F-35 Joint Strike Fighter

Concurrency Quick Look Review

November 29, 2011

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Executive Summary

On October 28, 2011, the Acting USD (AT&L), citing concerns about F-35 developmental issues and the degree of risk associated with additional production commitments, chartered a small OUSD (AT&L) team to conduct a Quick Look Review (QLR) of the Joint Strike Fighter program. This team was tasked to review and assess F-35 test data and analyses to evaluate whether there is adequate confidence in the stability of the basic design to justify additional concurrent procurement. Specifically, they examined currently known issues in the F-35 program and the potential for significant future design change in order to assess the risk associated with modification to aircraft being produced while the design is still being tested and changed, which is referred to in this report as concurrency risk.

The Department began the F-35 program confident that benefits from a new generation of advanced design and simulation tools would provide a more mature system design earlier in the test program than previously experienced in fighter development programs. It was this expectation that led the Department to accept the economic risk of beginning low rate initial production concurrent with the development and test of the F-35 design with the implication that the need for rework of early procured aircraft would be modest. This assessment shows that the F-35 program has discovered and is continuing to discover issues at a rate more typical of early design experience on previous aircraft development programs, which calls into question the assumed design maturity which supported the decision to conduct significant concurrent production.

The Technical Baseline Review (TBR) completed in November 2010 represented an important step in the continuing evaluation of the program's premise of design maturity. As a result of the TBR, the program extended the planned duration of the overall development effort. After a year-long effort, there is now an Integrated Master Schedule (IMS) that reflects this restructure, clarifying the extent of development and production concurrency more precisely than was understood in previous planning. Additionally, flight and ground tests in the last year have revealed technical issues with rework implications for concurrently procured aircraft. This information is not consistent with the premise that the F-35 would represent a fundamental break from precedent, and motivates a new assessment of concurrency risk.

In the team's review of F-35 data and analyses, no fundamental design risks sufficient to preclude further production were identified. Five issues were found where major consequence issues have been identified, but root cause, corrective action or fix effectivity are still in development: Helmet Mounted Display System, Fuel Dump Subsystem, Integrated Power Package, Arresting Gear System (CV variant) and a classified issue. Three issues were found where potentially major consequence discovery is likely pending outcomes of further discovery: Buffet, Fatigue Life, and Test Execution. Five issues were found where consequence or cost is moderate, but the number of moderate issues poses a cumulative concurrency risk: Software, Weight Management, Thermal Concerns, Autonomic Logistics Information System and Lightning Protection. The combined impact of these issues results in a lack of confidence in the design stability. The QLR team concludes that this lack of confidence, in conjunction with the concurrency driven consequences of the required fixes, supports serious reconsideration of procurement and production planning.

The F-35 is early in its flight test execution. The program has been finding, and expects to continue to find, issues which will require consideration of potentially significant rework to concurrently procured aircraft. The most challenging portions of flight test (high angle-of-attack flight, mission systems and weapons employment) have yet to be entered and the team anticipates that these stressing cases will produce additional discovery of issues with potentially significant design impact. As a result, the QLR team assesses the current confidence in the design maturity of the F-35 to be lower than one would expect given the quantity of LRIP aircraft procurements planned and the potential cost of reworking these aircraft as new test discoveries are made. The QLR team recommends that further decisions about F-35 production be event driven, based on the achievement of sufficient test data to support increased confidence in design maturity and of a well-controlled process for executing and minimizing design changes across concurrent production. Further, the QLR team recommends each variant should be considered independently with respect to concurrency.

1.0 Introduction

On October 20, 2011, the Commanders of the U.S. Air Force Operational Test and Evaluation Center (AFOTEC), the U.S. Navy Operational Test and Evaluation Force (OPTEVFOR), and the United Kingdom (UK) Royal Air Force Air Warfare Center (AWC) released their Operational Assessment (OA) OT-IIE report of the F-35 program's progress toward readiness for Initial Operational Test and Evaluation (IOT&E). The operational test community expressed concern that, with IOT&E officially scheduled for 2015; the program was not making sufficient progress toward meeting operational effectiveness criteria for the helmet mounted display, night vision capability, aircraft handling characteristics, and certain classified issues. They also expressed concern that the system was not on track to meet certain suitability requirements, including thermal management, the performance of the Autonomous Logistics Information System (ALIS), and aircraft material repair times.

Although the most recent draft of the program's Integrated Master Schedule (IMS) places IOT&E in late 2016, the magnitude of the issues identified by the operational test community and their potential implications for aircraft design, test, and production warranted a detailed examination of the underlying performance issues. OT-IIE represented the first OA that included significant Developmental Flight Test data, and thus presented an excellent opportunity to assess the concurrency risk of the F-35 design and test program. At the Acting USD (AT&L)'s request, AFOTEC hosted a classified VTC with DOT&E, SAF/AQ, ASN(RDA), and the JPEO on October 26, 2011, to expand upon the findings listed in their report and provide direct feedback on their operational concerns.

On October 28, 2011, the Acting USD (AT&L), citing concerns about F-35 developmental issues and the degree of risk associated with additional production commitments, chartered a small OUSD (AT&L) team to conduct a Quick Look Review (QLR) of the Joint Strike Fighter program. This team was tasked to review and evaluate F-35 test data and analysis to evaluate whether there is adequate confidence in the stability of the basic design to justify additional concurrent procurement. Specifically, they examined currently known issues in the F-35 program and the potential for significant future design changes. This document is a report of the team's findings and recommendations.

The OSD team consisted of:

Mr. David Ahern, Deputy Assistant Secretary of Defense (Strategic and Tactical Systems)
Mr. Stephen Welby, Deputy Assistant Secretary of Defense (Systems Engineering)
Mr. Edward Greer, Deputy Assistant Secretary of Defense (Developmental Test and Evaluation)
Mr. James Woolsey, Deputy Director, Performance Assessments (PARCA)
Mr. James MacStravic, Senior Technical Advisor, PDUSD (AT&L)

In conducting their review these principals were supported by technical experts from their staffs and technical support from the office of the Director, Operational Test and Evaluation.

