Generation Time	From the receipt or discovery of target by FAC(A) *until* the initiation of the 9-line brief.
	Correlation Time	From the initiation of 9-line brief *until* the CAS pilot has correlated the target.
CSAR	Coordination Time	From when Sandy 1 first crosses the Forward Edge of the Battle Area (line differentiating friendly from hostile territory) *until* Sandy 1 commands "Execute."
	Recovery Time	From when Sandy 1 commands "Execute" *until* the downed aircrew is extracted and the recovery force is safe from threats.
SCAR/AR	SCAR Catalogue Time	Time from start search in kill box to time a priority target is cataloged by the pilot.
	SCAR Coordination Time	Time from when the SCAR pilot begins transmitting target information (voice or digital) to the Strikers to when the Striker pilots have confirmed they are tally/contact/capture the target.

(b)(1) [redacted]

(U) Reconnaissance

(U) To evaluate the F-35 solely as a RECCE aircraft, the test plan required three open-air trials flown by a 2-ship of F-35s collecting imagery using either the SAR mapping function of the radar or the Electro-Optical Targeting Sensor. The images would be processed post flight and prepared for dissemination across intelligence networks. Image ratings and time to process would be measured to assess overall support to the RECCE role. The trials would be flown in both littoral and desert environments to assess the difference of those environments on F-35 sensor performance in collecting imagery.

(U) Anti-Surface Warfare

(b)(1) [redacted]

allows the JTAC or FAC(A) to use means other than visual confirmation of the attack to ensure safe conduct. Type 3 control allows the controller to clear a CAS aircraft for multiple attacks within a single engagement provided specific constraints (e.g., location, attack azimuth) are met. Variations in these operational conditions and test design factors drove the requirement for 42 data collection points across the 12 trials.

(U) Forward Air Controller (Airborne)

(U) To evaluate mission effectiveness of the F-35 in the FAC(A) role, the IOT&E plan required four open-air test trials of variant-unique 2-ship F-35s controlling strike aircraft. Strikers included both fixed- and rotary-wing, conducting CAS in both day and night conditions in a contested threat environment. The trials were planned only for F-35A and F-35B aircraft, as the U.S. Navy does not have a FAC(A) mission for the F-35C.

(U) Combat Search and Rescue

(U) To evaluate mission effectiveness of the F-35 in the CSAR role, the IOT&E plan required six open-air test trials, two for each variant, conducting the roles of rescue coordination and escort for a survivor in hostile territory. Trials were flown both day and night and in contested environments. The scenarios were designed to have a four-ship ("Sandy" flight) coordinate the rescue of a downed aircrew from a pre-planned response posture (i.e., notified prior to takeoff to conduct the CSAR mission vice reacting airborne from another mission to initiate the rescue operation). Tasks included coordinating the Personnel Recovery Task Force, escorting the personnel recovery vehicles, locating and authenticating the downed aircrew, sanitizing the recovery area by suppressing or destroying any ground threats that hindered mission accomplishment, coordinating the pickup, and escorting the recovery vehicles back to a designated safe zone. The F-35A and F-35B trials were assigned as 4-ship missions while the F-35C trials were assigned as a 2-ship of F-35C aircraft with a 2-ship of F/A-18F aircraft.

(U) Strike Coordination and Reconnaissance

(U) To evaluate the F-35 mission effectiveness in the RECCE roles of SCAR, and Armed RECCE, the plan required eight open-air trials where a 2-ship of F-35s, variant-unique, were tasked to find and identify specific targets within a designated geographic area, referred to as a "kill box," and prioritize them according to mission tasking. For example, a mobile SAM battery would be assigned priority one, artillery priority two, armored vehicles priority three, etc. Once located, the F-35 SCAR mission commander created a Prioritized Target List of all targets and coordinated attacks with the second F-35 aircraft, or prosecuted the target himself. Additional strikers were assigned to the mission to attack additional targets from the target list. The test teams collected the time each SCAR pilot took to locate and catalogue each priority target within the kill box, beginning with the start of the test trial or immediately after a target was catalogued. This measure accumulated time for each target; referred to as SCAR catalogue time. The teams also collected the time intervals between the SCAR pilot assigning a priority target from the target catalogue to a striker and the striker pilot confirming that they had located the target and were able to conduct an attack. This measure of time increment for each target is referred to as SCAR coordination time.

