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F-35 Weapons Integration Analysis and Improvement

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Abstract

To expedite F-35 weapons integration, a holistic program change in philosophy and business practices regarding software development, contracting, testing, and certification is required. The current estimated timeline for a weapon from requirement submission to fleet release is seven years. This timeline does not serve the F-35 customer, the warfighter, because it delivers a solution to an emerging threat late to need. Additionally, longer schedules drive costs and impact weapons capabilities and other critical systems on the aircraft. F-35 Leadership acknowledges this problem and continuously requests solutions. The Weapons Program Office responded with solutions to shorten the weapon delivery timelines. Solutions such as incremental capability certification and utilizing computer modeling to minimize the need for aircraft testing are a good start. However, no single solution will fix all weapons integration delays. Significant time savings can be achieved through a paradigm shift by the Government and the lead contractor.

Executive Summary

A change in philosophy and business practices regarding software development, contracting, testing, and certification is required to expedite F-35 weapons integration. The current estimated timeline for weapon development is seven years. This timeline does not serve the warfighter because it delivers a solution late to need.

Solutions such as incremental capability certification and utilizing computer modeling to minimize the need for aircraft testing are a good start. However, no single solution will fix all weapons integration delays.

Significant time savings can be achieved through a paradigm shift by the Government and the lead contractor. The solutions include:

- Delivering incremental functionality
- Changing aircraft software development
- Reassessing schedules by assessing the overall impact to the F-35
- Providing better support for developmental testing
- Changing the mindset of management to understand the ripple effects of adding new capabilities

The Weapons Program can reduce the timeline to deliver capability to the F-35 by implementing holistic changes concurrently with current improvement efforts. This strategy involving a change in philosophy, cutting edge technology, and process improvement will require significant effort, but will result in savings that will benefit the entire F-35 community especially in the areas of schedule, cost, and morale.

Introduction

The most advanced fighter plane in the world becomes a reconnaissance plane without the ability to deliver weapons on target. This would lead one to believe that weapons integration on the F-35 is a top priority and expedited to support the warfighter. Currently, the F-35 enterprise is averaging more than 90 months to integrate weapon capability on the aircraft from the date of a formal requirement being submitted. Leadership has stated that this timeline is unacceptable and needs to be expedited. With new, more advanced threats emerging from adversaries regularly, it is understandable that there is need to accelerate capabilities to counter these threats. However, there is no panacea for expediting these efforts, but an overall change of approach could yield a more expedited timeline and possible cost savings.

The F-35 weapons integration efforts total $300 million per year in integration costs. Overall, the weapons program is responsible for over 400 pieces of equipment per aircraft including items such as Support Equipment (SE), Alternate Mission Equipment (AME), test, and all up rounds (Bortle, 2022). The F-35 community is currently integrating 15 new weapons and managing 14 legacy weapons.

New weapons require a variety of work including air worthiness testing, systems integration efforts, mission planning development, pilot and aircrew training (Wagner, 2020). These more than 30 weapons capabilities are competing with many other F-35 capabilities for test facilities, personnel, and other resources which strain the F-35 infrastructure creating delivery delays.

The Joint Program Office (JPO) developed the Continuous Capabilities Development and Delivery (C2D2) plan with Lockheed Martin to address modernization of the aircraft of which TR-3 was a main crux. This plan moved from the traditional development to a more rapid strategy for capability delivery (Barnes, 2018). C2D2 attempts to deliver capability in increments similar to the popular Agile development strategy used by many software development companies. The basis of the plan is summarized in the motto “model-simulate-test-iterate.”

> The JPO is implementing agile and lean acquisition and sustainment approaches throughout the enterprise to meet F-35’s challenging schedules and capability goals that require operational flexibility, better and faster communication, and more frequent delivery of value (Joint Program Office [JPO], n.d.).

Current Process From Proposal Forward

Systems Engineering and Architecting

Systems design focuses on how the weapon will function on the aircraft in accordance with the listed requirements. Generally, this involves two facets: hardware integration and software integration. The hardware establishes how the aircraft will carry and employ the weapon while the software design establishes how the weapon interacts with the aircraft’s mission computers.

During C2D2, weapons integration migrated from a traditional systems engineering “V” to the initial Agile model. This approach enables the correction of anomalies found through an incremental approach to design and development. There has been limited success with this approach, which is seen by the number of weapons capabilities missing required delivery dates. The current development process is more of a hybrid between the Waterfall and Agile philosophies. The weapons program is trying to balance the regular updating of requirements (Krumenacker, 2021) and keeping Waterfall milestones to ensure that development is on track.

Traditional SETR reviews conflict with the Agile process. Agile processes replace traditional SETR reviews with incremental reviews that occur both sequentially and

incrementally. In fact, for Agile programs, major milestones are not recommended (Lapham et al., 2016).