The QLR was conducted from October 28 through November 11, 2011. Initially the team reviewed the October 20, 2011, F-35 OA OT-IIE report; the October 28, 2011, report to Congress on the F-35 System Management Plan; and the October 2011 F-35 congressional metrics report. The team then conducted a fact-finding effort through direct discussions with and briefings from responsible flight test pilots and key developmental engineering and test staff.

The review included:

- Videoconferences with responsible technical authorities at Naval Air Systems Command and USAF Aeronautical Systems Center.
- Discussions with F-35 Joint Program Office personnel.
- Site visits to Patuxent River Naval Air Warfare Center, Aircraft Division (NAWC-AD), for discussions with engineering and flight test personnel.
- Site visit to Lockheed Martin (LM), Ft Worth, Texas, for discussions with engineering personnel.
- Teleconference with Commander, DCMA Fort Worth.
- Videoconference with flight test personnel at Edwards Air Force Base.

The team collected and reviewed a wide range of data, including more than 115 documents, briefings, and reports. Figures and tables showing applicable data which support these findings can be found in the Appendix to this report.

1.1 Operational Assessment OT-IIE Report Topics

The operational test team conducted an operational assessment from June 1, 2010, to June 1, 2011, to assess the F-35's progress toward operational effectiveness suitability, and mission capability. The team also assessed the program's progress toward readiness for operational test and evaluation (OT&E).

Air-to-Surface Attack: The OA OT-IIE report cited unsatisfactory progress towards meeting performance requirements for the air-to-surface (A/S) attack mission capability and survivability. The chief concern cited in the report was the lack of a legacy-quality night vision capability, predicated on the lack of progress in the helmet mounted display (HMD), as well as certain classified survivability issues. The report also expressed significant concerns with aircraft performance characteristics, particularly transonic roll-off and buffet, as well as maneuvering performance. Finally, the report noted that recent design changes should improve thermal management within the cockpit but certain operating environments were likely to stress that capability. The QLR confirmed that, although progress had been made against these issues, each remains a source of concern for concurrency risk.

Close Air Support (CAS): Although the test report described progress in this mission area, the report expressed concern with the lack of certain legacy aircraft CAS capabilities on the F-35, as well as some flaws in HMD symbology. The QLR considered a wide range of legacy (non-ORD) requirements and none were identified as sources of concurrency risk.

Air Warfare: The operational testers cited unsatisfactory progress and the likelihood of severe operational impacts for survivability, lethality, air vehicle performance, and employment. These conclusions were driven by certain classified issues, critical performance criteria for the helmet mounted display, air vehicle performance, and air-to-air weapons employment. While the QLR did not consider weapons employment requirements for the UK's Advanced Short-Range Air-to-Air Missile (ASRAAM), the team did find concurrency risks for both the helmet mounted display and air vehicle performance, particularly for structural loading.

Electronic Attack (EA): The OA report cited specific concerns related to EA performance for suppression and defeat of enemy air defenses as well as classified lethality and survivability issues. The QLR team evaluated the classified concerns and determined that while program plans were in place to address those risks, the aforementioned concerns with the HMD and aircraft maneuverability still held.

Combat Search and Rescue (CSAR) and Reconnaissance: The operational testers reiterated concerns about aircraft maneuverability and survivability as well as certain non-ORD data transfer requirements but the QLR team did not identify additional concurrency risks in these areas.

Deployability/Mission Generation/Training/Fleet Support: The report concluded with an assessment of the F-35 system's readiness to forward base, deploy, and retrograde; to generate missions in the intended operating environment; to train pilots and personnel; and support flight operations. Chief among their concerns were the readiness of the ALIS and its multiplicity of configurations; the thermal management system; the integrated power package (IPP); the overall logistics footprint and systems interoperability; progress on the HMD; and low observable (LO) maintenance. While it did not explicitly review the F-35 logistics footprint, the QLR found sources of concurrency risk in several of these areas.

2.0 Development & Production Concurrency

From program inception the F-35 represented a technical and managerial challenge. In addition to the complexity associated with developing and manufacturing a new fifth generation tactical aircraft, the program must also produce three separate variants for three different operational regimes, one of which being a vertical lift variant.

The Department chose a concurrent acquisition strategy in order to balance the cost and schedule risks of development and production and had several factors supporting this choice. First, concurrency is present to some degree in virtually all DoD programs, though not to the extent that it is on the F-35. Appendix Figure 1, page A-1, shows a graphical depiction of the F-35 developmental test progression and procurement in comparison to other legacy fighter programs. Second, and most important, a new generation of integrated design, simulation, and test computational tools was introduced in the 1980s and 1990s which held the promise (with some evidence) of delivering far more mature designs to testing than traditional methods. Finally, the Department had invested the time and funding required for extensive pre-SDD risk reduction efforts. The Department initially funded three contractor teams to work on what became the F-35 and, after a down-select to two, held a flying prototype competition between the bidders. Importantly, these prototypes were of both conventional and vertical lift models. Taken in total, the Department had a reasonable basis to be optimistic that the F-35 might represent a new generation of development efforts, and the concurrency built into its plans was a reflection of confidence that the problems uncovered in test, and the associated cost to mitigate them, would be fewer and more modest than previous experience.

Concurrency risk is the risk associated with modification to aircraft being produced while the design is still being tested and changed. This concurrency was maintained in the program plan despite a series of F-35 developmental issues over the past decade involving weight, producibility, and vertical lift issues. The F-35 program began procurement in FY07 before flying the first developmental aircraft (BF-1) in FY08. Production aircraft were placed on contract through FY10 for a total of 58 U.S. F-35s in Lots 1-4.

Appendix Figure 2, page A-2, shows a graphical depiction of the F-35 developmental test progression and procurement as currently planned in the 2012 President's Budget (PB12).

The Technical Baseline Review (TBR) completed in November 2010 represented an important step in the continuing evaluation of the program's premise of design maturity. As a result of the TBR, the program extended the planned duration of the overall development effort. The new program plan also made modest reductions in near term concurrency.

Since the TBR, the Department has gained additional insight into the program. After a year-long effort, there is now an Integrated Master Schedule (IMS) that reflects this restructure, and the two years added to the SDD program clarify the extent of developmental concurrency more precisely than was visible in previous planning. Additionally, flight and ground tests in the last year have revealed technical issues with rework implications for concurrently procured aircraft. This information is not consistent with the premise that the F-35 would represent a fundamental break from precedent, and motivates a new assessment of concurrency risk.