(U) Table 2-5 Test Design Factors: Additional Missions

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Factor	Levels	Applicable Mission Areas					
		CAS	FAC(A)	CSAR	SCAR/AR	RECCE	ASuW
F-35 Variant	A, B, C	X	X	X	X		
Time of Day	Day, Night	X	X	X	X		
Ground Threat Spectrum	Permissive, Contested	X	X	X			
Target Environment	Urban, Rural (CAS) Desert, Littoral (Recce)	X				X	
Target Clutter	High, Low				X		
Terrain	Desert, Forest/Mountain				X		
Target Category	Building, Vehicle, Personnel	X					
Control Interaction	Digital & Voice, Voice Only	X	X				
CAS Type Control	Type 1, Type 2, Type 3	X					
Formation	Single Ship, 2-Ship	X					
Target Movement	Moving, Stationary	X			X		
CAS Aircraft Type	Fixed Wing, Rotary Wing		X				
Cueing from External Source	None, Real Time				X		
Intel Imagery Type	SAR Map, EOTS					X	
Threat Vessel Cooperation	Active, Passive						X

Acronyms: ASuW – anti-surface warfare; CAS – close air support; CSAR – combat search and rescue; EA – electronic attack; EOTS – Electro-Optical Targeting System; FAC(A) – forward air controller (airborne); RECCE – reconnaissance; SAR – synthetic aperture radar; SCAR/AR - strike coordination and reconnaissance/armed reconnaissance

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(U) Close Air Support

(U) To evaluate mission effectiveness of the F-35 in the CAS, the IOT&E plan required 12 open-air test trials of variant-unique 2-ship F-35s engaging ground targets as assigned by the Joint Terminal Air Controller (JTAC). Target environments varied between urban and rural while threat environments varied from permissive to contested. The targets included personnel (normally simulated due to range and safety restrictions), vehicles – both static and moving – and buildings. Trials were flown in both daylight and night conditions. Three different types of control can be used to minimize the risk of friendly fire while maximizing the opportunity for a successful attack. Type 1 control requires the JTAC or FAC(A) to maintain control of the attack by observing both the target and the attacking aircraft during the terminal phase (just prior to weapons release), minimizing the risk for collateral damage or friendly fire. Type 2 control

(b)(1) [redacted]

(U) For the JSE venue, the test plan allocated 31 trials to evaluate OCA S/DEAD, Sweep/Escort, and AI mission roles using the same combined mission concept. No JSE trials were conducted as DEAD-only missions.

(U) Defensive Counter-Air

(U) To evaluate the mission effectiveness of the F-35 in the DCA roles, the IOT&E plan required 16 open-air trials where a 4-ship of common-variant of F-35s operating alone, or a 2-ship of common-variant of F-35 operating with a 4-ship of additional 4th-generation blue aircraft (i.e., F-15s with F-35As or F/A-18s with F-35Bs or F-35Cs) were tasked to defend a lane of airspace against threat aircraft. The threat force consisted of six aircraft and varied between one 2-ship of 5th-generation aircraft plus one 4-ship of 4th-generation aircraft and a 6-ship of 4th-generation of aircraft.

(b)(1) [redacted]

(U) The IOT&E plan allocated 11 trials to the JSE venue for evaluating the DCA mission against strike aircraft, and 22 trials for evaluating DCA against cruise missiles. The former had the same design characteristics as the open-air DCA trials. Eight of the JSE trials had a common-variant 4-ship of F-35s as the blue force, the other three had a 2-ship of F-35s joined with four 4th-generation blue fighter aircraft as a fighter integration force. The DCA missions protecting against cruise missiles added supersonic speed to, and varied the radar cross-sections of, the cruise missile targets. The number and formation geometry of cruise missiles entering the battlespace varied as well, ranging from 4 to 22.

(U) Additional Missions Open-Air Trial Designs

(U) Additional missions in the open-air trial designs included CAS, Forward Air Controller (Airborne) (FAC(A)), combat search and rescue (CSAR), strike coordination and reconnaissance (SCAR), RECCE, and ASuW. To ensure the test plan adequately covered the operational environment, the trial design varied important factors; a list of these factors is provided in Table 2-5, with additional information provided in the individual mission areas below. Critical measures were also selected that would reveal the performance of the F-35. These are listed in Table 2-6.

