F-35 Joint Strike Fighter (JSF)

The F-35 program made some progress in FY21 in IOT&E, but the necessary verification and validation of the Joint Simulation Environment (JSE) continued to delay readiness to conduct the 64 JSE test trials required for completing IOT&E. An official estimated date for the execution of IOT&E trials in the JSE is still to be determined.

The Program Office continues to field immature, deficient, and insufficiently tested Block 4 mission systems software to fielded units. The operational test teams identified deficiencies that required software modifications and additional time and resources, which caused delays in Block 4 capability release. The Program Office has implemented process improvements to address software development issues.

System Description

The F-35 JSF is a tri-Service, multinational, single-seat, single-engine strike fighter aircraft produced in three variants:

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

The F-35 Block 4 Modernization Capability Development Document specifies required capabilities and associated capability gaps that drive incremental improvements in capability from 2018 and beyond. Table 1 shows the linkage between development phases, hardware, block designation, mission systems software, and operational testing.

Program

The F-35 Joint Strike Fighter is an Acquisition Category ID program. DOT&E approved the F-35 Overarching Block 4 Test and Evaluation Master Plan (TEMP) and Increment 1 Annexes on May 18, 2020. The Annexes (one classified and one unclassified) cover the Block 4 developmental and operational testing of software versions 30R03 though 30R06. Increment 2 Annexes, which cover Block 4 software version 30R07 and later, are in final coordination and staffing as of the time of this report. DOT&E approved the fourth revision of the System Development and Demonstration TEMP, which governs the conduct of IOT&E, in March 2013.

Table 1. Linkage of Development Phase with Hardware, Block Designation, Mission Systems Software, and Operational Testing

F-35 Development Phase	Major Avionics Hardware	Capabilities	Mission Systems Software	Operational Testing
SDD	TR-1	Block 2B	Block 2B Software	• Marine Corps Fielding Reports and F-35B IOC • Service and JOTT test events • Formal OUE canceled
	TR-2	Block 3i	Block 3i Software	• Air Force Fielding Reports and F-35A IOC • Service and JOTT test events
		Block 3F	Block 3F/ 3FR6**	• **Pre-IOT&E Increment 1 (Jan - Feb 2018) Cold Weather Deployment** For-score testing to evaluate the suitability of the F-35 air system and alert launch timelines in an extreme cold weather environment.
			Block 3F/30R00***	• Navy Service Fielding Reports • **Pre-IOT&E Increment 2 (Starting Mar 2018)** For-score testing of limited two-ship mission scenarios, F-35A deployment, F-35C deployment to a carrier, and weapons delivery events.
C2D2		Block 4, 30 Series	30R02.04	• **Portion of Formal IOT&E** (Dec 2018 - Sep 2019)
			30R04.52	• **Portion of Formal IOT&E: Electronic Attack (EA) trials** (Jul 2020)
			30R06.041 & .042	U.S. Operational Test Team evaluated these versions in FY21
			30R06.042	Software fix needed for **IOT&E weapons event in June 2021**
C2D2	TR-2	Block 4, 30 Series	30R07, 30R08+	Dedicated operational tests planned for each release of capability
	TR-3	Block 4, 40 Series	40R0X	Dedicated operational tests planned for each release of capability

Table 1. Linkage of Development Phase with Hardware, Block Designation, Mission Systems Software, and Operational Testing

Notes:

* For-score IOT&E events are highlighted in bold.

** The final planned version of Block 3F software was 3FR6.

*** The program changed software nomenclature for the initial increments of Block 4 from "3F" used during SDD to "30RXX" for development and "30PXX" for fielding software. The 30 series of software is compatible with the Block 3F aircraft hardware configuration and is being used to address deficiencies and add Service-prioritized capabilities.

Acronyms: C2D2 – Continuous Capability Development and Delivery; IOC – Initial Operational Capability; JOTT – JSF Operational Test Team; OUE – Operational Utility Evaluation; SDD – System Development and Demonstration; TR-X – Technical Refresh [version #], referring to the suite of core avionics processors.