Contracts

C2D2 was contracted to major SETR milestones contrary to Agile philosophy. Lockheed Martin determined the work required to reach each milestone in accordance with the Government's schedule (Department of State, 2023).

Lockheed Martin evaluated the CSOW and provided estimates to complete the work required. Estimates were based on technical difficulty, past performance, risk, and cost (Lapham et al., 2016). Basis of Estimates (BOE) provide data and rationale for the scope of work. Government engineers review these BOE and use their judgement to determine if they are accurate.

When contract negotiations start threatening scheduled timelines, an Undefinitized Contract Award (UCA) option is often employed. Department of Defense (DoD) policy states that UCAs are used when negotiations cannot be completed to meet the government's requirements and work needs to begin (Department of State, 2023). A UCA supplies the contractor with initial funding with a cost "Not To Exceed" limit. There are currently 15 weapons related efforts funded under UCA through DT-C milestone (Bortle, 2022). However, there is risk for the Government because the contractor could overrun their budget (Defense Acquisition University, 2021). Initial proposals are often rewritten. This adds workload to the experts who review estimates while working integration leading to delays.

The United States could not fund these capabilities to completion which drove multiple contracts. Negotiations require multiple disciplines from the enterprise who also work ongoing integration efforts (Burrill, 2023).

Table 1. Negotiation Timelines (*Upgrades to Existing Capabilities)

Weapon	RFP	Full Award	Time (Months)
DCA	7 March 2018	7 June 2019	15
AIM-9X II/II+	7 March 2018	7 June 2019	15
JSM (SFR)	7 March 2018	7 June 2019	15
JSM (DTC)	24 February 2020	30 April 2021	14
TacPen*	8 August 2019	31 December 2019	4
ASRAAM B6	8 August 2019	31 December 2019	4
Lot 5A Seeker (SFR)	8 August 2019	31 December 2019	4
SPEAR 3 (SFR)	8 August 2019	31 December 2019	4
Meteor (SFR)	8 August 2019	31 December 2019	4
Lot 5A Seeker (DTC)	24 February 2020	Feb 2026	72
SPEAR 3 (DTC)	24 February 2020	Feb 2026	72
Meteor (DTC)	24 February 2020	Feb 2026	72
AGM-88G	24 February 2020	Feb 2026	72
AGM-158	24 February 2020	Feb 2026	72
SITB	24 February 2020	Feb 2026	72

Table 1 shows the average integration timeline is more than 40 months from RFP to award. The trend shows that these timelines are increasing. UCA dates associated with them are the current planned definitization (Defense Acquisition University, 2021).

Delays with contracts are understandable given the complicated nature of work required. Requirement changes and resource availability cause contract modifications. Lockheed Martin

requires new proposals when requirements change, triggering more negotiations and resources. Additionally, subcontracted companies are concerned about providing pricing information and rationale to Lockheed Martin. To protect proprietary information, they request Defense Contract Management Agency audits requiring additional time (Burrill, 2023).

The average weapon integration results in more than 50 cost estimates (Fleming, 2020). C2D2 was not just a weapons integration effort. Other aircraft capabilities had their own BOE requiring review and negotiations. There were more than 5,318 BOE processed for C2D2 (Fleming, 2021).

Contract Data Requirements List (CDRL)

Contracts also authorize deliverables from the contractor. These include test plans, test reports, and other analyses. The contractor has a certain amount of time to deliver these items to the Government based on a milestone. The Government reviews and provides comments or approval. The contractor then has an additional 30 days to respond. These timelines appear to be arbitrary (F-35 Contracts, 2020, 2021).

Software Development

Software is the crux of the F-35. Under Agile philosophy, each weapon integration breaks down into features that the software will support. Feature development is done in two-week sprints. Each sprint is designed to complete a certain amount of work. The sprints required depend on the complexity of the feature. Sprints flow into Program Increments (PI) which are 12-week periods of development following a plan, code, test, commit, repeat rhythm (Lockheed Martin, 2021).

Testing is done in six-hour shifts. Table 2 reveals the current weapons MSIL efforts require more than 2,580 hours of testing. This does not include the time required to test in the lower labs nor the more than 90 shifts required to regression test legacy weapons.

Table 2. MSIL Test Shifts (Bode, 2023)

Weapon	MSIL Shifts
AGM-88	60
SITB	40
SPEAR 3 (UK)	104
Seeker (UK)	15
Meteor (UK/IT)	53
JSM (NO)	48
SDB2	50
JDAM	35

Software development is the heart of modern weapons integration. The F-35 program ties weapons capabilities to specific aircraft software builds regardless of the software integration required. A new aircraft software build encompasses multiple capabilities. Delays to the development of one will delay release of others. Delays in 40R01 software led to a multi-year delay that impacted all weapons (Bode, 2023).

