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By the time The United States Department of Defense has developed and purchased its fleet of F-35 Joint Strike Fighters, it will invest nearly $1.5 trillion. However, in a world of evolving military powers, the F-35 will provide the US with unprecedented air-to-air and air-to-ground supremacy through advanced targeting coupled with sensor fusion technology. The F-35 brings unmatched lethality and situational awareness to any battlespace it enters. The sensor fusion technology gives the US warfighter the advantage of information dominance. Although the F-35 program experience several setbacks with timeline constraints and defense spending, it should by no means be underestimated in its capability.

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Lighting versus Thunder: The Defense of the F-35 Program

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Executive Summary

Title: Lightning versus Thunder: The Defense of the F-35 Program

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Thesis: By the time The United States Department of Defense has developed and purchased its fleet of F-35 Joint Strike Fighters, it will invest nearly $1.5 trillion. However, in a world of evolving military powers, the F-35 will provide the US with unprecedented air-to-air and air-to-ground supremacy through advanced targeting coupled with sensor fusion technology.

Discussion: The F-35 is the United States (US) military's most advanced fighter aircraft. Its concept of design began in the 1980 and was later refined throughout the 1990s. The aircraft was designed with the inputs from the US Air Force, Navy and Marine Corps with lofty requirements. The services wanted a reliable, affordable, supersonic, stealth, multi-role fighter capable of vertical takeoff for the US Marine Corps and naval flight deck operations for the US Navy. Lockheed Martin and Boeing fielded flying conceptual designs that met the design requirements and made significant milestones in the capability of short take-off and vertical landing (STOVL) aircraft. Ultimately, Lockheed Martin's X-35 design was chosen to fulfill the role of the Joint Strike Fighter (JSF). Since 2001, the X-35, later named the F-35 boasts many technological leaps that are unprecedented in today's fighter aircraft fleet. The F-35 is a true multi-role fighter but is deficient in several areas. The F-35 weapons loadout is minimal, it's experienced many hardware and software redesigns, and most notably the affordability is questionable. Although the acquisition of the aircraft needed more initial oversight to keep the program on par with estimates, the F-35 incorporates technology that makes other fighter aircraft more lethal. Its sensor fusion technology minimizes the trivial tasks of the pilot while enhancing tactical situational awareness. Combining the F-35 into a strike package greatly increases the situational awareness of all airborne friendly fighters and makes geolocation of air and surface threats nearly hands off. This capability is what early airpower advocates never imagined. From the early praises of the Norden bombsight's 1,200 foot circular error probable (CEP) bombing results, to the current precise pinpointing of concealed threats within seconds, combat aviation technology is a field that hinges on technology. Technology that can now fuse information and present it in a useful format to pilots can make the difference in life and death situations. Although the F-35 receives continuous criticism, its capability can't be denied. It does what no fighter is capable of doing, it sees the hidden and hides it's obvious, giving the fighter pilot first look, first strike and first kill capability.

Conclusion: The F-35 brings unmatched firepower and situational awareness to any battlespace it enters. The sensor fusion technology gives the US warfighter the advantage of information dominance. The technology incorporated into the aircraft and available to the pilot make it unmatched at multiple levels. Although the F-35 program experienced several setbacks with timeline constraints and defense spending, it should by no means be underestimated in capability. Comparing the F-35 to legacy fighters is trivial at best. Despite the criticism, the US needs the F-35 in its aviation arsenal in order to carry it through the 21st century as a dominant super power.

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Preface

The F-35 Joint Strike Fighter is a constantly debated topic with respect to technological validity, military funding and relevance to today's conflicts. The new aircraft was developed under the premise of suitability for all service requirements and affordability for the US and partner countries. Coming from eleven years of tactical fighter aviation, I've experienced the aging and replacement of fighter aircraft. For the aviators whose airframes have been consumed by the technology leaps, it's tough to see the once trustworthy machines become pieces of museum history. However, they do become historical treasures for a reason. Employing outdated technology for the warfighter means certain death.