Concurrency risk imposes a penalty of both time and cost to the program, since modifications take 6 months to 2 years to incorporate into the production line after discovery, in addition to the time and cost it takes to modify aircraft that were produced prior to implementation of the change. Concurrency risk increases with the severity of the design change needed to correct technical issues identified in developmental test.

There are several factors that impact concurrency associated with design change, including the quantity of changes in process, the span time for implementing change, the rationale for changes, and the ultimate cost of change implementation.

Quantity of Change in Process: As shown in Appendix Figure 3, page A-3, the quantity of major Change Requests (CRs) from June 2010 to November 2011 is a concern. Currently, there are 725 change requests which are in the process at the engineering kickoff stage, 696 change requests at the engineering release stage, 538 change requests awaiting manufacturing bill of materials (MBOM) release, and 148 change requests available awaiting implementation. Therefore, of the 725 change requests that have been at the engineering kickoff stage, 577 are still not yet available to implement. These figures are indicative of the large volume of change traffic on this program and low design maturity.

Span Time for Processing CRs (122 CRs): As shown in Appendix Figure 4, page A-4, the median time from issue identification to implementation of change into production ranges is 18 -24 months. This means that for each change, any aircraft that is in production up to 18-24 months after the issue is found will incur a concurrency cost to correct it.

Rationale for Changes: For the 143 CRs in process (September 2011, see Appendix Figure 5, page A-5), 78 (54%) were attributable to specification compliance, including failed parts, etc.; 14 (10%) for affordability; 12 (8%) for producibility; and the remaining 28% spread relatively evenly across reliability and maintainability improvement, weight reduction, etc. These figures indicate that there is not a single common source of change traffic.

CR Cost: Since current CR incorporation timelines will be greater than the LRIP 4 production span, as shown in Appendix Figure 6, page A-6, there is an increased likelihood that a subset of current CRs that will not be available for incorporation within the current planned LRIP lot. The QLR team anticipates that many more discoveries remain due to the immaturity of developmental test. The continual discovery of new issues requiring rework and the lag time in incorporating previous CR traffic leads to a high risk that rework and retrofit costs to concurrently procured aircraft will continue to be realized across the entire LRIP production flow.

3.0 Key Technical Findings

Based on the list of topics reviewed, found in Appendix Table 1, page A-6, the team identified technical issues that indicate a lack of adequate stability in the basic design which reduces confidence in additional concurrent F-35 procurement. The technical team separated these issues into four categories:

I. Areas where a fundamental design risk has been identified with realized consequences sufficient to preclude further production

II. Areas where major consequence issues have been identified, but root cause, corrective action or fix effectivity are still in development.

III. Areas where potentially major consequence is likely pending outcomes of further test discovery.

IV. Areas where consequence or cost is moderate, but the number of moderate issues poses a cumulative concurrency risk.

3.1 Findings Summary:

The following highlights the key findings:

I. The team identified no fundamental design risks sufficient to preclude further production.

II. There are 5 areas where major consequence issues have been identified, but root cause, corrective action or fix effectivity are still in development.

Helmet Mounted Display System: The Generation II Helmet Mounted Display System (HMDS) has deficiencies in three areas which currently detract from mission tasks and its use as a certified primary flight reference: display jitter, night vision acuity, and Electro-Optical Distributed Aperture System (EO DAS) image display latency.

Fuel Dump Subsystem: There is a potential risk of fire, particularly on the F-35B STOVL due to the wetting of external surfaces.

Integrated Power Package: The Integrated Power Package (IPP) is a key reliability and maintainability concern.

Arresting Hook System (CV variant): There are significant issues in the current F-35C design with respect to Mark-7 arrestment cable capture capability. The program is revising the hook point and hold-down damper design, however, if this change is not successful there is risk for significant airframe structures redesign and/or impacts to overall signature.

Classified Issue: See classified annex.

III. There are 3 areas where potentially major consequence is likely pending outcomes of further test discovery.

Buffet: The aircraft are experiencing higher than predicted buffet during flight test, and tests have not reached the areas of highest predicted buffet loads (above 20 degrees angle of attack). High buffet loads can produce higher-than expected airframe loads, particularly on the vertical tail surfaces, as well as poor ride quality and associated workload distractions. It can also interfere with use of the helmet mounted display system (HMDS).

Fatigue Life: Fatigue testing is less than 20% complete on CTOL and STOVL. CV fatigue test is not scheduled to start until March 2012. Therefore, based on historical precedence, there is a high likelihood of future failures that are not yet identified. Life-limited parts have already been discovered that are included in the LRIP 1-4 aircraft configurations.

Test Execution: The F-35 program is early in flight test execution with limited envelope explored, limited mission systems testing, limited angle of attack, and no weapons release completed.

IV. There are 5 areas where consequence or cost is moderate, but the number of moderate issues poses a cumulative concurrency risk

Software: Concurrent development and production drives the need for multiple software releases in test and in the field which increases time and resources required to develop, correct, and manage software.

Weight Management: Weight margins are extremely tight and even small weight growth will negatively affect ability to meet KPPs for CTOL & STOVL Combat Radius and STOVL Vertical Lift Bring-Back. Weight margins must be managed carefully through the remainder of aircraft life (post IOC).

Thermal Concerns: Fixes applied for previous thermal discovery have not been fully tested. Full extent of discovery will not be known until climatic tests are completed in FY14.

Autonomic Logistics Information System (ALIS): The immaturity of ALIS development and the data integrity of aircraft configuration information are program-level sustainment risks which affect ALIS usability in test and operations. Concurrent development and production drives the need for multiple ALIS software releases in test and in the field which increases time and resources required to develop, correct, and manage software.

Lightning Protection: The F-35 employs an active lightning protection system, which presents challenges to certification compared to a more conventional passive system. A 25 nm lightning restriction and dive rate limitations are in place for all aircraft until partial certification is completed at the end of 2012, with full certification expected in the 2014-2016 timeframe.

