The Curse of Complexity and Concurrency

The F-35 Joint Strike Fighter program and lessons learned for future major Marine Corps acquisitions programs

by LtCol A. Jack Ramthun

The F-35 Lightning II Joint Strike Fighter (JSF) program has faced significant challenges toward achieving its original acquisitions baseline objectives for cost, delivery schedules/milestones, and, in some cases, capability performance.[1] Representing the Marine Corps' largest military acquisitions program since 2001, the F-35 program's increasing costs, delayed fielding, and engineering compromises combined to prevent the Operating Forces the use of a highly lethal, game-changing combat capability during a long period of constant, hard-fought warfare. Additionally, the JSF program's acquisitions difficulties have created negative, unintended second- and third-order consequences across the Marine Corps tactical aviation enterprise; specifically, both the perpetual extensions of fourth-generation legacy tactical jet aircraft beyond their original out-of-service dates and the premature transition of low density maintainer and pilot talent from legacy platforms to the F-35 during periods of high operational tempo and demand.[2] These undesirable and inadvertent consequences created a resource vacuum (funding, personnel, and logistics/sustainment) that contributed to the present USMC tactical aviation flightline readiness crisis.[3]

Strikingly, many of the essential exploratory acquisitions questions, such as, "How did we get here?" and "How do we avoid this situation in the future?" remain in a *non grata* status among

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Marine Corps professional acquisitions circles. In an effort to inform, this article identifies and examines the two central acquisitions decision errors of the F-35 program. Additionally, to stimulate education, this article also captures and disseminates key lessons learned from the JSF's early development. Knowing the F-35 represents the most lethal aircraft in the USMC's present tactical aviation inventory,[4] this article avoids discussions focusing on the F-35's tactical capabilities or arguments to divest and/or invest in high-low mix-style alternatives. Rather, I will be describing the two principal decision miscalculations of the early F-35 acquisitions effort and presenting important lessons learned for use as "best practices" during future major Marine Corps acquisitions programs.

First Principal Error: The Joint Approach with Diverse Capability Requirements

Developing a single aircraft for use by three military Services and multiple international partners with very diverse mission and test requirements, resulting in rapidly increasing design complexity, represents the F-35's seminal acquisitions decisions' mistake. Joint programs often aim to achieve significant savings in overall life-cycle costs by reducing a number of duplicate acquisitions-related efforts (i.e., research, development, testing, contracting, etc.) and attaining economies of scale (i.e., commonality and size for production, spare parts, personnel training, etc.).[5] Thus, in January 1994, senior DOD officials launched the Joint Advanced Strike Technology (JAST) program in an effort to avoid the large projected cumulative costs associated with each of the U.S. Services creating their own uncommon type/model/series to replace their aging fourth-generation tactical fighter aircraft.[6] The senior executive conclusion to pursue JAST, later becoming the JSF program, attempted to capitalize on new technologies and procurement practices designed to mitigate the complexity risk associated with a large joint acquisitions effort while at the same time achieving savings from developing a single aircraft for multiple end users.[7] Then-Secretary of Defense William Cohen stated the joint nature of the F-35 program made the aircraft affordable and "avoids the three parallel development programs for service-unique aircraft that would have otherwise been necessary."[8]

The projected cost savings from the "joint approach" to the F-35's development hinged upon a common JSF aircraft design. However, the F-35 program faced large commonality challenges from the onset because of the many diverse partner requirements. For

An F-35B Lightning II prepares to land on the flight deck of the USS Wasp *(LHD-1). (Photo by LCpl Amy Phan.)*

example, the original JSF requirements for the Navy included a high-end, two-engine, two-seat aircraft with a large fuel capacity and a carrier landing capability.[9] In contrast, the Air Force required a low-cost, low-end, single-engine, single-seat stealth jet.[10] Additionally, original Marine Corps requirements were similar to the Air Force but included a vertical/short takeoff landing capability for austere landing sites and use on large amphibious ships, arguably representing the seminal technical challenge for the JSF program.[11] As a consequence of attempting to accommodate all of these diverse capability requirements into a single aircraft, the F-35 program suffered from rapidly increasing design complexity.

The "do everything" shoe represents the best analogy for the F-35 program's design complexity conundrum. Different types and styles of footwear meet very specific capability requirements. For example, running shoes provide improved cushion and are lightweight to enable high rates of foot speed. Sandals enable people to walk on the beach without getting sand inside their shoes while providing protection to the bottoms of their feet. Dress shoes enable men and women to look more professional while wearing formal attire. Hiking shoes provide improved grip and resistance to the elements for use in rugged terrain. Each type of shoe has its own cost; owning four different types of shoes to meet all foot travel mission requirements may be viewed as a costly acquisitions strategy. Question: Why not simply develop a single shoe that meets all the capability requirements for marathon running, beach excursions, formal events, and hiking trails and enjoy the cost savings of an "all in one" solution? The answer: significant design complexity and compromise lead to aggregately increasing development costs, production time, and decreasing performance in all capability areas. The engineering solution to create a multifunctional and high-performing design requires additional resources to achieve the designed end state. The result: a "single shoe strategy" costs more and performs less than designing and buying four different sets of shoes.