In reality, the US military is in a business of death and destruction during warfare. In order to defeat our enemies, we must always prepare for what is to come, not what we are used to doing. Preparing in this manner will put some warfighters outside of their comfort zone as many have become "comfortable" with the current wars of combatting terrorism and insurgencies in permissive aerial environments. Although aerial conflicts have been few to date, it does not guarantee that they will not return. For any service to maintain a fleet of aging aircraft that burdens logistics from lack of material resources strains their overall efficiency.

After my arrival at Marine Corps Command and Staff College, I've read numerous articles respective to the US Air Force about how the F-35 does not compare to the A-10. The F-35 is slated to replace the aging A-10 fleet in the USAF and that brings heartburn and distaste. It is also on track to replace aging fighters in the US Marine Corps and US Navy. Ground combat personnel love the A-10, and rightly so, it does what many air-to-ground platforms cannot. However, the A-10 is designed for specific missions including close air support (CAS) and combat search and rescue (CSAR). The F-35 is designed for a plethora of air-to-ground tasks but those tasks get overlooked by the comparison of its validity to conduct CAS, a mission that the A-10 still does very well in today's fight.

The goal of this paper is to educate the reader on the F-35 from conception to employment at the unclassified level. It will not be a "soundbite" of biased information that so many of us in the world are used to with today's media outlets. Instead, it will be a critical look at what the aircraft is designed to do and ideally a gateway of understanding as to why the US military needs such capability ready for employment.

INTRODUCTION

The United States (US) military stays on the cutting edge of technology on the ground, in the sea, and in the air. In order to maintain a credible stance against near pear aggressors, while downsizing the force, the US must leverage all of its technological advantages. The need for 5th generation aircraft is at the forefront for the US Air Force (USAF) as well as the aviation components of the US Navy (USN) and US Marine Corps (USMC). The F-35 Joint Strike Fighter will serve that purpose by combining stealth technology, sophisticated air-to-air and air-to-ground targeting couple with sensor fusion to mitigate complicated battlefield scenarios.

The F-35 is slated to replace the aging A-10 Thunderbolt II and the F-16 Fighting Falcon for the USAF; the F-18 Hornet and AV-8B Harrier for the USMC; and the F-18 Hornet for the USN. Although the F-35 is a very capable aircraft, controversy has plagued its development. Much of the controversy stems from the budget and timeline constraints originally presented to the Department of Defense (DOD) and the lack of oversight to keep civilian corporations true to their contract. In addition, comparison of capabilities, specifically to the A-10 spurred debate not only at the tactical military aviator level but into the congressional level on its validity to replace the aging A-10.

This paper will serve to set the stage on the development of the F-35 and its history of inception. It will cover the design and some basic capabilities of the F-35 that make it an aircraft like no other. It will briefly discuss why the naysayers voiced their opinion due to budget concerns as well as capability comparison in today's counterinsurgency operations. I will discuss the way ahead with the status of milestones achieved, the reorganization of the program, and address some causes for concern with aircraft development.

It cannot be denied that the F-35 possesses qualities that are lacking in today's fighter aircraft. The US military maintains a fleet of 4^{th} generation fighter aircraft, and even bomber aircraft with legacy ties to the Cold War. The only 5^{th} generation fighter aircraft owned by the US is the F-22A Raptor which is designed primarily for air-to-air superiority. In the world of evolving military powers, the F-35 will provide the US with unprecedented air-to-air and air-to-ground supremacy through advanced targeting coupled with sensor fusion technology.

From Inception to Conception – F-35 in the Making

The F-35's origin precede its manufacturing date by several decades. The roots of the F-35 date back to the late 1980s with several tactical concept aircraft programs. These programs attempted to create an aircraft that retained short take-off and vertical landing capability (STOVL), partnered with stealth technology and multirole fighter platform capability. The earliest of these programs begins with the Advanced Short Take-Off and Vertical Landing (ASTOVL) program that dates between 1983 and 1994.[1]

In 1983 the Defense Advanced Research Projects Agency (DARPA) pursued the viability of designing a fighter that would replace the AV-8 Harrier but incorporate supersonic capability.[2] The program was named ASTOVL and became a joint effort between the US and United Kingdom (UK). By 1987, DARPA recognized that technology required for the ASTOVL was not compatible with the design requirements. DARPA then reached out to Skunk Works, an advanced aircraft development division of Lockheed Martin in an effort to further develop the needed technology for ASTOVL.