AME

AME attaches and releases all weapons to/from the aircraft. AME is composed of launchers, pylons, and adapters. New AME is often needed for new weapons. Integration progresses with weapons development. AME proceeds through a separate systems engineering process because it is less complex than the weapon and requires minimal software interface with the aircraft (Diop, 2020). Most AME require Flight Science (FS) testing only to ensure air

worthiness (AW) as they do not communicate with the mission systems (MS) computers (Lemke & Lystrup, 2010). Newer weapons are utilizing smart launchers which interface with the aircraft at the software level requiring MS testing (Conlin, 2019; Moozhikkattu, 2020). The current development timeline for major pieces of AME is three to seven years (Bortle, 2023).

Flight Science (FS) Testing

Flight testing also takes a significant amount of time. There are two types of flight testing: FS and MS testing. FS testing ensures that weapons are safe to carry and release. In Table 3, the FS requirements for each capability are shown (Lemke & Lystrup, 2010).

FS testing is the basis for determining AW based on the MIL-STD-516. Approximately 13 of 18 AW disciplines cited are applicable to weapons integration. Ground and FS testing provide the data points and analyses required to satisfy the criteria for these disciplines. Requirements drive test points and data products (Speyer, 2022).

Wind tunnel testing is required prior to flight test. Wind tunnel testing gives confidence in the ability of the aircraft to safely carry and release the store (Lemke & Lystrup, 2010). It provides data to define critical flight test points. The wind tunnel planning, test, and analyses takes an average of 12 months (Bortle, 2022). Based on the wind tunnel analysis, the SME recommend areas of the envelope to test (Robertson et al., 2022). It can take years to reserve the wind tunnel because there is only one military wind tunnel test site (Wolf, 2023).

Table 3. Estimated FS Testing Flights (O'Melia, 2022)

Weapon	Aircraft	Test Flights	Comments
AARGM	F-35A	74	Requires mods to the test aircraft
AARGM	F-35B	61	Does not fit internal
AARGM	F-35C	108	
LRASM	F-35A	37	
LRASM	F-35B	49	
LRASM	F-35C	40	
JASSM	F-35A & C	16	8 each
JASSM	F-35B	10	
JSM	F-35A	27	Actual – Completed 2022
Meteor	F-35A	50	
Meteor	F-35B	52	
SPEAR 3	F-35B	38	26 for initial increment
SDB 2	F-35B	11	
SDB 2	F-35A & C	54	27 each
SITB	F-35A & C	30	15 each

MS Flight Test

MS testing ensures that the aircraft/weapon software interfaces function as required. The software/weapon interface is agnostic of platform. This means MS testing can be accomplished for all required variants by completing testing on one. Table 4 shows the reduced number of test flights. Additionally, MS test aircraft represent production aircraft so there are more available. Anomalies found during testing that must be fixed prior to operational release are incorporated and then retested. These anomalies can drive delays in the completion of flight test (Lockheed Martin, 2022). Table 4 shows the current MS flights estimated for each weapon.

Table 4. Estimated MS Flight Test Flights (O'Melia, 2022)

Weapon	Aircraft	Flights
AARGM	F-35A	28
JASSM/LRASM	F-35A	26
JSM	F-35A	20
Meteor	F-35B	41
SPEAR 3	F-35B	80
SDB 2	F-35A	10
SITB	F-35A	7

Weapon Demonstration Events

Weapon Demonstration Events (WDE) are part of MS flight testing. WDE test end-to-end capability for the weapon with a live fire event. This occurs at the end of the developmental test once there is confidence that the weapon will perform as expected. Each live fire event requires test range, support personnel, and support aircraft. Since testing variables are volatile, WDE are difficult to schedule and often postponed (Lemke & Lystrup, 2010).

Current Flight Test Capacity

Each test sortie takes 2–3 hours not including preflight and post flight actions. A total of 2,354 flights are projected for the flight testing listed in Tables 3 and 4, which does not include a 20% re-fly rate for missed test points, data stream failures, aircraft malfunctions, etc.

The FS aircraft are aging out of service. These aircraft fly test points in stressful parts of the envelope. Current FS aircraft will begin retiring in June 2026. Currently, these aircraft are in a modification process to extend the life of the airframe. The MS flight test aircraft are also in a predicament. The majority of the MS aircraft will migrate to a different configuration than fleet aircraft, preventing them from providing capability to the legacy fleet aircraft (Pickett & O'Melia, 2023).

Certification

The weapons certification effort begins after test reports are received. This effort ensures that weapons are safe to employ and interoperable with the software. The certification process takes on average six months. This is a lengthy review when the results of testing are known and often the target of shortening delivery timelines (Ormaza, 2026).

Analysis of the Weapons Program

The problem of long timelines delivering complicated weapons systems is not unique to the F-35. In fact, delays and disfunction over various programs in both the Government and commercial sector have been the focus of many academic studies.