3.2 Key Technical Findings Details

This section describes the details of the identified technical issues that indicate a lack of adequate stability in the basic design, which indicates the need for reconsideration of procurement and production planning.

Appendix Figure 7, page A-8, is a compilation of upcoming knowledge points expected to aid in mitigation of risk associated with these issues.

I. The team identified no fundamental design risks sufficient to preclude further production.

II. Areas where major consequence issues have been identified, but root cause, corrective action or fix effectivity are still in development

Helmet Mounted Display System: The Generation II (Gen-II) Helmet Mounted Display System (HMDS) has deficiencies in three areas which currently detract from mission tasks and the HMDS use as a certified primary flight reference: display jitter, night vision acuity, and Electro-Optical Distributed Aperture System (EO DAS) image display latency. The Gen-II HMDS is currently rated as a program-level high development risks.

Aircraft buffet induces HMD display jitter, making symbology unreadable under those conditions. This is tactically significant, especially for visual-range air-to-air weapons employment (gun tracking, high off-boresight [HOBS] missile cueing) and surface-to-air / air-to-air threat reactions. Turbulence may induce significant effects even during low-g, administrative phases of flight. A Micro Inertial Measurement Unit is being considered in an attempt to cancel out jitter effects, but this remains to be tested.

The current JSF system provides poor night vision acuity with the existing Gen-II night vision camera. Acuity of the current night vision camera (approximately 20/70 under best-case full moon conditions) is not as capable as the currently fielded military night vision goggles (NVG) (approximately 20/25). Also, camera acuity drops off more rapidly than NVG acuity as illumination levels decrease. A proposed improvement to the night vision camera is currently planned. However, it is not expected to achieve legacy acuity, and it is not yet available for integrated testing.

HMDS latency is excessive and detracts from mission capability. Currently, DAS video imagery latency is approximately 130 msec and basic symbology latency is approximately 50 msec, while the specifications are less than 40 msec and less than 30 msec respectively. A full-motion simulator study will be conducted in the spring of 2012 to characterize effects of different time latencies. The results of this study will help to inform a technical solution. It should also be noted that the simulator is very limited in its ability to duplicate the effects on the HMDS due to buffet environment, g-loading, or vestibular phenomena, so the effects of latency may not be fully understood until the chosen corrective action is flight tested.

To reduce technical risk, the JPO instituted an alternate helmet path where night acuity is achieved with currently fielded military Night Vision Goggles (NVG) rather than a camera. An additional subcontract was awarded in September 2011 for the alternate HMD development. This helmet faces issues of buffet and latency for basic symbology, with no DAS video capability (and thus not ORD-compliant). PDR is currently scheduled for early 2012.

An ORD-compliant Gen-II helmet remains high technical risk. It will require changes to the overall system architecture, including new integrated processor, DAS sensor modifications, and helmet modifications.

Conclusion: Major Concurrency Risk – The HMD system is integral to pilot safety, situational awareness, and tactical effectiveness and faces hardware / architecture changes to meet full requirements

Fuel Dump Subsystem: The current fuel dump design has shown to be ineffective in dumping fuel clear of the aircraft surfaces, resulting in pooling and wetting aircraft surfaces with the potential risk of fire due to ingestion into the Integrated Power Package (IPP) exhaust. Fuel dump test results on CF-1 and BF-4 were non-compliant with airworthiness certification criteria and JCS requirements due to the aircraft landing with wet surfaces and fuel spillage on deck from fuel accumulation in the flaperon. This situation poses a fire risk, more critical to STOVL given the larger number of hot surfaces and exhaust flow, as fuel on deck could be ignited during aircraft taxi after landing. This also presents a maintenance burden for inspections, panel removal, and LO restoration following a dump event.

Due to these issues, the Air Force and Navy consider the present fuel dumping capability unacceptable. Two STOVL fuel dump design modifications were attempted unsuccessfully, resulting in an aircraft operating limitation (AOL) preventing fuel dumping except in an emergency situation or in pursuit of specific flight test points. Operationally, this could lead to the need for stores jettison as an alternative to adjust landing weight. The Air Force has prohibited fuel dump on CTOL.

Further development of a long-term solution is required; however, the path forward is unknown at this time. Repositioning of the fuel dump valve would present a significant concurrency issue. Any additional structure, such as a dump mast, would potentially impact LO properties for all variants.

Conclusion: Major Concurrency Risk – This is a significant current safety hazard and requires an aircraft hardware change.

Integrated Power Package: The Integrated Power Package (IPP) is a reliability and maintainability concern. The design is novel, incorporating the engine starter, power generator and environmental control system into a single unit. Loss of the IPP results in the loss of primary avionics capability, loss of backup electrical generator power, and loss of primary oxygen supply and cabin pressurization. Designed as a high-reliability, 2,200-flight-hour subsystem, there have been 11 removal and replacement instances at Air Force Flight Test Center, Edwards AFB, one at Fort Worth, and four at NAWC-AD, Patuxent River to date. Of these removals, 8 occurred in a 12-week period, which lowered aircraft electric power system reliability to less than 13 Mean Flight Hours Between Maintenance Events (as of July 2011).

A recent catastrophic failure was due to a valve-control pin failure, during which liberated parts were not contained and punctured an adjacent fuel tank. This resulted in the grounding of all aircraft for two weeks until a change to valve control was implemented. The approach to resolving the issue of uncontained parts is yet to be determined.

The IPP is also a test execution pacing risk because the IPP remove-and-replace effort (requiring approximately two days with 24-hour coverage) has been characterized by testers as more complex and manpower-intensive than that for engine removal. The low demonstrated reliability coupled with high maintenance times were key factors in the Operational Assessment finding of high risk to meeting suitability requirements. Other than long term software changes planned in the future, there is no defined way ahead and thus the IPP remains a major concurrency risk.

Conclusion: IPP is a Major Concurrency Risk – IPP reliability and maintainability requires significant maturing

Arresting Hook System (CV variant): There are significant issues with respect to how the CV variant's AHS interoperates with aircraft carrier based MK-7 arresting gear. Roll-in arrestment testing at NAWC-AD, Lakehurst, resulted in no successful MK-7 engagements (0 successes in 8 attempts). Root cause analysis identified three key AHS design issues: (1) the aircraft geometry has a relatively short distance between the aircraft's main landing gear tires and tailhook point (when lowered), (2) tailhook point design was overemphasized for cable shredding features versus ability to scoop low positioned cables, and (3) tailhook hold-down damper performance is ineffective to support damping of small bounces relative to runway / deck surface profiles.