Transitioning into the late 1980s, Lockheed's Skunk Works also began working with the National Aeronautics and Space Administration (NASA) to further develop a supersonic fighter that was stealthy and maintained the STOVL capability. The end result was proof that a fighter aircraft could retain all the attributes of stealth and still fly supersonic.[3] Lockheed then proposed the technology be used to create a fighter aircraft that the USAF, USN, and USMC could benefit from. The services joined the initiative and the classified development came out of the "black world" as the STOVL Strike Fighter (SSF), which was developed from 1987 until 1994.[4]

As the ASTOVL and SSF were under development, the capability of the design proposals struck a common chord with the services. The services wanted the new fighter to not only be a replacement for the AV-8 Harrier but also a replacement for other aging fighters. The services proposed that multiple variants should be developed and tailored for all branches; this proposal redubbed the program as the Common Affordable Lightweight Fighter (CALF) between 1993 and 1994.[5] DARPA maintained the ASTOVL program as well as the new CALF program which later took on the name, Joint Attack Fighter (JAF) which was a subset of the original ASTOVL program that began in 1983.[6]

In parallel with DARPA's developments, US service branches explored cost effective measures of replacing aging fighter platforms. The USAF began the Multi-Role Fighter (MRF) program in 1991 as a means of replace the fleet of F-16s. The plan was to develop a low-cost, single engine, single seat fighter with an off the shelf price tag between $35-50 million.[7] As the Cold War died down, US defense forces began a drawdown. The drawdown had a positive effect on F-16 health with negative effects on the MRF program. Due to the slimming post-war defense budget, F-16s flew less which in turn extended their service life making a replacement aircraft less critical.

Not only did the USAF deem it necessary to undergo the development of its own fighter platform, but the USN worked on a medium attack role aircraft from 1983 to 1991. They required a stealth aircraft, with long range and relatively high payload to replace its A-6 fleet known as the Advanced Tactical Aircraft (ATA).[8] However, severe schedule flaws and lack of budgetary discipline cut the program short and in 1991 it was permanently cancelled. Nevertheless, Congress intervened on the Navy's behalf to initiate development of a fighter that could be the fleet replacement for the F-14 Tomcat. The USAF's ATF program was looked at from a naval perspective and the proposal for a Naval Advanced Tactical Fighter (NATF) emerged in the early 1990s.[9] A NATF office was established at Wright-Patterson AFB to evaluate and modify naval variants of the NATF program. The NATF and ATF production proposals were reduced in order to save costs of the combined program. Then in the late1990s, the chief of naval aircraft requirements, Admiral Richard Dunleavy, believed that the NATF was not affordable for the USN and the program was subsequently scrapped. The USN's alternative approach was to upgrade the existing F-14 fleet to carry the airframe through the start of the 21st century.[10]

After the cancellation of the USN's ATA and subsequent NATF programs, the Secretary of the Navy, Henry L. Garrett III (1989-1992), requested a new program to replace the A-6.[11] In January of 1991, a new program emerged dubbed the Advanced-Attack (A-X) and later the Advanced Fighter-Attack program (A/F-X) combining stealth technology, all weather capability, multi-engine, multi-crew and an advanced avionics suite coupled with self-defense countermeasures.[12] Although technological milestones were being made under A-X and A/F-X, the USN again realized a more cost effective measure with the development of the F-18 and the Defense Tactical Bottom up Review (BUR) board decided that both the A/F-X and MRF programs be cancelled.

Once the A/F-X program was disbanded, small working teams were created under the Joint Advanced Strike Technology (JAST) program. The primary goal of JAST was not to create an advanced strike platform, but to develop and mature the technology that could be used in a multitude of tactical aircraft. Timing was on the side of the ASTOVL program and the leadership of the JAST and ASTOVL program agreed that JAST would be the sponsor for the Phase III flight demo of ASTOVL. Since both JAST and ASTOVL were making significant headway in development, the FY95 Congressional budget legislation required JAST and ASTOVL to be consolidated. This would be the starting foundation of what was later coined as the Joint Strike Fighter or JSF. Under the Concept Definition Phase (CDP), the JAST program was renamed the JSF and both Lockheed and Boeing were tasked with creating multiple flying demonstrator aircraft that could enter full-scale production.