One of the most basic weapons is the GBU-12. The GBU-12 is a modular air-to-ground laser guided munition developed in the 1970s. Since it does not communicate with the F-35, it is easier to integrate than other weapons. The original integration took approximately seven years after Texas Instruments was awarded the contract (Pike, 2017). This is on par with the current F-35 weapons integration of more complicated weapons (about eight years).

Among current platforms, the F-35 compares similarly with weapons integration timelines. Joint Air-to-Surface Standoff Missile (JASSM) took seven years to field on the F-16. The Advanced Anti-Radiation Guided Missile Extended Range (AARGM ER) required a similar timeline. SDB-2 was awarded Raytheon 10 years prior to the F-15 declaring it operational capable (U.S. Air Force, 2019). Weapons integration has always been a long process with growing complexity driving longer timelines.

F-35 weapons integration is not unique in long delivery schedules. Currently, the F/A-18G test personnel face similar delays and constraints and the causes are starkly similar. The F/A-18 test team faces many tasks that require flight clearances, contract efforts, and cyber security safeguards. Personnel, test aircraft, and range availability (which the F-35 also uses) are constraining their ability to produce at an acceptable pace (Dunlap, 2023).

Stating that all weapons integration efforts suffer from delays will not resolve leadership's grievances. This is a Defense procurement problem. In a more theoretical discussion, Integrated Computer Engineering (ICE), Inc. investigated more than 280 government and commercial software projects to determine failure causes (Evans et al., 2002).

ICE found seven traits that were common among the various programs that failed:

1. **There exists an overall issue with providing essential project management to the program** (Evans et al., 2002). The program's process does not lead to a satisfied user. No one in the F-35 program is satisfied with weapons delivery. The team corrects development problems and working unrealistic schedules. Plans often do not accurately account for other systems' impact to delivery. Contracting guidance is specifically for software development (Department of State, 2023). However, the F-35 tries to apply it to systems that require both hardware and software development. Poor resource planning developed 20 years ago is another issue. Lockheed Martin's control of software code development limits JPO engineers' ability to assist development (Georgi, 2023).
2. **A culture of unrealistic expectations can blind leadership to the unrealistic timelines being presented and the complexity of development** (Evans et al., 2002)**.** The roadmap plan for weapons delivery in 2019 (ASP 13) showed 13 weapons being delivered by 2025 (F-35 Weapons, 2019). The most current ASP shows the last weapon now delivering after 2032. The program has added three new weapons capabilities to the timeline (Ormaza, 2026). This reveals two issues. First, the program created an overly optimistic schedule. Second, despite delays, the program added more weapons without adding resources. These decisions appear agnostic of task magnitude. Management turnover eliminates experience which leads to a naivety that schedules can be met. ICE stated it best: "When managing or participating in a system acquisition or development project there is absolutely no rationale for optimism" (Evans et al., 2002). Recognizing the limitations allows for accurate schedules.
3. **The software processes implemented are not effective** (Evans et al., 2002). Agile is a process intended for small developers with limited resources when users have undefined constraints (Coursera Inc., 2023). This does not apply to the F-35 enterprise. There are too many groups with too many individual needs. The three U.S. services, the seven other partner nations, and nine FMS countries (and growing) all have their own requirements. Additionally, there are a slew of systems requiring integration efforts such as Air Vehicle, Radar, MS, etc. (Ormaza, 2026). This organization is huge with many teams. Weapons integration is not Agile because the requirements are well defined. "Routinely, an RFP is formulated around a known solution with a majority of the requirements already identified" (Lapham et al., 2016). For the most part weapons specific requirements do not change. In some cases, like JDAM, the capability already exists on other platforms, so performance and interfaces are known (Krumenacker, 2021). However, each weapon is unique requiring different integration efforts. This makes it difficult to impose a common process and timeline. For example, JDAM requires GPS information and crypto keying from the aircraft. The aircraft requires minimal information from the weapon and the mission planning environment (Dowden, 2020). On the opposite end, the JSM requires mission planning data, tactical networking

keys, GPS information, and aircraft data. The aircraft receives launch area and other data from the missile. Post release the weapon will be connected via data links. The same development strategies will not work for both weapons (Conlin, 2022).