As shown in Appendix Figure 8, page A-9, the F-35C's main landing gear to tailhook point distance is 7.1 feet. Accordingly, when the aircraft's main landing gear rolls over the arresting cable, the responsive dynamics are such that the cable lies nearly flat on the deck. Comparing similar geometries with other, currently operating carrier based aircraft which range from 30.2 feet (C-2) to 14.6 feet (T-45), the F-35C is an outlier. The current F-35C tailhook point design (Appendix Figure 9, page A-10) was based on the F/A-18E/F design which has a blunt face to better provide cable shredding protection versus scooping. However, the F/A-18E/F's geometry places the distance of its main landing gear to tailhook point at 18.2 feet; a much longer distance than the F-35C. Since there is more distance in the geometry, the trampled cable has enough time to respond and flex back toward its original setting position by the time the tailhook point intercepts for arrestment. The hold-down damper contributes to overall aircraft arresting gear poor performance by allowing the tailhook to bounce excessively.

To address these issues, the program is designing modifications to the tailhook point and hold down damper components. The proposed hook point redesign in Appendix Figure 10, page A-11, both reduces the blunt face geometry with a more pointed front end and lowers its apex point by 0.5 inches (68%) such that it is now below the arresting gear cable centerline to better enable scooping performance. The proposed hold down damper redesign will consist of modifications to the AHS actuator damper such that a lesser number of orifices will temper tailhook bounce dynamics (Appendix Figure 11, page A-12). The AHS redesigned components will undergo Monte Carlo probability of engagement analysis as a lead-in effort for design review which is scheduled in December 2011. Following successful design review, the plan is to manufacture the redesigned components and then conduct rolling engagements at NAWC-AD, Lakehurst in April 2012.

With corrective action still in development, the AHS is considered an area of major consequence. If the proposed redesigned components do not prove to be compatible with MK-7 arresting gear, then significant redesign impacts will ensue. Accordingly, the program is conducting a formal trade study to assess options beyond AHS redesign. One option includes adjustments of AHS airframe location. However, since arrestment loads are significant and the aircraft has certain constraints with respect to engine location and survivability considerations, any readjustment of AHS location will have major, direct primary and secondary structure impacts.

Since rolling engagements in April 2012 represents only the initial stages leading into full carrier suitability demonstrations of the F-35C, complete knowledge of how truly compatible AHS redesigned components perform under nominal and off-nominal approach to engagement conditions will not be realized until well into the program's developmental test timeline. This issue represents a major concurrency risk which would have a significant retrofit impact to LRIP aircraft already delivered a large re-adjustment to the current F-35C production process build-up flow and, in many aspects, invalidate previously obtained developmental test and evaluation data.

Conclusion: Major Concurrency Risk – Significant redesign risk and options are unknown at this time.

Classified Issue: See classified annex.

Conclusion: See classified annex.

III. Areas where potentially major consequence is likely pending outcomes of further test discovery

Buffet: F-35 flight test aircraft are seeing higher than predicted buffet loads during flight test, and flight test has not yet been conducted in the regimes where the highest buffet loads are predicted (above 20 degrees angle of attack). One effect of buffet can be high airframe loads, particularly on vertical tail surfaces. Buffet loads on vertical tails have appeared on all twin-tailed tactical aircraft, and have often been larger than predicted, particularly for the F/A-18A/B and the F-22 programs. The consequences of these high loads can include structural retrofits and increased inspections of in-service aircraft. This risk will not be retired until high angle of attack loads flights are completed and their results are fed into airframe structural analyses. These flights cannot be performed until aircraft have been certified as stable for these flight regimes, so the full extent of buffet issues may not be apparent until CY2014.

Buffet also affects the ride quality of the aircraft, and the ability of the pilot to manage workload, perform fine tracking operations, such as required for HOBS missile targeting and gun-tracking tasks, and manipulate controls that require fine motor skills. Although the buffet severity experienced so far has been described as similar to that seen in previous tactical aircraft, the buffet does occur in an important and large part of the flight envelope. Appendix Figure 12, page A-13, shows an example of buffet flight test data at 10000 ft MSL.

Completion of flight test is critical to determining the full extent of this issue. Currently this testing is scheduled to begin fall of 2012. There is significant risk that buffet spectrum will not match inputs for durability testing, affecting confidence in results. In addition, as described previously in this report, buffet detracts from HMDS utility.

Conclusion: Major Concurrency Risk – Potential structural impacts and retrofit costs as flight test explores areas of greatest predicted loads - Impacts tactical employment due to effect on cockpit environment and utility of helmet mounted display system.

Fatigue Life: Fatigue tests are a primary element used to certify airframe structures for their required service life, and in the process of doing so, experience test failures that identify individual airframe components that fall short of this requirement. The consequence is that aircraft that have been delivered, or will be delivered before changes can be incorporated in production, will not meet requirements for airframe life. The options may include accepting the shorter lives of affected aircraft, inspecting aircraft more often, or retrofitting the aircraft with structural modifications. Modifications can be expensive for individual aircraft, and obviously become cumulatively more expensive as the number of affected aircraft increases. Appendix Figure 13, page A-14, shows examples of life limited structural parts and their relative difficulty to access and modify.

The F-35 is early in its fatigue test program. The F-35 airframe is required to reach a service life of 8,000 flight hours. Full demonstration of this life requires 16,000 equivalent flight hours (EFH) of fatigue testing. To date, the F-35A variant has been tested to 3,000 EFH, the F-35B has been tested to 1500 EFH, and F-35C testing has not yet began.

The F-35 test program has experienced two major fatigue test failures. The F-35B test experienced a major failure of the FS496 bulkhead at 1,500 hours, is being modified with a retrofit design and is scheduled to re-start testing in first quarter CY2012. Analysis identified an area on the F-35A Wing Forward Root Rib that had an insufficient fatigue life, and subsequent inspection of the test article identified a crack at the predicted location. In addition, analysis has identified components with less than required life, although failures at these locations have not yet been experienced in fatigue testing: 24 parts on the F-35A, 19 parts on the F-35B and 15 parts on the F-35C.