Boeing's answer was the X-32 (Figure 1) which first took flight on September 18, 2000, while Lockheed fielded the X-35 (Figure 2) which completed its first flight on October 24, 2000.[13] Boeing's X-32 test program developed an A and B variant of the aircraft. The X-32A was the conventional take-off and landing version while the X-32B incorporated STOVL technology. The X-32 went through rigorous tests including field carrier landing practice, high and low speed handling, conventional and STOVL transitions, sustained hovers and supersonic dashes. The X-32 also accomplished the longest sustained hover from a STOVL platform of eight minutes in June of 2001. By July 28, 2001, the X-32 made its final test flight comprised of high-altitude supersonic dashes under the command of Lieutenant Commander Paul Stone of the UK Royal Navy.

Figure 1. Boeing X-32

Lockheed's X-35 program also developed multiple variants of the test aircraft – the X-35A, B and C. The X-35A tests exceeded all milestones and expectations; its success achieved all objectives within one month of testing. The X-35A was then converted to the X-35B STOVL version which incorporated a shaft-driven lift fan, the first of its kind. Additionally, the X-35C was tested in parallel at Edwards AFB in California. The X-35C incorporated a larger overall wing area, larger flight control surfaces, and beefed up landing gear spars for high-impact carrier landings. The most notable milestone in aviation history for the X-35B was the sustainment of vertical flight by the lift fan design. On June 23, 2001 the X-35B did a vertical hover up to 20 feet for several minutes, the first aircraft to ever hover under the power of a shaft-driven lift fan. The final test flight for the X-35 would take place on August 6, 2001 bringing the test program to a close. The X-35A/B and the X-35C were retired and put on display at the Smithsonian Institution's Stephen F. Udvar-Hazy Center in Virginia and the Patuxent River Naval Air Museum in Maryland.[14]

Figure 2. Lockheed Martin X-35

Is the F-35 another "F-4?"

The most commonly criticized fighter procured by all service branches was the F-4 Phantom II. The eighth Secretary of Defense, Robert McNamara (1961-1968), pushed for a fighter with "commonality" that was capable of serving all branches of the US military.[15]

McNamara's approach stemmed from a cost saving emphasis of the DOD as a whole, a byproduct of President John F. Kennedy's focus on furthering national aims through wiser budgetary discipline. Although McNamara's name is commonly tied to the failures of the F-4, the aircraft's roots date back to Cold War requirements before McNamara's era.

During the Cold War the main focus of US foreign policy was containment.[16] The USAF's development of the Strategic Air Command (SAC) became a deterrent against Soviet nuclear aggression through the use of long-range, nuclear capable bombers and intercontinental ballistic missiles (ICBM). SAC was seen as the most cost effective measure for the US government's nuclear defensive plan. Because SAC inherited the bulk of US defense spending during that era, USAF tactical aviation under Tactical Air Command (TAC) suffered with relevancy alongside the USN. Interdiction, close air support, and air-to-air superiority were looked at as fights of the past; fighter development during the Cold War era focused mainly on high-altitude, high-speed, long range intercepts. The birth of the F-4 during the 1950s was influenced by requirements of the current fight, nuclear deterrence. The USN strived to procure a healthier portion of the defense budget and their focus was developing a fighter either capable of employing tactical nuclear weapons, or capable of destroying enemy nuclear bombers. Throughout years of development and previous program failures, the McDonnell Douglas F-4 was chosen. Some even dubbed this research and development of the new fighter as "orchestrated confusion" as the USN gave no specific guidance to McDonnell Douglas on exactly what they needed.[17]

In the Cold War mindset, the USN wanted a fighter that was capable of nearly everything. They wanted a platform capable of high-speed intercepts, escort missions, fleet defense that carried primarily air-to-air missiles, a design flaw that would prove costly for the F-