(b)(1) [redacted]

(b)(1) [redacted]

(U) Combined Offensive Counter-Air and Air Interdiction

(b)(1) [redacted]

(U) Combined Offensive Counter-Air: DEAD Only

(U) The IOT&E plan required an additional four open-air test trials that combined a 4-ship of F-35As with a 4-ship of F-35Cs to conduct the suppression or destruction of long- and medium-range out-of-band SAM threats with no aircraft in the AI role. Variations in these test trials included augmenting the F-35s with digital representations of self-powered decoys (Miniature Air-Launched Decoys) on two of the trials and with digital representations of EA-18G electronic attack aircraft on two of the trials, which affected the enemy integrated air defense network, and combining both the decoys and EA-18G augmentation on one of the four trials.

(U) These additional trials were conducted on the Point Mugu Sea Range (PMSR), off the coast of Ventura and Oxnard, California, with SAM sites emplaced on the mainland coast at Naval Air Station, Point Mugu; on San Nicolas Island, approximately 60 nautical miles off the coast, southwest of Point Mugu; and at Vandenberg AFB, approximately 75 nautical miles further north, up the coast. Conducting the trials on PMSR provided the ability to examine F-35 performance under operationally representative conditions not available at the Nevada Test and Training Range.

(b)(1) [redacted]

(U) Table 2-4. IOT&E Design Critical Measures: Primary Missions

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Mission Area	Measure	Definition
Offensive Counter-Air: Destruction of Enemy Air Defenses	Proportion of valid trials meeting OCA DEAD success criteria	The number of valid trials where F-35 OCA forces *destroy the DEAD target objective* out of the total number of valid trials
	Proportion of assigned DEAD target objective SAMs destroyed by F-35	The number of DEAD target objectives destroyed out of the total number assigned
Offensive Counter-Air: Sweep/Escort	Proportion of valid trials meeting OCA Sweep/Escort role success criteria	The number of valid trials where F-35 OCA aircraft *prevented the loss of any F-35 AI aircraft to red air* out of the total number of valid trials
	Proportion of F-35 AI force not killed by red air	The number of F-35 AI aircraft not killed by red air out of the total number assigned
	Proportion of F-35 aircraft lost to red air	The number of F-35 aircraft in either the OCA or AI role killed by red air out of the total number of F-35 aircraft assigned
Air Interdiction/ Attack	Proportion of valid trials meeting AI role success criteria	The number of valid trials where F-35 AI aircraft *destroy all primary assigned targets* out of the total number of valid trials
	Proportion of assigned primary AI targets destroyed by F-35	The number of primary AI targets destroyed out of the total number of assigned
	Proportion of F-35 AI aircraft killed	The number of F-35 AI aircraft killed out of the total number assigned
Defensive Counter-Air (Red Air Threat)	Proportion of valid trials meeting commander's intent	The number of valid trials meeting overall commander's intent of *preventing red aircraft from reaching the mission fail line* out of the total number of valid trials
	Proportion of red aircraft that cross the mission fail line	The number of red aircraft that cross the mission fail line out of the total number of red aircraft assigned
	Range to mission fail line where red air is killed by F-35	The range in nautical miles from the mission fail line where red aircraft are destroyed by an F-35
Defensive Counter-Air (Cruise Missile Defense)	Proportion of cruise missiles detected by F-35	The number of cruise missiles detected by the F-35 aircraft out of the total number of cruise missiles presented
	Proportion of cruise missiles destroyed by F-35	The number of cruise missiles destroyed by the F-35 aircraft out of the total number of cruise missiles presented
Acronyms: AI – Air Interdiction; DEAD – Destruction of Enemy Air Defenses; OCA – Offensive Counter-Air; SAM – surface-to-air missile;		

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[redacted]

(b)(1) [redacted]

(U) Table 3. Blue Force and Red Force Loss Comparison – Open-Air Trials

(b)(1) [redacted]

(U) Table 4. Blue Force and Red Force Loss Comparison – JSE Trials

(b)(1) [redacted]