Although major failures have occurred early in fatigue testing, they are not remarkable when viewed against the background of other tactical aircraft programs. They appear to be individual engineering failures of the kind routinely discovered in fatigue testing. The bulkhead failure did reflect inadequate analysis on an important airframe detail, but significant re-analysis of similar details has been performed to remedy this shortcoming.

The major risk in the area of fatigue life comes not from the from the results seen in the limited testing to date, but from failures that will occur during the great majority of fatigue testing that remains to be performed. The program's parametric analysis based on historical data indicates a total expected value of 22 major and 43 moderate failures to be found before completion of fatigue testing. Appendix Figure 14, page A-15, shows the schedule for durability, aka fatigue, testing.

By the time of scheduled completion of fatigue testing, the current F-35 program plan (PB12) will have produced over 300 aircraft. These aircraft will incur retrofit costs to correct any anomalies, operational restrictions, reduced service life and/or increased inspection burden.

Conclusion: Major Concurrency Risk – future fatigue test failures will incur retrofit costs to correct any anomalies, operational restrictions, reduced service life and/or increased inspection burden.

Test Execution: The program is early in test execution with roughly 19% of the nearly 60,000 planned flight test points flown mainly in the conservative regions of the test space (Appendix Figure 15, page A-16). Full government approval of test point closure is a significantly lesser percentage. Less than 5% of the total 10,260 mission systems test points planned have been flown. There is significant opportunity for discovery. Of particular interest, there has been very limited testing on the CV variant to date (2,000 out of 14,300 test points), and none of the variants have done any significant high angle of attack testing or weapons clearance work. Loads, flutter, and buffet testing to 80% allowable design loads continues through the 2014 timeframe, with 100% loads testing not complete until the 2015-2016 timeframe. Testing above 40,000 feet is not scheduled until the 2015-2016 timeframe. As previously discussed, full-scale ground durability testing is also in the very early stages with CTOL furthest ahead, having completed 3,000 of 16,000 test hours, while CV tests will not begin until early 2012.

While test execution at the two primary test sites is meeting planned fly rates, test progress is approximately 8% behind that expected to date for the SDD program as of October 31, 2011. This is mainly due to discovery and needed design changes as well as aircraft availability due to shortfalls in reliability and spare parts. For example, CTOL maturity flight tests and other activities to resolve issues have delayed mission systems tests. STOVL lift fan door actuator failures delayed vertical landing envelope expansion and initial sea trials. As mentioned elsewhere in this report, current fuel dump restrictions are an issue and could impact future sea trials.

Other delays in the program can be attributed to software updates. Additional mission systems capability is being added in each software block. The program has already encountered six weeks of down time on AF-6 for software Block 1B, and Blocks 2A and 2B, which add weapons and more sensor fusion, remain to be tested. Test data access issues exist between the two test sites affecting classified data sharing and analysis, which must be corrected before complex mission systems testing.

Of note, following a schedule risk assessment, differences remain between the flight test schedule and the Integrated Master Schedule for major DT&E completion dates (e.g., 160-day difference for Block 3F completion). These must be reconciled in order to properly align test execution events.

Conclusion: Major Concurrency Risk – Since the program is early in flight test execution, with limited envelope explored, limited mission systems testing, limited angle of attack, and no weapons release completed, the majority of discovery remains.

IV. Areas where consequence or cost is moderate, but the number of moderate issues poses a cumulative concurrency risk.

Software: In order to meet aircraft production schedules, software functionality for portions of each software build are being deferred which creates significant challenges in developing, integrating and supporting multiple configurations released at various levels of maturity as shown in Appendix Figure 16, page A-17. There are three software baselines supporting LRIPs 1-4, all of which have both on-board and off-board aspects at varying levels of maturity. Additionally, simultaneous to development of multiple individual major software baselines, software interfaces are augmented for developing hardware which support aircraft test and evaluation and training which results in increased risk to both cost and schedule. Appendix Figure 17, page A-18, highlights a few examples of such a challenge by showing flight test on Full Block 1 Avionics software for LRIP 3 to be 25% complete compared to the planned 100% complete in addition to the Mission Systems Integration at having a 2.5 month slip to plan. At the same time the Mission Systems Integration for the System Integration and Test/Rework for the LRIP 4/5 Initial (Block 2A) is only 35% complete for the 67% planned.

Appendix Figures 18-23, pages A-19 through A-24, illustrate each block software schedule and percent complete. This offers another perspective of the complexity of orchestrating multiple software integration efforts with each software build at a different stage of maturity, since each software build and each block upgrade requires the same scrutiny and resources for successful systems integration.

Though the program does have software management infrastructure in place, managing resolution of software problem reports (SPARs) for Block 2A are currently behind schedule as a result of reallocation of resources as shown in Appendix Figure 24, page A-25. The SPARs for each software load are expected to have the normal growth with developmental test discovery, but with a growing number of configurations and the concurrency of both hardware and software development, resources will be consumed at a greater rate

Currently, there are eight (8) flight release versions to manage in SDD (4 for Mission systems and 4 for Flight Sciences), resulting in significant balancing effort to meet SDD and LRIP aircraft demands. Increasing software demands on hardware have consumed margins. As additional hardware configurations affect software functionality within the software builds additional risk will burden the program. Beyond the challenges associated with development, integration, and support of multiple software configurations, there are concerns that finite capacity in software integration labs will not be sufficient to address development, release and correction of concurrent multiple software blocks.

Conclusion: Moderate Concurrency Risk – Concurrent development and production drives the need for multiple software releases in test and in the field which increases time and resources required to develop, integrate, and manage software.