Major Contractors

Lockheed Martin, Aeronautics Company – Fort Worth, Texas. Pratt & Whitney, a subsidiary of Raytheon Technologies – East Hartford, Connecticut.

Test Adequacy and Performance

IOT&E Progress

The F-35 program is nearing completion of a multi-year IOT&E. The JSF Operational Test Team (JOTT) has completed cold-weather testing; a series of weapons trials (both bombs and missiles); cybersecurity testing of the air vehicle, training systems, mission data reprogramming laboratory, and the Autonomic Logistics Information System (ALIS); deployments to ships and austere environments; and testing that compared F-35 performance to that of fourth-generation fighters against traditional and more modern surface-to-air threats currently fielded by potential adversaries. Open-air test missions evaluated the F-35 in multiple roles: offensive counter-air (OCA), defensive counter-air (DCA), cruise missile defense (CMD), suppression/destruction of enemy air defenses (S/DEAD), reconnaissance, electronic attack (EA), close air support, forward air control (airborne), strike coordination and armed reconnaissance, combat search and rescue, anti-surface warfare, and air interdiction. Test trials were conducted in varying threat environments using two-, four-, and eight-F-35 aircraft mission scenarios. During the S/DEAD and EA trials, the F-35 faced operationally representative surface-to-air threat environments represented by Radar Emulators (RE). Open air test trials were completed in June 2021, with the execution of the final AIM-120 missile trial accomplished using an F-35C aircraft. Deficiencies in earlier versions of the aircraft software prevented this event from being accomplished sooner. The program delivered software version 30R06.42 with the fixes in June 2021, enabling the operational test team to complete the trial. Suitability and cyber data collection required for the IOT&E test plan were completed by the end of CY20.

JSE Development Progress

The only remaining module of the IOT&E test plan is the 64 trials in the JSE at Naval Air Station Patuxent River, Maryland. These trials include 11 DCA, 22 CMD, and 31 combined OCA/AI/DEAD trials in operationally representative, dense, defense in-depth scenarios with the latest threat systems that are not available on open air ranges. All three F-35 variants will be involved in the execution of the trials.

Although the JSE team made steady progress in maturing the simulation and improving overall system stability, significant work remains to complete the necessary verification and validation process, which compares JSE component and system-level performance to F-35 flight test data to accredit the JSE for operational test trials. The JSE team completed a schedule review and risk analysis to update the integrated master schedule, but an official estimated date for execution of for-score IOT&E trials in the JSE is still to be determined.

The JSE schedule has suffered multiple delays since 2015, when the Joint Program Office (JPO) transferred development and overall management of the simulation from Lockheed Martin, in an environment referred to as the Verification Simulation (VSim), to the combined JPO and Naval Air Systems Command (NAVAIR) government team at Naval Air Station Patuxent River, Maryland. Constructing and integrating the complex hardware and many software models, including Lockheed Martin's "F-35 In-A-Box" digital model of the aircraft, into the JSE has proven to be a difficult undertaking. The JPO and NAVAIR team underestimated the required level of effort to integrate and accredit a simulation of this complexity. When it was initially transferred to the government team in 2015, the JPO projected the JSE to be completed in 2017, but the schedule slipped nearly year-for-year over the following six years, despite significant progress in development. As of December 2021, significant work is required to complete the development, validate the models, and accredit the simulation before scored trials can begin.

An independent technical assessment, conducted by Johns Hopkins Applied Physics Laboratory, the Carnegie Mellon University Software Engineering Institute, and the Georgia Tech Research Institute, was completed in May 2021. The team concluded that the JSE effort needed additional financial and personnel resources, along with strong support from all stakeholders to support IOT&E requirements. DOT&E requires the JSE to complete the planned verification, validation, and accreditation process to ensure the JSE will accurately represent aircraft performance and the threat environment, so the JSE results inform an adequate effectiveness evaluation.

Block 4 Development

The JPO designed the current development process, referred to as Continuous Capability Development and Delivery (C2D2), to provide new capabilities and updates in six-month increments, but it has not worked as envisioned. The program continues to field immature, deficient, and insufficiently tested mission systems software to fielded units without adequate operational testing. Although the program designed C2D2 around commercial "agile software" development concepts, it does not adhere to the published best practices that include clear articulation of the capabilities required in the Minimum Viable Product, focused testing, comprehensive characterization of the product, and full delivery of the specified operational capabilities. The program did not deliver programmed capabilities to operational units, as defined in the Air Systems Playbook.