(U) Table 2. Combined Offensive Counter-Air/Air Interdiction Mission Results

(b)(1) [redacted]

(b)(1) [redacted]

(U) Operational Effectiveness Assessments

(b)(1) [redacted]

(U) Combined Offensive Counter-Air and Air Interdiction

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Operational Effectiveness – Primary Missions

(U) Detailed Trial Success Criteria

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1) [redacted]

(U) The OCA and AI missions were executed as combined trials, planned to have four F-35s of one variant (a "4-ship") performing OCA and four of another variant performing AI. The DCA missions were executed separately and included trials against manned threat aircraft and trials defending against cruise missiles. The DCA trials against manned aircraft were planned with a 4-ship of F-35s of a single variant conducting the mission, or two F-35s of a single variant operating in conjunction with four 4th-generation aircraft. The DCA CMD trials featured from one to four F-35 aircraft in the role.

(U) Each of these missions was evaluated in both open-air and JSE trials, with the JSE trials being more challenging, as noted, due mainly to more realistic and challenging threat presentations. The JSE trials strictly adhered to the planned total aircraft numbers and variant force mixes. The open-air trials sometimes deviated from planned numbers and force mixes due to aircraft fallouts for maintenance issues, on the day of the trial.

(b)(1) [redacted]

(b)(1)

[redacted]

(U) Test Execution – Primary Missions

(U) The intent of the F-35 Block 3 development program was to deliver a strike fighter aircraft capable of countering current and emerging advanced threats and yielding improvements in lethality and survivability over earlier generations of aircraft, through the introduction of innovative, "5th-generation" design features, with respect to aircraft signatures and electronic mission systems capabilities. The design of the F-35 electronic mission systems attempted to combine advanced sensors and communications links with new sensor fusion methods, to provide pilots the capability to successfully execute the steps of a so-called "kill chain" – find, fix, target, track, engage and assess – against challenging airborne and surface targets. The aircraft was to achieve lethality in this way while remaining survivable through a combination of low observability improvements to the airframe and engines, in the form of radar and infrared signature reduction, and through defensive mission systems capabilities, including advanced countermeasures.

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) The mission-level effectiveness outcomes measured in the JSE trials for the primary IOT&E missions are more credible than the outcomes from the open-air trials, in terms of being representative of likely real-world lethality, survivability, and mission accomplishment against peer threats. Testing in the JSE revealed critical F-35 performance shortfalls that were masked by limitations in the open-air tests, such as replication of key aspects of real-world combat scenarios (threat capability and density). The JSE was essential for coming to a realistic understanding of the F-35's mission-level capabilities.

(U) Open-air range testing was also critical to the successful execution of IOT&E and the overall evaluation of the aircraft. It was essential for establishing and quantifying actual F-35 system- and subsystem-level performance, especially with regard to the areas of radar and electronic warfare. Since the digital models of F-35 systems and subsystems running in the JSE do not have the level of fidelity necessary to do so, they are not able to predict the installed performance of the modeled components at an engineering level. Open-air testing under operationally representative, real-world conditions is required to fully characterize installed system- and subsystem-level performance.

(U) The models in the JSE needed to be compared to, and thereby validated against, the installed system- and subsystem-level performance observed in the open-air trials, as well as against additional performance data obtained in airborne and ground-based developmental testing. The testing in the JSE could not have been credibly accomplished without the information the open-air trials provided and the information gathered in developmental testing.

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(U) Summary of IOT&E Test Activities and Events

- (U) Open-air flight testing: 89 mission-level trials, 75 live WDE events
- (U) JSE testing: 64 trials supporting assessments of primary missions
- (U) An F-35A vs A-10 comparison test conducted as part of IOT&E, for CAS and related missions – reported separately in February 2023
- (U) Suitability evaluation deployments: a cold weather deployment, sortie generation demonstrations, deployments to intended operating environments
- (U) Nine training site evaluations
- (U) Thirty-two dynamic, in-flight radar cross-section measurement test missions
- (U) Reviews of more than 2,000 maintenance records, covering over 2,500 flight hours, to evaluate the aircraft's reliability, maintainability, and availability
- (U) Twenty-four F-35 air vehicle subsystems and support systems evaluated for cyber-survivability, most assessed across multiple test events
- (U) A separate live fire test and evaluation program, spanning the years 2002 to 2020, which assessed F-35 vulnerability to kinetic threats (missiles and guns) and chemical, biological, radiological, and nuclear (CBRN) threats