Weight Management: Weight Management is a formidable challenge for the F-35. Following the weight reduction effort in 2004, the program implemented a rigorous EMD weight management plan restricting STOVL weight growth from CDR to IOC to ~ 3.0%, and both CTOL and CV to ~2.5%. That equated to an allowance of ~0.33% growth per year for STOVL and ~0.28% growth per year for CTOL and CV. The 2010 re-plan, resulting from the Nunn-McCurdy breach and subsequent Technical Baseline Review further stressed the weight management plan by extending EMD and therefore potential for weight growth well beyond the original plan. The current metric is based on reaching the end of weight growth in 2015, which is well before IOC. This further amplifies the challenge as the need for weight management will continue well beyond the weight Technical Performance Measure (TPM) timeframe. In fact, a rigorous weight management program will be required throughout the life of the program.

Though weight management is not a new issue for aircraft programs, the F-35 challenge is significant. Fighter aircraft typically grow at a higher rate, with an average weight growth from first flight (FF) to IOC of ~ 3.5%. Comparatively, the F/A-18 E/F grew ~2.5% from FF to IOC and the F-22 grew about 5% from FF to IOC. This equates to growth rate of about 0.45% and 0.6% per year respectively. By comparison, the F-35 planning factor is about half that of recent legacy fighter programs. To highlight the challenge - historically legacy fighter aircraft experienced higher growth rates in about half the time.

STOVL weight growth is limited by the Vertical Landing Bring Back (VLBB) KPP. This is essentially driven by the weight of the aircraft and installed performance of the engine in the STOVL mode. The weight growth has been extrapolated to planned NTE limit (Appendix Figure 25, page A-26). The program shows a 53 lb margin to the revised planned weight growth curve. There are thirteen (13) weight threats to STOVL (totaling ~140 lb increase) along with 37 opportunities (totaling ~ 250 lbs), of which not all will be realized. The current VLBB NTE of 32,719 lb includes an anticipated 100 lb increase in thrust and yields a 142 lb margin over the planned NTE of 32,577 lbs.

The STOVL weight challenge is further complicated by the need to maintain a center of gravity (C.G.) aft of Flight Station (SF) 440, which is required to meet specification required thrust (Appendix Figure 26, page A-27). The impact of the current C.G. further limits weight reductions aft of FS 440 without compensatory changes to move the C.G. aft. The EOTS addition has been included in the projections, which accounts for the spikes in early 2011.

CTOL maximum weight growth is currently limiting the aircraft maximum maneuvering loads and is a contributing factor to the risk of not meeting the CTOL combat radius KPP. The weight growth was extrapolated to a planned NTE limit of 29,371 lbs. Currently, the program shows a 69 lb margin to the planned weight growth curve and the current planned NTE weight. The current weight limits the maximum maneuvering capability to lower than the specification (Appendix Figure 27, page A-28).

CV weight growth is ultimately limited by the carrier landing weight under specified conditions; primarily bring back capability, reserve fuel requirements and approach speed. The weight growth has been extrapolated to planned NTE limit of 34,868 lbs. The program shows a 26 lb margin to the revised planned weight growth curve and an additional 442 lb margin to the Carrier Landing Design Gross Weight (CLDGW). While the CV is the least mature of three variants, the program has similarly identified weight threats (65 lbs) and opportunities (32 lbs). (Appendix Figure 28, page A-29).

While the program has effectively executed the weight management program to date, the culmination of outstanding risks and concurrency present increased risk to the program. Especially significant is the potential for unknown changes to physical structure. Weight growth is predicted to continue beyond the reporting period with additional deficiency discovery / design changes and will likely negatively affect meeting Combat Radius and VLBB KPPs.

Conclusion: Moderate Concurrency Risk – Weight margins are extremely tight and even small weight growth will negatively affect ability to meet KPPs for CTOL and STOVL Combat Radius and STOVL Vertical Lift Bring-Back. Weight margins must be managed carefully through the remainder of aircraft life.

<u>Thermal Concerns</u>: Currently, the effects of all temperature conditions are not well known and the majority of data is from pilot and maintenance crew feedback. The thermal concerns generally result from a lack of cooling air flow and heat buildup impacting pilot controls and displays, and aircraft startup and sortie turn times. In addition, a number of specific component-related thermal issues have been identified for which fixes are in various stages of development and verification. Fixes applied for previous thermal discovery have not been fully tested. Cooling airflow to the pilot in the cockpit is insufficient in some operating environments, particularly in STOVL operations and with pilot equipment needed for flights over cold water. Workarounds with increased throttle during ground operations impact safety and increase wear on the brakes. Formal climatic lab testing (of STOVL only) is not scheduled until 2014. Several open thermal-related deficiency reports (DRs) from the DR database are on record.

The aircraft uses fuel as the primary heat sink with a fuel-air heat exchanger to provide cooling air to the cockpit and some avionics. Inability to maintain the fuel within temperature limits could lead to an over temperature condition in the full authority digital engine controls (FADECs); loss of both FADECs would result in engine failure. A solution using a dual-vane pump and enlarged fuel-air heat exchanger was installed in BF-5, in addition to concept-of-operations changes and sub-system software-logic improvements, but the solutions have yet to be fully tested in stressing environments.

The thermal environment (cooling air and ambient temp) provided to the panoramic cockpit display (PCD) does not meet specifications and is more severe than designed / expected, causing the PCD electronics unit (EU) to overheat (Appendix Figure 29, page A-30). While previous changes have resulted in some improvement, the issues have not been resolved. Also, aircraft supply / exhaust plenums are leaking on some aircraft leading to improper cooling flow at altitude.

Overheating of the Electro-hydrostatic Actuation System (EHAS) is also a watch item. Although a fix for the EHAS components has been installed on an F-35C developmental test aircraft, the system remains a thermal watch item pending qualification of this component. CV thermal trade studies, pilot duty cycles and electronics unit technologies are in progress.

Several issues require operational adjustments and limitations. For example, STOVL aircraft have experienced high brake temperatures impacting sortie turn times and sortie generation rates. Retrofitting the CTOL brakes onto STOVL would carry a considerable weight penalty (~90 lbs). The STOVL clutch drag heating is a concern and cooling ducts and a PCD temperature indicator are fixes under consideration. STOVL roll-post actuator overheating from bleed air leaks limits slow speed / Mode-4 operations. An insulation blanket is a potential fix, but carries a 2.5 lb weight penalty. Although areas of concern for shipboard integration have been identified and incorporated into test plans over the last year, shipboard operations remains a watch item for effective system fielding.