4 during the Vietnam War. Even with all the technological advances of that time, the F-4 testing was focused on interceptor tactics of quickly achieving maximum speed and altitude. The notable world records (which the Phantom set over a dozen) gaining 98,557 feet of absolute altitude and flying at an average speed of 1958 miles per hour (for 16 minutes) peeked the USAF's interest in procuring the fighter as a strategic nuclear asset.[18] Testing of maneuverability, aerial gunnery and air-to-air specific tasks were non-existent and quite frankly seen as irrelevant. The USN was so sure of its fighter and the war it would fight, that it closed its Fleet Air Gunner Unit (FAGU) in 1960 under the assumption that new long-range beyond visual range (BVR) missiles were the key to air-to-air combat. The BVR look, shoot, kill design of the F-4 was contradictory to the restricted rules of engagement (ROE) of visual identification (VID) over Vietnam.

What gave the F-4 the perception of failure was the broader operational considerations of the fighter. It was an aircraft with technological advancements that drove the application of doctrine. The service branches procured a fighter that they were unsure of how to employ. It took on the varying roles of tactical nuclear bomber, fighter interceptor, fighter escort and naval fleet defender to name a few. The F-4 was known as the greatest fighter for a war it would never fight. Instead its development lacked necessities in WVR tactical engagements and it inherited capabilities that would be underutilized during the Vietnam conflict.

Moreover, what should not be overlooked was the "concurrency testing" model that was used for design and procurement of the Phantom II.[19] The goal of concurrency testing was to reduce the F-4's development timeline by beginning production prior to the completion of the aircraft's final design. This meant that McDonnell Douglas was committed to producing the aircraft structure without knowledge of all interior components of the jet. Component's used inside the aircraft were constantly changing and the "concurrency testing" concept proved to be a coordination nightmare between McDonnell Douglas and its subsystem design contractors.

The end result of the F-4 program was the procurement of a highly capable fighter designed for a war that it didn't fight. With over 600 Phantom IIs shot down over Vietnam, F-4 aircrew found themselves routinely in high-G force, high stress, turning fights in an aircraft designed for high speed, high altitude tactical intercepts. The poor rearward visibility made it tough for pilots to visually clear their "6 o'clock" or tail area during visual engagements while the unsightly black smoke of the afterburning engines gave the enemy a visual intercept advantage, easily placing the Phantom II at their "12 o'clock" or nose position. After all, the F-4 was supposed to kill enemy aircraft BVR so the need for turning engagement capability was ignored. The lack of an internal gun system, replaced with cost saving BVR air-to-air missiles proved deadly when engaging jets in close quarter combat over targets in North Vietnam.

F-4 Similarities – No New Lessons

The "concurrency training" model that the F-4 program utilized is now common practice with respect to military equipment procurement.[20] F-35's system development and demonstration (SDD) began in 2001 and to date F-35s are still being produced and refined as anomalies and production issues arise. Although F-35s continue to roll off the production line, critical software codes are still being developed and aircraft equipment failures are still being identified. What draws the bulk of criticism of the F-35 program is the cost of procurement and the expansion of the defense spending budget. After Lockheed won the F-35 contract in October of 2001, a contract of nearly $19 billion was awarded to develop and demonstrate the aircraft used by the US military and our partner countries. Lockheed Martin then quoted a price tag of $233 billion for 2,852 F-35s.[21] However, by 2013, that price rose to $400 billion with 400 less planes than promised. This price increase stemmed from lack of fiscal oversight by government contractors, production delays, software updates, increasing technology costs and projected maintenance costs to keep the fleet airworthy. Additionally, as engineering modifications are identified and parts of the aircraft redesigned, the DOD will pour an additional $4 billion into the program to retrofit its existing fleet. Critics claim that the only thing stealthy about the F-35 is its ability to evade a budget.[22] To date, the F-35 program has approximately $1.5 trillion invested by the DOD and partner countries, and it's expected to be operational for the USAF, in limited regards, by August 2016.[23]