4. **Success is declared too early** (Evans et al., 2002). Immature capability is often delivered to the warfighter. This leads to failure during operational test or in the field. Lockheed Martin is under pressure to deliver on time to ensure they meet contractual obligations. The JPO is under pressure to meet battlefield requirements. Thus, schedule drives delivery, leading to a product that does not satisfy the user. The weapons team is tracking more than 50 weapons anomalies (Vernava, 2023). A balance needs to be found.
5. **Program Management is not aware of the magnitude of the task** (Evans et al., 2002). Program Management is unaware of the effort required for weapons integration. The Weapons team is asked often to explain timelines (Bortle, 2022; Ormaza, 2026). This lack of understanding results in schedule decisions that may satisfy time requirements but set up the program to fail. Misplaced optimism is directly related to turnover. Leadership experienced with weapons integration is hard to find and changes often. There is also a desire to implement one correction to shorten weapons integration. This problem is too complicated for a “silver bullet” solution.
6. **Decisions are made at the wrong times** (Evans et al., 2002). This pitfall is hard to avoid. Decisions regarding the program need to be made prior to contracting work which makes it impossible to account for arising challenges. To compound the problem, the JPO did not foresee the current lack of capacity at the beginning of the program. As requirements grew, delays became inevitable and failure likely. Lockheed Martin has repeatedly informed the JPO that they are operating at capacity (Sharpe, 2023). The ITF also operates at capacity. Not addressing these issues means the program will have to accept longer weapons’ delivery timelines. “Agile utilizes ‘just in time’ planning: waiting to make decisions until ready to execute, preserves trade-space and gives agility to change” (Lapham et al., 2016).
7. **Risk management is reactive not proactive** (Evans et al., 2002). The JPO tracks risks as shown in their Risk Tracking Matrices report (F-35 Risk Management, 2023). This report reveals more than 14 high level risks to all weapons integration efforts. These 14 risks do not include risks to other programs that impact weapons. Most weapons risks relate to test asset delivery. Test assets have long lead times and tracking a risk to deliveries this late in the program is not effective. Ideally, these risks need to be identified much earlier to mitigate their effects. Failure to do so leads to reacting to unforeseen risks with little time.

The ICE (2002) paper concludes that technology is rarely the problem, and a culture of denial is:

> A major cultural barrier to accurate estimation (and scheduling) [is]. . . . If an early estimate predicts higher cost, longer schedules or lower quality . . . there is a strong tendency to challenge the validity of the estimate. . . . the PM is directed to recast the estimate so that it falls within preset and arbitrary boundary conditions. (p. 17)

This quote is magnified when success is reliant on the maturity of other programs. TR-3 development slogged through anomalies to maturity, in part, because major parts of the software development required rework. UAI Rev 5 and NEW capability each underwent significant rework. Both capabilities support current and future weapons. Other systems development caused delays. Radar upgrades were not stable, regularly crashing during tests. The Next Generation Defense Aids System was delayed due to the inability of the supplier to

acquire TR-3 hardware. Development of many systems occurs outside of Lockheed Martin's plant. This inhibits quick fixes and requires complicated logistics to continue (Georgi, Joint Program Office Cost Analyst, 2023). These issues snowball to the dependent programs and create an avalanche of delays.

Agile employs an iterative approach to increasing capability as development and test continue. Weapons were contracted in an Agile philosophy but delivered in a Big Bang (all or nothing) drop. Recently, weapons began delivering capability in incremental steps to provide some weapon capability while full capability is developed (Anton et al., 2020; Ormaza, 2026). Carnegie Melon echoed this type of approach in their review of Government acquisition Agile methods. They stated that end-to-end contracting restricted quick development and fielding of technology and suggested an incremental approach (Evans et al., 2002).

The F-35 program contracted C2D2 in an incremental approach, but the increments were tied to systems engineering milestones. The original contracts did not provide the user capability until the final milestone. Some capabilities did have multiple capability releases. This foresight helped get some capability such as embedded training to the fleet earlier (Bode, 2023). Contracting interim capabilities accelerates delivery. Agile philosophy is pervasive in JSF organization. The RAND corporation performed an analysis of Agile acquisition programs and provided advice on improving agility. They confirmed that most agility approaches are not universal. Given the differences found in weapons integration, it is difficult to find one Agile process for all weapons (Anton et al., 2020). Agile tenets mandate that responding to change is more important than following a plan (Beck et al., 2002). Currently, only one of the original 13 capabilities contracted under C2D2 met the original schedule. Since 2018, four more capabilities have been added while resources shrink.

Table 5. Current Weapons Delays (Ormaza, 2026)

Weapon	Need Date	Current Est.	Delay (months)
ASRAAM Block 6	April 2022	December 2021	- 5
AGM-88G	December 2026	February 2027	3
JSM	June 2023	August 2026	38
Six-in-the-Bay (A)	September 2025	February 2027	17
TACPEN	March 2022	December 2023 (Full)	21
AGM-158A	December 2024	February 2027	26
AGM-158B	December 2024	February 2027	26
Six-in-the-Bay (C)	September 2025	January 2028	28
PWIV Seeker	April 2022	December 2025	43
SDB-2 (Full)	April 2023	February 2026	34
GBU-38/53	October 2021	September 2024	35
SPEAR 3	December 2024	December 2031	84
Meteor (F-35A/B)	December 2024	January 2032 (est.)	85

Communication among stakeholders is essential. Delays occur due to poorly defined requirements leading to misunderstandings regarding the effort required. Lockheed Martin also has integrators who should work with their estimators for labor hours. However, the required communication among groups does not always happen. A critical example of poor communication is the JSM integration. Norway and the JPO agreed to do all FS testing with the Air Force Seek Eagle Office (AFSEO). This eliminated the necessity for Lockheed Martin to bid/contract this work. This was clearly defined in the Norway JSM Stores Integration Plan which Lockheed Martin, JPO, and AFSEO signed prior to negotiations (Yost, 2020). However, Lockheed Martin estimated and tried to contract 17 efforts totaling over 6,800 labor hours and

thousands in material cost for FS testing support (Fleming, 2021). In the end, this effort was correctly contracted but poor communication could have led to a loss of schedule and money.