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In the context of the F-35, the "all in one" requirements solution led to a rapid and uncontrollable increase in program scope, complexity, and technical challenges. Additionally, popular program risk mitigation measures during this period overwhelmingly failed to account for the extreme complexity embedded in multiple complicated design/mission requirements. With noticeably increasing risk during the F-35's early development, JSF program leadership accepted considerable aircraft design compromises to stay on schedule. These compromises led to a reduction in overall capabilities performance for each aircraft variant while at the same time increasing delivery delays and costs. In theory, the F-35 program should have been delivered on schedule and saved overall costs by sharing research development, test, and evaluation resources. However, compromises in design, performance failures, and disagreement among stakeholders all further reduced opportunities for the program to achieve economies of scale in procurement and later operations and support costs.[12]

The joint approach to the F-35 largely failed because of problems encountered in the attempt to accommodate multiple ambitious and substantially different/diverging mission requirements into a common aircraft design with a goal of achieving 70 to 90 percent commonality in design, parts, and logistics support.[13] Though the JSF's high-priced components (i.e., engines, panels, and major airframe structures) remain somewhat common, the majority of parts may only be used on a single variant. Rather than achieving 70 to 90 percent commonality and saving operations and support costs in the long run, developmental engineers for the F-35 modified the designs of each variant to meet the divergent mission requirements of each partner and created the present situation where only 20 percent of commonality actually exists.[14] As a result, nine years beyond acquisitions Milestone B, the F-35 life cycle costs are significantly higher than if the Services had pursued and developed three distinct and separate strike fighter jet aircraft programs.[15]

Second Principal Error: Concurrency with Immature Technology

The second major acquisitions decision error, over-relying on concurrency (the method of producing end-user level equipment during design and test phases) to accelerate aircraft delivery timelines and realize long-term cost savings, actually achieved the opposite effect. In theory, the JSF's development and production process of concurrency should have achieved major cost savings for the program. During the program's infancy, senior executives in both industry and the military hailed recent advances in modeling and computer simulation; specifically, they believed these technological innovations would surpass and replace flight testing, effectively driving down program costs and delivery timelines.[16] The JSF program fully embraced this concurrency theory, authorizing Lockheed to design, test, and produce the F-35 all at the same time instead of identifying and fixing design defects discovered during the developmental flight test and before fully energizing the JSF production line.[17] As of late fiscal year 2017, 340 total F-35s were purchased, and another 178 will be purchased by 2019, making 21 percent of total planned aircraft procurement before the completion of operational tests.[18] This represents the F-35 program's "all-in moment," as it embraced an unprecedented and increasing level of "concurrency risk," consistently approving increasing sizes of block buy production aircraft many years prior to the completion of developmental testing.[19]

The application of the concurrency theory to the JSF largely failed because the leadership at both Lockheed Martin and the F-35 program made a seminally poor assumption: that advanced modeling and simulation would identify significant flaws embedded in immature technologies early in the design phase of the JSF. However, in reality, modeling and simulation are well known in the engineering profession to be poor methods to assess immature technologies, as these methods fail to account for the same number of variables as a flight test does. The JSF design, principally based on immature technologies, did not possess such a widely scoped and wholly accurate database of known performance parameters to develop useful stand-alone models and simulations. As a result, these efforts did not identify significant design flaws across the spectrum of the aircraft (control surfaces, engine, software, hardware, etc.) early on during its development.

In calendar year 2015, the F-35 program maintained a five percent discovery rate in developmental testing; in effect, for every 100 actual flight tests, five new design problems were discovered.[20] These new discoveries, not found via modeling or simulation, must be corrected and tested again, which effectively increases program costs and delivery delays. This situation snowballed into a debilitating situation, where engineers identified problems faster than they had the capability to correct them, while at the same time producing flawed aircraft and delaying deliveries to the fleet in order to execute costly post-production design modifications. For example, post-production discoveries of critical flaws and errors requiring major design changes and modifications include: cracking and metal fatigue in the wing structure, fuselage bulkheads, multiple doors on the airplane, software errors and fault codes, gunsight deficiencies, engine seal, the automated logistics system, the helmet mounted display, ejection seat safe separation problems, wing fuel tank over-pressurization, disintegrating sealant on coolant lines, and the underperforming life-limitations of the F-35B bulkhead.[21]

The practice of concurrency by the JSF program created both a very expensive and immensely frustrating loop: develop, model/simulate, flight test, and produce a complex design all at same time; discover major design flaws during this process; pause other scheduled efforts to redesign and introduce major corrections to the aircraft; re-flight test; expend additional resources to modify already-existing production aircraft with the new design solutions; and repeat. The consequences of F-35 concurrency have caused the program to expend additional resources to send aircraft in for major re-work, in some cases multiple times, in order to sim-

Three F-35B Lightning IIs from VMFA-211 prepare for inflight refueling. *(Photo by LCpl Becky Calhoun.)*

ply keep up with the aircraft design as it progresses.[22] Retrofits represent a normal part of any acquisitions process; however, the level of concurrent production and the increasing rate of newly emerging design failures caused an unprecedented number of F-35s to be modified before entering fleet service at significant financial expense to the government. This costly phenomenon is known as the "concurrency tax," causing the program to be "unaffordable for the Services as they consider the cost of upgrading these early lots of aircraft while the program continues to increase production rates in a fiscally-constrained environment."[23]