With the trillions of dollars invested in the technology of the F-35, it is still lacking in one area that basic fighter aviation deems necessary. The F-35A design incorporates the GAU-22/A, an internally mounted 25mm cannon with only a thrifty 180 round capacity.[24] The F-35B and C variants, due to service specific requirements of their respective airframes, are not equipped with an internal gun but will utilize an externally mounted gun pod similar to the retiring AV-8B Harrier.[25] In comparison, today's average US fighter utilizes a 20mm cannon (except the A-10's 30mm capability) with a 500 round capacity, which equates to five seconds of gun, or 100 rounds per second. The F-4 however was designed without an internal gun in the mindset that "dogfighting," air-to-air visual combat, was a thing of the past. F-4s were supposed to kill their opponents BVR, not within visual range (WVR). Eventually, an externally mounted gun pod was retrofitted to the jet due to the frequency of WVR engagements. Later models of the F-4 incorporated an internally mounted gun. Although the F-35 design paid tribute to the F-4s original lack of a gun, its actual gun capability is reflected by its design capacity. The F-35A will have approximately two seconds of gun time and the F-35B and C will sacrifice its stealth design for an externally mounted pod. An eerie similarity of the design mindset comes to fruition in the quote: “The F-35’s technology is designed to engage shoot and kill its enemy from long distances, not necessarily in visual dogfighting situations.”[26]

The F-35’s multi-service procurement requires it to be multi-functional with respect to fighter aircraft requirements. In order to be a fitting replacement for the inventory of 4th generation fighter and attack aircraft, the F-35 must be capable of servicing all missions that legacy fighters held specific to their design. This can be a help and a hindrance when developing a fighter that serves so many needs, the common phrase comes to mind, “jack of all trades, and master of none.” Initially conceived as an interceptor, the F-4 design was quickly strained with what Michael Hankins coined “mission creep.” This term referred to the overburdening of tasks in the design of the F-4, the insistence of the aircraft to handle multiple roles ultimately sacrificing capability in other roles.

The F-35 carries this same burden, and unlike the F-4, has only one pilot to handle its employment. In order to fully capitalize on all of the F-35 capabilities, squadrons must be dedicated to perform specified tasks much like the multi-role F-16 community. For example, an F-16 squadron specialized in Suppression of Enemy Air Defense (SEAD) may not be as proficient in performing Offensive Counter Air (OCA), thus requiring the squadron training to focus heavily on SEAD rather than OCA. This training specificity, coupled with tighter DOD budgets forces multi-role fighter squadrons to lose proficiency in varying degrees of their fighter capability. As the F-35 becomes fully combat operational, it will soon replace these fighter platforms, and the multi-role training of F-35 pilots will place a burden on their overall proficiency. Services need to leverage mission requirements, like CAS, on existing 4th generation fighter aircraft so as not to over rely on a jet to fulfill needs that don’t harness the aircraft’s full potential.

Although certain elements exist for critics to compare the F-35 against the F-4, it is safe to say that the F-35 isn't and will not be another F-4. Its capability and capacity far exceed what the F-4 was intended to do. It is an aircraft suitable for all services with the technology that makes it a game changing advantage in combat. What should really be studied is how to harness its full potential during conflict. Operational planning must weigh all of its capabilities to best optimize its employment in combat. In order to do so, subject matter experts (SME) must be highly versed in all aspects of F-35 combat planning applications. Military branches must ensure that SMEs are cross-flowed into multi-service planning events and exercises. This mindset will expose SMEs to tactical considerations that may be overlooked in service specific mindsets. For example, a USAF F-35A pilot may share knowledge on how to employ the F-35 as an effective interdiction fighter to an expeditionary USMC F-35B pilot. Its capabilities are so vast that it will take continued multi-service training and engagement to bring the F-35s tactical capability into an operational planning environment to produce strategic visionary success.

F-35 Capabilities

The fifteen years of F-35 testing and development yields a fighter unlike any other, regardless of disputed similarities. Unlike the F-4 program, the F-35's technological advancements are driven by doctrinal applications. It is a fighter designed to counter a plethora of enemy capabilities. The F-35 uses a combination of stealth, speed, integrated electronics and sensor fusion to maintain the upper hand in both air-to-air and air-to-ground combat. As the US becomes plagued with wars in counterinsurgency operations, the F-35 routinely gets compared to the A-10. In reality, critics should compare the A-10 to the F-35. It is true that the F-35 will not bring a 30mm 1,100 round cannon to a CAS fight. Nor will it fly low and slow to the ground to cover ground forces. Nonetheless, the F-35 will bring lethality coupled with precision to accurately pinpoint unknown threats and destroy the enemy while minimizing collateral damage to friendly forces. The sensor suite of the F-35 provides situational awareness (SA) to F-35 pilots that have yet to be seen in any other fighter.