The RAND Corporation highlighted the need for work force proficiency in acquisition programs. Currently, Lockheed Martin has a resource shortage in software development. Lockheed Martin maintains one lab facility and minimal coders to support the copious amounts of testing for all aircraft systems. Even with more personnel, it is doubtful that there would be an increase in testing. The ITF also has limited resources which limit the proficiency for test. Lockheed Martin's ability to meet fleet requirements depends completely on resources to support development and testing. If programs "prioritize schedule over cost [and] or technical performance," they increased risk by sacrificing development and safety checks (Anton et al., 2020). Requirements in a schedule driven program must remain flexible and define what is acceptable. Risks can be mitigated through trade-offs. Delivery of a useful product is equally important as the speed of delivery.

Solutions

The program is aware of the issues with the current development method. Perhaps the analysis above can provide insight into why. The important question is, "What can be done to improve these schedules to meet the warfighter's need?" The answer is not simple, but the F-35 Weapons Branch proposed several solutions in various discussions with leadership in the past.

Flight Test Approach Improvements

The Weapons team promoted a plan to gain efficiency in flight test by identifying similarities between the three variants, understanding and using them to reduce flight test points (Bortle, 2022; Wagner, 2020). This led to some successes. The Australia F-35A program was able to integrate the JSOW with only one separation test point based on flight testing done by the F-35C, saving months of integration effort (Wagner, 2019). Understanding the aerodynamics of the F-35 variants better will lead to this use of similarity by developing more accurate models. However, there must be high confidence in the models' outputs to ensure eliminating test points does not increase risk. This can be achieved through more analyses now to save schedule later.

Flight testing requires the procurement of test assets. Currently, it takes two or more years to acquire these assets (Bortle, 2022). This requires these assets to be identified and contracted early. If flight test assets are on hand early, the test team can take advantage as opportunity arises. The JSM program did this successfully. Norway worked with the weapons supplier to procure JSM FS test assets early. This allowed fit checks to occur on all variants of the F-35 well prior to JSM integration contracts being awarded. Norway also took advantage of flight test availability in the 2020–2021 timeframe at the ITF to perform earlier than scheduled flight testing. Test asset delivery allowed the JSM program to fill a gap in the flight test schedule (Roesok & Conlin, 2019). This resulted in completing FS testing 18 months early and deconflicted with other capabilities.

F-35 needs to increase flight test capacity. This would require an increase in both aircraft and personnel at the ITF. The Weapons team is investigating assistance from Partner and FMS aircraft. Timelines would decrease and testing availability would increase by using Partner/FMS resources. Another approach is the use of surges. Surges were used for Systems Design and Demonstration. They accomplished large amounts of weapons flight testing in a short amount of time. Weapons testing took priority over other testing (Integrated Test Force, 2016).

Dr. Oleg Yakimenko, Systems Engineering professor at the Naval Postgraduate School, echoed this sentiment in his Test and Evaluation class. He stated that delays in systems development are caused by the overall culture of acquisition programs. This culture encourages

"over optimism, unrealistic schedule estimates and emphasizes completing the test on schedule over conducting the test according to plan." Program managers develop schedules that meet priorities and do not account for historical data. This path is fostered because few people would want to fund a project that will be late. This same system does not allow objective systems development. Optimistic views convince leadership to agree to high-risk schedules. Culture fuels optimism which in turn reinforces the culture (Yakimenko, 2014).

> *With the fast pace of software development, it is imperative that a project manager be the voice of reason in regard to capabilities, schedule, and funding. The project manager must recognize when constraints of schedule, cost, and technology are too much for his/her team and tell the customer and upper management prior to beginning development.* (Conlin, 2014)

While Dr. Yakimenko's class focused on test, it applies to all parts of weapons integration. Improper funding also contributes to the lack of resource availability and optimistic scheduling. It is easy to meet current budget restraints when the program encounters perfection (Yakimenko, 2014). However, these circumstances are highly unlikely.