First Lesson Learned: Reduce Complexity Using a Pragmatic Requirements Approach

The JSF program's approach to attain both maximum design performance and system commonality represents an oxymoronic acquisitions proposition. When factoring highly divergent partner requirements into a single design, increasing technical complexity and engineering compromises ultimately reduce commonality, leading to reductions in joint cost savings. In the case of the JSF, as design complexity increased because of the technical challenges to meet all partner requirements, the theoretical cost savings from the joint line of effort quickly evaporated.[24] In the end, the F-35 program will cost the Services

> more in total lifecycle costs than if they had pursued separate, single-service programs, which might have produced differing designs better optimized to meet their unique individual service operating environments and requirements.[25]

As a best practice, Marine Corps program managers should mitigate acquisitions risk by actively reducing complexity. The same "keep it simple, stupid" (KISS) principle taught at TBS to every young lieutenant also has application when developing new technologies to serve the Operating Forces. Looking beyond the JSF, the Marine Corps should avoid participating in future joint acquisitions programs with partners maintaining very different mission requirements. To be clear, this lesson learned focuses on the full alignment of design performance and priorities among partners to achieve significant cost savings; to achieve this end, the Marine Corps must partner with Services and countries sharing very similar (if not the exact same) mission and capability requirements. This approach reduces complexity and mitigates technical risk from program onset, likely leading to the attainment of cost, delivery schedule, and performance goals. Commonality of design, a noble acquisitions endeavor, must have a realistic opportunity of succeeding.

Additionally, outside of the context of joint acquisitions programs, the Marine Corps must also be more pragmatic when developing and validating new capability requirements. Attempting to lump multiple diverging requirements into a single weapons system program only increases complexity and risk. For example, an aviation platform with seven tactical "shooting" capability requirements should not also be needed to carry pallets of "logistical" gear onto the battlefield. This "do everything" requirements solution, subject to increasing technical risk and compromise, will likely be unable to achieve all of the diverse performance goals at an affordable cost to the Marine Corps. Thus, applying all-in-one requirements strategies acts as a "self-inflicted wound," achieving the same negative outcomes as joint programs with multiple partners and different requirements.

Second Lesson Learned: Invest in the Test When Dealing With Immature Technologies

Similar to the first principal decision error of the joint approach with diverse requirements, concurrency exposed the JSF program to immense risk. F-35 concurrency, though an honorable attempt to reduce costs, actually will result in the U.S. Government expending additional financial resources equating to greater than four additional sixteen-plane squadrons of F-35Bs. For the JSF, most of the problems and negative consequences of concurrency resulted from "being in a hurry [and] being confident things will be cheaper, better, [and] faster than they actually will be."[26]

In future major acquisitions programs, the Marine Corps should invest in and accept the costs of proper pre-production testing as an "insurance policy" to buy down risk associated with developing immature technologies. The F-35's "buy before you fly" method of military acquisitions may work well with commercial off-the-shelf technologies and systems with proven records. However, immature technolo-

An F-35B Lightning II landing at MCAS Iwakuni, Japan. The aircraft is with VMFA-121. ***(Photo by Sgt Neysa Huertas Quinones.)***

gies, especially associated with expensive acquisitions programs, should be treated much differently and with caution. The decision and commitment to produce represents a critical moment in any acquisitions program. At this point, the technology absolutely must maintain design stability, verified by testing, before proceeding to produce in mass quantities.

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Ironically, program managers often have the propensity to cut test budgets first before trimming other areas of a given acquisitions program when operating in a fiscally constrained environment. However, testing enables program managers to achieve greater savings throughout the life of a program via cost avoidance. The earlier a program can discover and fix design problems, the greater the cost avoidance down the road. A reasonable amount of balance and judgment must be applied by program managers in this case, as the program does not have infinite time to conduct tests prior to full-rate production. Additionally, concurrency should not be completely ignored as an acquisitions strategy. Obviously, some degree of concurrency may be acceptable while moving into operational testing; however, the degree of concurrency varies greatly with the willingness of senior leaders to accept risk and rapidly deploy a new technology to the fleet. In the end, the Marine Corps preserves money, time, and capabilities when "flying before buying."

Conclusion

The F-35 JSF program fell victim to two key decision mistakes early in its development: the joint approach with diverse requirements and concurrency with unproven technologies. The significant negative consequences from these mistakes include schedule delays stretching greater than five years, program costs more than doubling from original estimates, and decreasing legacy tactical aviation readiness. From these failures, Marine Corps leaders and acquisitions professionals have learned two critical lessons: use the joint acquisitions approach only when mission requirements align, and invest in testing over applying concurrency when working with immature technologies. These lessons learned from the early development of the F-35 can be applied to future land, sea, and air major Marine Corps acquisitions programs to maximize capability performance, achieve speed to the fleet, and reduce program risk.

Notes

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