Finally, recent testing at Air Force Flight Test Center, Edwards AFB, revealed excessive structural heating with the afterburner on for extended periods. Flight tests to speeds up to 1.6 Mach with the afterburner engaged for several minutes, generated enough heat to damage the horizontal tail (peeling and bubbling of coating about the size of a fist). There was also some degradation of the thermal panels in the engine. While solutions are being evaluated, the program office has established aircraft operations limits, reducing the top speed to 1.0 Mach with afterburner operations limited to 1-2 minutes. In order to get full afterburner performance back in the aircraft, it may be necessary to change the material and or add structure to the tail.

Conclusion: Moderate Concurrency Risk – thermal management system may be insufficient for some conditions and mission profiles, climatic lab testing is scheduled for 2014

Autonomic Logistics Information System (ALIS): ALIS and the aircraft are tightly coupled. Therefore, the immaturity of ALIS development and data integrity of aircraft configuration information are program-level high sustainment risks which affect ALIS usability in test, training and operations.

The currently used system, the Computerized Maintenance Management System-1 (CMMS), was determined in 2007 to not be suitable to support the F-35. This system will be used until ALIS 1.0.3 is released, planned for December 2011. Transition is first scheduled for LRIP 1 aircraft: AF-6 in December 2011 and AF-7 in February 2012. The transition of all 15 SDD aircraft is not expected to be complete until December 2012, as seen in Appendix Figure 30, page A-31. Additionally, the Prognostic Health Management (PHM) System has multiple workarounds due to system immaturity. These workarounds are labor intensive and currently take approximately 2 hours to process after each flight. Complete integration of PHM data to ALIS will not be possible until ALIS 1.0.3.

ALIS is currently not capable of complete Configuration Management (CM) for the "As Maintained" data. LM staff must complete a workaround procedure (Release Authorization Notice) for every flight to ensure an audit trail for the components installed on the aircraft. As numbers of aircraft increase at various locations, the inability of ALIS to enable release following maintenance will adversely affect Sortie Generation Rate (SGR). Appendix Figure 31, page A-32 further describes these issues.

The Training Management System (TMS) is intended to be used for tracking personnel training, but it is currently not set-up to track training for multiple maintenance personnel skill levels. All F-35 training classes and general tasks are loaded against everyone assigned to a particular base, section, or aircraft. TMS does not have the capability to identify different specialties or skill levels and is unable to separate training requirements by specialty or skill level. TMS is unable to query by course or task, thereby not allowing a user to see who is qualified on a particular task. Also, the scheduling function in TMS will not be utilized while scheduling flight test sorties.

Concurrency in development and production of aircraft amplifies the issues associated with supporting concurrent development, test, training and operations of multiple ALIS configurations in multiple locations, requiring more personnel and resources in the short term to accomplish these tasks. Appendix Figure 32, page A-33 depicts this graphically showing activity in up to 4 different ALIS releases in 2012. Note that this does not include activity to retrofit SDD aircraft and acquire data from developmental activities.

Conclusion: Moderate Concurrency Risk – immaturity of ALIS development and data integrity of aircraft configuration information are program-level high sustainment risks which affect ALIS usability in test, training and operations.

Lightning Protection: The F-35 employs an active lightning protection system, which presents challenges to certification compared to a more conventional passive system. The F-35 outer surfaces are safety compliant, but there are seven subsystems not yet meeting safety qualification standards. In addition, the On-Board Inert Gas Generating System (OBIGGS) does not provide sufficient nitrogen to inert the fuel tanks under all conditions, which presents a potential ignition risk. Specifically, rapid altitude changes in steep dives allow additional ambient air (and thus oxygen) into the fuel tanks, beyond the capability of OBIGGS to support with nitrogen supply. In addition, there is no fuel tank inerting (and therefore no lightning protection) when aircraft are parked. Improved inerting is being addressed via a two-phase design effort. The first phase has completed a Preliminary Design Review and will focus on OBIGGS changes. The second phase will emphasize fuel vent valve redesign in order to allow full dive rate capability (however, this is not currently scheduled before 2014). The contractor is also investigating design options for lightning protection while aircraft are parked, such as pre-charging fuel tanks with nitrogen using an auxiliary cart and adding a dedicated service port to the aircraft.

In the interim, a 25 nm lightning restriction and dive rate limitations are in place for all aircraft until partial certification is completed at the end of 2012, with full certification expected in the 2014-2016 timeframe. As Eglin AFB is located in a significant lightning environment, the current 25 nm restriction could lead to cancelling an estimated 25-50 percent of planned training events due to typical proximity and frequency of thunderstorm activity.

Conclusion: Moderate Concurrency Risk – full certification is not expected until 2014-2016

4.0 Conclusions

In the team's review of F-35 data and analyses, no fundamental design risks sufficient to preclude further production were identified.

Five issues were found where major consequence issues have been identified, but root cause, corrective action or fix effectivity are still in development: Helmet Mounted Display System, Fuel Dump Subsystem, Integrated Power Package, Arresting Gear System (CV variant) and a classified issue.

Three issues were found where potentially major consequence discovery is likely pending outcomes of further test discovery: Buffet, Fatigue Life, and Test Execution.

Five issues were found where consequence or cost is moderate, but the number of moderate issues poses a cumulative concurrency risk: Software, Weight Management, Thermal Concerns, ALIS and Lightning Protection.

The combined impact of these issues results in a lack of confidence in the design stability. The QLR team concludes that this lack of confidence, in conjunction with the concurrency driven consequences of the required fixes, supports serious reconsideration of procurement and production planning.

5.0 Recommendations

The QLR team recommends that further decisions about F-35 concurrent production be event driven, based on the achievement of sufficient test data to support increased confidence in design maturity and of a well-controlled process for executing and minimizing design changes across concurrent production. The team has identified key knowledge points in Appendix Figure 7, page A-8, for each variant relative to design and test maturity which should be considered as a factor in reconsideration of production plans.

The JSF is a single acquisition program with F-35A CTOL, F-35B STOVL, and F-35C CV variants. Due to the significant differences in design as well as the differing timelines of development, testing and production, the QLR team recommends each variant should be considered independently with respect to concurrency.

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Attachment
Appendix: Supporting Documentation