The F-35 should align with more specific Agile principles. For instance, Agile welcomes late changing requirements. "Agile methods have proven effective in rapidly and responsively delivering functionality in commercial environments" (Ambler, 2011). The current contracting relationship and development process does not. For example, contracting clashed with the emergence of Italian Meteor CFD. Also, the JSM program's request to accelerate FS testing was met with resistance because of contracting. This forced JPO to pivot to AFSEO to lead testing (Roesok & Conlin, 2019). It worked out in the end but resistance to change was evident. The use of flexible contracts would help programs pivot quickly.

Incentivizing Lockheed Martin to accelerate development is a useful tool to be deployed but it is not a universal solution. Incentivizing everything makes no program a priority. Government guidance encourages performance-based contracting (Department of State, 2023). The Data Analysis Center for Software (DACS) developed a gold process for acquisition. This process states that using incentive fees aggressively is a "must" for meeting schedule (DACS, 2005). UK's ASRAAM Block 6 program used incentives to deliver capability to their fleet five months earlier than scheduled (Percy, 2020). However, incentive fees do not ensure success. The JSM program also has incentive awards but will deliver late to need. Even monetary incentives will not overcome deficiencies in technological development (Lockheed Martin, 2021).

When contracting methods do not meet operational requirements, the TechFar suggests the use of other contracting vehicles to meet the plan (Department of State, 2023). The JSM program had success using AFSEO to contract FS testing efforts. Contracting with AFSEO is comparatively quicker than with Lockheed Martin because transferring money between government agencies does not require negotiations. The process from RFP to contract award took two months. Another benefit of this process was government experts responsible for certification were directly involved with the test efforts as many worked for AFSEO (Yost, 2020).

Contract Deliverable Improvements

The CDRL process needs to be revisited to shorten schedules. Agile principles require that formal CDRL delivery be limited. However, sharing of data must occur among all parties involved. Security concerns may make this difficult at times, but most data can easily be shared. This plan should limit response time and enable the F-35 team to be proactive in managing risks. The CDRLs that are delivered should be iterative and develop along with the program. Currently, many CDRLs are a one-time delivery which limits exchange of data until all work is complete. An iterative process would shorten timelines required for CDRL development

(Ormaza, 2026). Streamlining the AW process would save several months at the end of the integration cycle. By sharing data early and often, CDRL review and certification timelines would be shortened.

Personnel and Management Improvements

Retaining personnel maintains accountability and historical knowledge. The Government Accountability Office (GAO) attempted to understand why the F-22 program failed. One factor was high personnel turnover, which led to a lack of accountability. Contracting was priority. Management made schedules that met requirements but not based on reality. Leadership approved because it met requirements. Once problems arose, new personnel were ladened with correcting the problem. The F-35 also has high personnel turnover. Schedules are unsupportable with the current resources. The F-22 program failed to match technology development to resources, and the F-35 program follows suit. The GAO stated: "Unless pressures are alleviated in the DoD to get new acquisition programs approved . . . programs will continue to be compromised from the outset with little chance of [success]" (Walker, 2003).

Speed can lead to negative consequences. Quick fielding often provides products but ignores logistics aspects required for a fielded system. The U.S. Army realized this when they rushed improvised explosive device (IED) jammers through minimal testing to field them during the Iraq war. The need for the user was critical, and it was decided to use the battlefield to continue test. This posed risk that the system would not work as intended and put the lives of the operator at risk. However, the need for immediate IED protection was greater than the risk posed by the devices failing. Additionally, the U.S. Army was able to analyze feedback from the users to improve the IED jammers. Government budgeting is not as responsive as required by the rapid fielding approach. The lesson is clear: If the program is willing to accept the risk of eliminating portions of testing, capabilities can be fielded quickly (Wong, 2020).

Current F-35 Efficiency Improvement Efforts

The F-35 Weapons program is attempting to remedy current delays with a variety of efforts. While some are effective, overall delays in the enterprise are muting success.

Use of Standardized Interfaces

The Weapons team advocated for the use of universal interfaces for integrating weapons such as UAI and NEW. The advantages these standards bring to weapons integration is a reduction in some software design and testing while providing added capability (Millet, 2023).

However, the current implementation of UAI Revision 5 and NEW has encountered delays (Lockheed Martin, 2023). While the interfaces are standardized, the understanding of the requirements to meet the standard differs between the platform and weapons supplier. These interfaces are not immune to the same challenges of software dependencies. For standardized interfaces to succeed, more holistic improvements to the overall weapons program are needed.

Weapons Acceleration Contingency (WAC)

Currently, there is an effort to accelerate the integration of two weapons. This effort is known as WAC. Like the Army's IED jammer program, the threat to the armed forces was deemed greater than the risk of accelerating integration. If the effort is successful, these weapons will be delivered for war time use by the end of 2026, two years faster than traditional development schedules. The current forecasted date for full fleet integration is mid-2028 (F-35 Weapons, 2023).

This is a bold move by the JPO. Even with leadership support, this plan faces challenges. The flight test aircraft will not have the air frame modifications required to perform

the FS testing. While the air frames team works to allow safe testing, there is no guarantee that the current strength of the aircraft is sufficient enough to avoid damage. The modifications required present a risk to the schedule as they will take more than 12 months to complete.