(U) Mission-Level Effectiveness Testing Overview

[redacted]

(U) These physical assets were used in conjunction with digital models of all weapons employed in the mission-level open-air trials, other than inert weapons employed in CAS and related additional missions, since safety considerations and other range constraints precluded the use of actual weapons in anything other than the tightly controlled, dedicated WDE portion of IOT&E. Special instrumentation known as Open-Air Battle Shaping (OABS) was used for scoring the digitally simulated weapon engagement outcomes in the open-air trials and for implementing key features of the weapons models and the RSEs.

[redacted]

(U) Table 1. IOT&E Mission Areas Mapped to Service-Defined Mission Areas

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<table>
<tr><th>Mission Category</th><th>IOT&E Test Design Mission Area</th><th>USAF (F-35A)</th><th>USMC (F-35B)</th><th>USN (F-35C)</th></tr>
<tr><td rowspan="8">Primary</td><td rowspan="2">Air Interdiction</td><td>Attack Operations / Air Interdiction</td><td rowspan="2">Air Interdiction</td><td rowspan="2">Air Interdiction</td></tr>
<tr><td>Strategic Attack</td></tr>
<tr><td rowspan="5">Offensive Counter-Air</td><td>Offensive Counter-Air</td><td>Anti-Air Warfare</td><td>Offensive Counter-Air</td></tr>
<tr><td>Suppression of Enemy Air Defenses</td><td>Suppression of Enemy Air Defenses</td><td>Suppression of Enemy Air Defenses</td></tr>
<tr><td rowspan="3">Destruction of Enemy Air Defenses</td><td>Destruction of Enemy Air Defenses</td><td>Destruction of Enemy Air Defenses</td></tr>
<tr><td>Inherent Electronic Protection</td><td>Inherent Electronic Protection</td></tr>
<tr><td>Electronic Attack and Electronic Warfare Support</td><td>Electronic Attack and Electronic Warfare Support</td></tr>
<tr><td>Defensive Counter-Air</td><td>Defensive Counter-Air</td><td>Anti-Air Warfare</td><td>Defensive Counter-Air</td></tr>
<tr><td rowspan="10">Additional</td><td>Close Air Support</td><td>Close Air Support</td><td>Close Air Support</td><td>Close Air Support</td></tr>
<tr><td>Forward Air Controller (Airborne)</td><td>Forward Air Controller (Airborne)</td><td>Tactical Air Controller (Airborne) / Forward Air Controller (Airborne)</td><td>Forward Air Controller (Airborne)</td></tr>
<tr><td rowspan="3">Combat Search and Rescue</td><td rowspan="3">Combat Search and Rescue</td><td>Support of Tactical Recovery of Aircraft and Personnel</td><td rowspan="3">Combat Search and Rescue</td></tr>
<tr><td>Combat Search and Rescue</td></tr>
<tr><td>Assault Support Escort</td></tr>
<tr><td rowspan="4">Reconnaissance</td><td rowspan="4">Armed Reconnaissance</td><td>Armed Reconnaissance</td><td rowspan="2">Armed Reconnaissance</td></tr>
<tr><td>Aerial Reconnaissance</td></tr>
<tr><td rowspan="2">Strike Coordination and Reconnaissance</td><td>Strike Coordination and Reconnaissance</td></tr>
<tr><td>Mining and Reconnaissance</td></tr>
<tr><td>Anti-Surface Warfare</td><td>N/A</td><td>N/A</td><td>Attack of Maritime Surface Targets</td></tr>
</table>

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(b)(1) [redacted]

(U) Detailed Summary

(U) Test Adequacy

(U) The testing conducted in IOT&E was adequate to evaluate the effectiveness and suitability of the F-35 aircraft in all Service-specified mission areas *in the operational conditions delineated in the test plans.* Test planners mapped specific Service mission areas to IOT&E mission area as shown in Table 1.

(b)(1) [redacted]