The program has not sufficiently funded the developmental test (DT) teams to adequately test, analyze data, or perform comprehensive regression testing to assure that unintentional deficiencies are not embedded in the software prior to delivery. In addition, integration labs must undergo a continuous verification, validation, and accreditation (VV&A) process using flight test data to provide adequate lab infrastructure. Finally, additional instrumented DT aircraft must be provided to test the wave of new capabilities, configurations, and fixes to program deficiencies from System Development and Demonstration (SDD).

The current C2D2 process has resulted in frequent shifting of priorities, discoveries of critical warfighting deficiencies after fielding to the combat units, and marginalization of meaningful operational testing and data analyses. Developmental testing of software is often truncated early, so baseline system characterization is inadequate and structured operational testing is executed simultaneously with software deliveries to the field units. The program planned to reduce flight testing with the C2D2 process by leveraging more testing in Lockheed Martin's laboratory and simulation environments, but to date that plan has not been successful due to the limitations of those test environments. The Lockheed Martin laboratories and simulations are not capable of replicating operationally representative flight conditions or target complexities and densities.

Because the current six-month C2D2 timeline has proven unsustainable, and in order to stabilize major hardware configuration changes prior to the transition to the Technical Refresh-3 configuration, the JPO is extending the development timeline to one-year increments with software version 30R08 that will begin developmental testing in December 2021.

Although designed to introduce new capabilities or fix deficiencies, the C2D2 process has often introduced stability problems and/or adversely affected other functionality. This results in the operational test units and the field units discovering deficiencies in the software. Significant operational deficiencies (classified) were identified by the operational test units and field units in CY20 that required software modifications.

The program adjusted the overall timeline and sequencing of capability development, based on an approved list of requirements, in a new Air System Playbook, version 16.1, that was presented to the JSF Executive Steering Board in September 2021.

The JSF program continues to carry a large number of deficiencies, and conducts recurring reviews with Service requirements representatives to prioritize resources to address them. Although initial development in Block 4 focused on addressing deficiencies that were identified during SDD while developing some new capabilities, the overall number of open deficiencies has not significantly decreased since the completion of SDD due to the continued discovery of new problems.

The program had to stop work on some development efforts in late CY20 and CY21 to redirect funding to the development of the new Technical Refresh (TR)-3 avionics configuration due to significant cost overruns and reductions. Further delays in the TR-3 development and integration may affect production delivery of aircraft delivered in the TR-3 configuration. Delays in Block 4 capabilities and weapons integrations activities may also limit the initial capabilities of aircraft delivered in the TR-3 configuration.

The integrated test teams at Edwards Air Force Base, California and Naval Air Station Patuxent River, Maryland, responsible for developmental flight testing of all F-35 variants, conducted testing with software versions 30R06 (eight iterations: 30R06.01, 30R06.02, 30R06.03, 30R06.031, 30R06.04, 30R06.041, 30R06.042, 30R06.043) and 30R07 (four iterations as of the end of September: 30R07.00, 30R07.01, 30R07.02, 30R07.03).

Block 4 Operational Testing

The U.S. Operational Test Team (UOTT) completed operational testing of 30R06 software in August 2020. Test missions included:

- Four Close Air Support test missions flown with F-35A and F-35B aircraft
- Four DCA test missions flown with F-35A and F-35C aircraft
- Three OCA test missions flown with F-35A and F-35C aircraft
- Two D/SEAD test missions flown with F-35A and F-35C aircraft

The UOTT completed some of these test missions by collecting limited data during large force training exercises over the test and training ranges in Alaska and off the Pacific coast. Although required by the DOT&E-approved test plan, Open Air Battle Shaping (OABS) instrumentation was not available for these training scenarios, which limited the utility of the data collected. Adequate evaluation of Block 4 capabilities against air- and surface-to-air threats continues to require the use of OABS instrumentation and threats surrogated by Radar Emulators.