The contract schedule is also at risk. WAC is funded under a UCA and not definitized. The estimates for the integration efforts are being reviewed and will be negotiated prior to finalization. It is possible that funding may be expended if the threshold is reached.

The WAC effort requires top priority from the enterprise. This prioritization will further delay others. Currently, it is estimated that this effort will slip at least three other weapons integration efforts two or more years. There is risk to the FS aircraft. Without the structural modifications required for the carriage of these weapons, there exists a risk that the aircraft will sustain damage during test further delaying all testing efforts (F-35 Weapons, 2023).

Operation THUNDER

Operation THUNDER is an effort initiated by the UK government to accelerate UK weapons integration. When delays began to occur, they decided to act proactively to try to mitigate these issues. The program collaborated among all groups. Novel contract solutions including Stream Line Delivery Orders and incentive fees were used. Iterative integrations and capability prioritization are used to deliver capability to the warfighter sooner (Belgium & Conlin, 2020).

Operation THUNDER has had an early success story. The program delivered the ASRAAM Block 6 capability to the fleet five months ahead of date by awarding Lockheed Martin incentives for meeting milestones at objective dates. Additionally, they used read-across data from the ASRAAM Block 4 efforts to limit the amount of testing required.

Delays, out of the UK's control, ultimately impacted delivery dates despite these innovative solutions. The current ASP projects that SPEAR 3 will deliver initial capability in 2031, seven years late. Similarly, Meteor is forecasted to deliver in 2032, again, seven years late (Ormaza, 2026). Success was fleeting too. Working with the weapons supplier, the Paveway IV Seeker program was able to provide test assets early to the ITF to perform ride along testing with the TACPEN effort. This allowed FS testing for the Seeker program to be completed years ahead of schedule. However, flight testing issues delayed the last WDE by six months. Setting up for success sometimes still means failure (Belgium, 2021).

Flight Science Lite

The FS testing fleet are retiring, increasing the risk of test delays. The JPO and ITF are leading the "Flight Science Lite" program to mitigate this risk. As discussed previously, this will involve modifying current production aircraft to support FS testing. The four aircraft will be modified with instrumentation to capture FS data. However, the external wing stations will not support FS work. This will limit all FS testing to the inboard stations only (Pickett & O'Melia, 2023). While this mitigation strategy will prevent delays, it is unlikely to improve weapons schedules.

Computational Fluid Dynamics (CFD) Modeling

The Store Separation team is leading an effort to replace portions of wind tunnel testing with CFD modeling. This computer modeling program would provide weapons separation data quicker than the wind tunnel testing. The CFD model requires high performance computers to deal with large amounts of data and computations required for accurate modeling. The model identifies critical cases in the flight envelope for carriage and release. These cases will become the priority for flight testing. The team has encountered recent success with the CFD modeling of GBU-38/-54. The models accurately predicted what was encountered during flight test. The more confidence that develops in the CFD modeling, the less flight tests will be required. The

Stores Separation team estimates that accurate CFD results would lead to a 30% reduction in flight testing (F-35 Weapons, 2021).

Significant investment and support are required to make CFD a viable tool for reducing flight tests. The CFD models require that Lockheed Martin share proprietary modeling data for the aircraft with the JPO which is proving to be a difficult agreement. More high-powered processing computers are also required to process the large quantity of data.

Conclusion

The weapons integration schedule is a product of many factors. Some of these factors cannot be easily overcome. As weapons become more capable and reliant on interfaces with the aircraft, the design, integration, and test process will become more intricate and time consuming. The lack of available resources will continue to hinder the F-35 weapons integration programs through the foreseeable future and may become worse. This problem is aggravated by naïvely optimistic schedules that masks reality with the promise of success at an unattainable pace.

What can the F-35 program do to integrate weapons faster? There is no panacea that would save years on integration, but we must implement a realistic view of the problem. The GAO agreed that there is no one magic cure noting that policy changes are not sufficient to avoid delays and cost overruns in various studies of Government acquisition programs. Anyone solution will result in saving of a few months at best. When schedules are delayed years, months will not satisfy the users. The solution is a change in the philosophy of management to go together with creative solutions at the integration level such as CFD and WAC. Plans and schedules will need to reflect the reality of trying to integrate not only weapons but all the other aircraft systems with the given personnel and supporting equipment at hand. The F-35 program needs to invest in more resources now to support weapons integration in the future. Contract development, funding, award, and their deliverables will need to be reworked to support a more rapid integration plan. Finally, tough choices will need to be made regarding the priority and focus of the weapons integration plans in order not to overburden the resources available. Until the program shifts how they approach weapons integration, no significant progress will be made in reducing the time frame to deliver capabilities to the warfighter.

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