Similar to the F-22, the F-35's design maximizes its low observable advantage to gain the edge on the enemy.[27] It utilizes a proprietary radar absorbent stealth coating to mask its signature to the enemy. In addition, the aircraft incorporates an integrated airframe that minimizes its radar cross section through a variation of angular designs on the leading and trailing edges of airfoils. The F-35 is designed with low emissions avionics, and embedded antennas that reduce the overall electronic signature of the jet.[28] The intake and exhaust nozzle have been designed to mask the reflectivity of the engine blades. In addition, the aircraft was designed with internal weapons bays (although limited) to reduce the reflectivity of external stores. This feature gets the F-35 into any battlespace undetected.

The F-35's survivability is also enhanced with the incorporation of a distributed aperture system (DAS) which provides the pilot with a 360° bubble of battlefield information. Designated as the AN/AAQ-37, the DAS is designed to perform a myriad of functions to include detection and tracking of hostile missiles, day and night vision navigation, detection of weapons launch points, pilot sensor cueing, support of onboard weapons solutions and positional information of both friendly and hostile aircraft. The DAS is coupled with the onboard electro-optical targeting system's (EOTS) six sensors allowing the pilot to enter a hostile combat environment while the aircraft autonomously pinpoints threats in a matter of seconds – a function the A-10 could never do. The DAS demonstrated effectiveness during airborne testing by tracking five ballistic missile launched in rapid succession from a location unknown to the aircraft.[29] In addition, the F-35's DAS was able to locate a tank solely from its ballistic cannon fire, a key feature that will be autonomously distributed to both air and ground forces.

The DAS, paired with the F-35's APG-81 active electronically scanned antenna (AESA) radar, affords the pilot an unmatched lethal capability to locate and engage threats from greater distances. The AESA radar, unlike legacy mechanically scanned antenna (MSA) radars, replaces internal moving components that increase its overall reliability and processing time. The AESA does not require electronic servos to create a sweeping motion of a legacy radar dish, instead it uses electronic beam shaping to point its antenna in multiple directions, nearly simultaneously. Unlike older MSAs that would lock on to targets limiting its processing ability, the AESA uses a track while scan (TWS) function to engage multiple targets. Some MSA radars incorporate a limited TWS function but it requires targets to be in a specific beam width in order to locate them. Older TWS functions of legacy MSA radars tied up processing time; as the MSA searched for additional threats, it would have to "revisit" the previously tracked targets in order to maintain the target's positional information. Depending on the speed and maneuvers of threat aircraft, an MSA could easily lose a target as it maneuvers outside of the antenna beam width. The TWS function of the AESA allows the radar to identify and maintain positional SA of a target while simultaneously sweeping the area for additional targets through the use of adaptive beam forming (ABF).[30] ABF gives the AESA the ability to create multiple radar beams to track targets thus eliminating overall radar search time. The F-35 demonstrated the remarkable ability to identify and track nineteen targets in under three seconds, a function that would take a legacy MSA radar several minutes![31]

As AESA radar technology was developed in the early 2000s, a function known as space-time adaptive processing (STAP) was understood but minimally harnessed.[32] Radar designers realized that the AESA radar's beam shaping could be utilized to counter electronic-attack (EA) by emitting lower radar signals in the direction of a jamming platform. Furthermore, the AESA could be optimized to function as a jammer by emitting high amounts of radar energy towards radar equipped vehicles. The designers of the F-35 capitalized on this once fledgling technology to increase the F-35s lethality. The jet can precisely locate unknown threats with its DAS, jam and suppress the threat through beam shaping of its AESA and then target the threat with a combination of its AESA and EOTS. The F-35's APG-81 proves to be a radar unmatched to date. Its ability to autonomously track multiple targets and display information in a user friendly format tremendously reduce pilot workload. The reduction of moving components increased the radar operational reliability rating to 99% with a lifetime expected to outlast the airframe.