Per the Block 4 TEMP and associated Annexes, operational test (OT) aircraft are required to support both developmental and operational testing. Modifications to these aircraft must be funded, scheduled, and completed just after developmental test (DT) aircraft modifications to enable integrated DT/OT, DT assist, and relevant mission-level testing of future capabilities. Without these modifications, Block 4 OT is likely to be inadequate.

U.S. Fleet Performance

In FY21, the trend in aircraft availability rates plateaued during the year and began declining in the final months of the year. Improvement in aircraft availability prior to June 2021 was a result of a program initiative to increase spare part availability and the lower percentage of aircraft needing depot modifications as more late-lot production aircraft entered the fleet. The sharp reduction in availability since June 2021 has been predominantly driven by spare parts not being available when needed. The lack of spares inventory, and limited component-level depot repair capacity, contribute to the shortfalls in spares supply. A significant shortage of fully functional F135 engines has contributed to reduced aircraft availability. This shortage has been exacerbated by a lack of depot repair capacity. Almost all aircraft requiring an engine are F-35A variants. Although the program and the Services manage engine spares by prioritizing combat-coded units over test and training units, the shortage of spare engines has adversely affected deployed combat units as well.

The F-35 fleet remains below Joint Strike Fighter Operational Requirements Document (ORD) thresholds in some areas for overall reliability and maintainability. Maintenance data gathered through June 2021 from the U.S. fleet of all three variants show that the F-35A and F-35B are not meeting, and the F-35C is not projected to meet, the full set of ORD reliability and maintainability requirements for mature aircraft. The F-35A has accumulated the flight hours designated for maturity (75,000 hours), making it eligible for an assessment against the full ORD requirement. In June 2021, the F-35A fleet alone exceeded 200,000 flight hours, the total hours designated for the entire fleet for maturity. The F-35B fleet also reached its 75,000-hour threshold in June, making it eligible for an assessment against the full ORD requirement as well. The F-35C has not yet reached its individual variant threshold of 50,000 hours and was consequently assessed against interim goals. The tables below show reliability and maintainability trends from June 2020 to June 2021 and whether ORD requirements or imputed interim goals are being met. For the reliability metrics, higher numbers reflect better performance (a more reliable system) and for maintainability metrics, lower numbers reflect better performance (less maintenance burden). Tables 2 and 3 show trends in the reliability and maintainability metrics respectively based on data aggregated in 3-month rolling windows, where monthly reports are generated based on the last 3 months of data. This process enables trends to be observed more clearly than reports generated by only a single month of data.

Operational Suitability Testing

The UOTT conducted suitability testing per the annual DOT&E-approved suitability test plan in FY21. The test team conducted interviews with maintenance personnel and pilots on training, technical orders, the use of ALIS, software updates, maintenance of the low observable characteristics of the aircraft, support equipment and tools, and safety issues.

Table 2. F-35 Reliability Metrics (Up Arrow Represents Improving Trend)

Variant	Flight Hours for ORD or JCS Threshold	Assessment as of June 30, 2021												
		Cumulative Flight Hours	MFHBCF (hours)			MFHBR (hours)			MFHBME (hours)			MFHBF_DC (hours)		
			ORD Threshold	Change: June 2020 to June 2021	Meeting Interim Goal for ORD Threshold	ORD Threshold	Change: June 2020 to June 2021	Meeting Interim Goal for ORD Threshold	ORD Threshold	Change: June 2020 to June 2021	Meeting Interim Goal for ORD Threshold	JCS Requirement	Change: June 2020 to June 2021	Meeting Interim Goal for JCS Threshold
F-35A	75,000	202,172	20	↓	No	6.5	↓	No	2.0	↓	Yes	6.0	↓	Yes
F-35B	75,000	75,141	12	↓	No	6.0	↑	No	1.5	↑	Yes	4.0	↓	Yes
F-35C	50,000	42,449	14	↑	Yes	6.0	↓	No	1.5	↓	No	4.0	↑	Yes

Variant	Flight Hours for ORD Threshold	Cumulative Flight Hours	MCMTCF (hours)			MTTR (hours)		
			ORD Threshold	Change: June 2020 to June 2021	Meeting Interim Goal for ORD Threshold	ORD Threshold	Change: June 2020 to June 2021	Meeting Interim Goal for ORD Threshold
F-35A	75,000	202,172	4.0	↓	No	2.5	–	No
F-35B	75,000	75,141	4.5	↑	No	3.0	↑	No
F-35C	50,000	42,449	4.0	↓	No	2.5	↓	No

The UOTT continued developing plans to conduct a 30-day demonstration of flight operations without ALIS connectivity. As required by DOT&E, the demonstration and corresponding results must be scheduled for completion prior to the approval of the next increment of TEMP annexes.

ALIS and Operational Data Integrated Network (ODIN)

The program continued making plans to transition from ALIS to ODIN, but progress stagnated due to program funding constraints and the need to address pressing ALIS obsolescence and cyber challenges. The JPO altered the ALIS-to-ODIN (A2O) strategy in early 2021 to a phased approach, replacing the previous strategy of a rapid transition to and fielding of ODIN. The result was a significant delay to the planned ODIN development timeline and a merger of the ALIS and ODIN organizations into one. The key to A2O success lies in the definition of the new data architecture, fixing cybersecurity deficiencies in ALIS, and ensuring that any new ODIN hardware and software solutions build in cybersecurity from the start of development.

In June 2021, the JPO elected to down-select one ODIN hardware solution to address urgent obsolescence needs, choosing the Lockheed Martin-produced ODIN Base Kit (OBK). Thirty-four OBKs were procured in FY21 and are currently being fielded. Fourteen are replacing the oldest ALIS Standard Operating Unit (SOU) v1, sixteen support future site stand-ups, and four are spares for the fleet. Initial performance measurements indicate the OBK runs ALIS significantly faster than existing the SOU v1 and v2 hardware. Additionally, the OBK is significantly smaller and lighter than the legacy SOU hardware. The OBK alone weighs 65 pounds. It requires an uninterruptible power supply, which weighs an additional 69 pounds. An optional battery expansion can be included, which weighs 68 pounds. The total OBK hardware weighs between 134 and 202 pounds, much less than the 891-pound SOU. The size of the OBK is significantly less than the SOU as well, roughly a 75 percent reduction in volume. The path forward is to make all new ALIS or ODIN software compatible with minimal retrofit to the OBK hardware. ALIS will be required to be compatible with both the existing SOU and OBK hardware until all of the SOUs are replaced, which is currently expected in late 2023.

Quarterly ALIS software development in FY21 focused primarily on cybersecurity improvements, software stabilization, improved processing times, and some usability improvements. The cybersecurity authorizing officials are closely monitoring progress on cyber risk reduction. Although no formal operational test occurred apart from cybersecurity testing of the Mission Planning Support Environment described below, testing of ALIS software updates took place at the Integrated Test Force facility at Pauxent River, Maryland and the Operationally Representative Environment at Edwards Air Force Base, California. The Quarter 1 (Q1) approval for fleet release was granted in June 2021 and fielding is ongoing. The Q2 release was delayed due to issues found in flight test. It was subsequently loaded into the U.S. Central Point of Entry and Nellis Air Force Base OBK to begin an operational assessment prior to release to the fleet. The Q3 development is complete and ORE/Flight Test will be done in November. The Q4 release is in development. Both developmental and operational testing for ALIS and ODIN continue to be under-resourced, increasing risk to fielding and support. While the quarterly software development cycle that started in 2019 will continue into 2022, the program plans to transition the software release cycle to two releases per year.

The rate of spare parts with Electronic Equipment Logbooks arriving at warehouses ready for issue has historically been lower than the JPO goal of 90 percent. Recent JPO data show that this rate increased to between 80 and 90 percent.

Cybersecurity vulnerabilities and attack vectors found during testing of ALIS will need to be addressed by the program as data structures transition from ALIS to ODIN. Rigorous testing of data integrity will also be necessary to ensure a secure transition, testing that needs to be planned and documented for DOT&E approval. These steps will be critical to the success of A2O while also supporting operational unit day-to-day activities.

Cyber

While some cybersecurity-related system discrepancies have been resolved, cybersecurity testing during FY21 continued to demonstrate that some vulnerabilities identified during earlier testing periods remain in the system.

The UOTT cyber test teams conducted a Cooperative Vulnerability and Penetration Assessment on the Mission Planning Support Environment (MPSE) at Marine Corps Air Station Yuma, Arizona in July 2021 and an Adversarial Assessment on the MPSE at Eglin Air Force Base, Florida in September 2021. Both were conducted in accordance with DOT&E-approved test plans.

The UOTT worked with the JPO and stakeholders across the DOD to identify relevant scenarios, qualified test personnel, and adequate resources for conducting cybersecurity testing on AV components and support systems.

More testing is needed to assess the cybersecurity of the AV. Actual aircraft, as well as appropriate hardware- and software-in-the-loop facilities, must be used to facilitate operationally representative air vehicle cyber testing. To this end, the F-35 JPO arranged for an operationally representative F-35B AV at Naval Air Station Patuxent River, Maryland to facilitate testing.

The F-35 JPO intends to use a Security Development Operations and agile software construct with frequent software updates to the field in support of the ODIN path forward. The Block 4 construct of 30 and 40 series operational flight program software is also providing more frequent updates to the combat forces than SDD. An increased frequency of new software deployments may further stress the capacity of cybersecurity test teams to thoroughly evaluate each update. Under these new constructs, the importance of cybersecurity testing of the software development environments will increase.

In light of current cybersecurity threats and vulnerabilities, along with peer and near-peer threats to bases and communications, DOT&E required the F-35 program and Services to conduct testing of aircraft operations without access to the ALIS SOU for extended periods of time, with an objective of demonstrating the SOU-specified 30 days of operations. The program is currently planning for a test of the ALIS Contingency Operations Plan in late 2021 or early 2022, which will test standardized procedures for lack of connectivity scenarios.

Recommendations

The F-35 JPO, Services, and Lockheed Martin as appropriate should:

1. Complete the remaining development and VV&A of the JSE as soon as possible to enable timely completion of the required IOT&E trials.
2. Fully fund new threat air defense radar simulators and upgrades to existing REs, the JSE, and OABS systems to meet test requirements for each C2D2 release of capability.
3. Adequately fund the development and sustainment of robust laboratory and simulation environments, data management and analysis architecture, and adequate VV&A plans that include the use of data from representative open-air missions in support of developmental and operational testing.
4. Complete development of the requirements for the Block 4 USRL while ensuring adequate lab infrastructure to meet the aggressive development timelines of C2D2 and the operational requirements of both 30 and 40 series Block 4 F-35 aircraft.
5. Per the DOT&E TEMP, Increment 1 approval memo:
    - Fully fund, develop and update the detailed plan to modify all OT aircraft with the capabilities, life limit, and instrumentation, including OABS requirements.
    - Complete a 30-day demonstration of flight operations without ALIS connectivity.
    - Align the components of the F-35 air system delivery framework for each increment of capability to allow enough time for adequate testing of the fully representative system that is planned to be fielded.
6. Continue to pursue maintenance system improvements, especially for common processes distributed among many different Non-Mission Capable Maintenance drivers, such as low observable repairs and adhesive cure times.
7. Improve spare posturing, especially for F135 engines, to reduce down-time for aircraft waiting spare parts by developing alternate sources of repair (including organic repair).
8. Continue to expedite fixes to Electronic Equipment Lists.
9. Accomplish rigorous testing of data integrity while the transition from ALIS to ODIN continues, as this will be critical to the success of A2O while also supporting operational unit day to day activities.
10. Ensure both developmental and operational testing for ALIS and ODIN are adequately resourced to reduce the high risk associated with fielding an immature and inadequately tested replacement.
11. Conduct more in-depth cyber testing of the AV and provide a dedicated AV cyber-test asset.
12. Correct program-wide deficiencies identified during cybersecurity testing in a timely manner.
13. Develop and routinely report software sustainment and stability metrics that show how well the program's overall software development capability for the air vehicle and logistics sustainment system is progressing.