Not only did the designers enhance the technological advantages of the aircraft, but they also incorporated the technology into pilot performance. F-35 pilots are equipped with custom fitted carbon fiber and Kevlar helmets that integrate as another tactical display. The F-35 is not equipped with a traditional heads-up display (HUD) but rather uses a helmet-mounted display system (HMDS) to fuse necessary flight information directly in front of the pilot's eyes. What makes the F-35 HMDS standout is the ability to seamlessly incorporate basic navigational information with tactical employment information. The F-35s DAS merges the six onboard cameras of the EOTS into the HMDS enabling the pilot to see a true 360° perspective around the aircraft.[33] A pilot could look directly at the floor of the jet and literally see right through it with this technology. The HMDS rids the pilot of cumbersome helmet-mounted night vision goggles (NVGs) that once took up valuable cockpit space. The HMDS provides unparalleled SA by combining a virtual HUD with digital night vision technology through its DAS, enabling rapid sensor cueing and target designation.[34]

In conjunction with the HMDS, the F-35 incorporates an 8"x 20" panoramic cockpit display (PCD). The design of the PCD was refined by Dr. Michael Skaff, a former F-16 pilot who's worked on the F-35 cockpit design for Lockheed Martin since 1995. The PCD is a contiguous screen that is interactive for the pilot through touchscreen, cursor placement and voice recognition technology.[35] The philosophy behind the PCD is minimizing the pilot's workload of administrative cockpit duties and giving pilots more time dedicated to performing tactical tasks. Pilots are able to configure the displays in accordance with their viewing preference of tactical information needed for employment. Lockheed started the design of the Mission Reconfigurable Cockpit (MRC) in the 1990s and incorporated this technology into the F-35.[36] The MRC not only gives the pilot viewing options, but also optimizes the pilot's overall performance through information dominance.[37] Information dominance is defined as, "A condition that results from the use of offensive and defensive information operations to build a comprehensive knowledge advantage at a time, place, and on decision issues critical to mission success."[38] In other words, information dominance gives the F-35 required tactical data versus available tactical data. Being able to decipher information quickly with a high degree of accuracy speeds up pilot mental processing and offers rapid tactical employment, a powerful advantage over the enemy.

The F-35 continues to set the bar from its enhanced digital electronic suite to its holistically integrated cockpit features. Pilots will appreciate the ease of information gathering and simplicity of tactical employment through the efficient use of technology. However, with all of the technology combined, the F-35 has seen several setbacks that arouse causes for concern. Military officials, civilian contractors and congressional delegates closely monitor the health of the F-35 program to ensure that setbacks don't create a drastic landslide for failure.

Causes for Concern

The F-35 program boasted extraordinary reliability, compatibility, sustainment and commonality. The program initially experienced failures with the Autonomic Logistics and Information System (ALIS) to streamline parts procurement. Its commonality between other fighter pilots is under modification as the F-35 only communicates effectively with other F-35s. Lastly, its commonality has decreased based on the multiple airframe variants and service requirements. Regardless of the concerns, Northrop Grumman is providing fixes to address these issues as they arise.

The Autonomic Logistics and Information System (ALIS) was designed to be a seamless behind-the-scenes health monitoring system that predicted F-35 spare parts requirements to support the aircrafts overall sustainability. The ALIS was designed to take the man out of the loop with regards to parts procurement. Recent testing has shown that the ALIS experienced multiple false positives and parts reporting and assessment was inaccurate.[39] The international supply chain was also lacking due to the failure of the ALIS to accurately forecast long range stock requirements leading to an overall shortage of spare parts on hand. Additionally, the time required to download the information is a one for one time swap – a one hour flight, takes one hour to download. Lockheed Martin is aware of the deficiencies and is developing a solution to bring human interaction back in the process as well as a digital solution with ALIS 2.0.2, scheduled to be released in June 2016.[40]

The F-35's proprietary technology puts its leaps and bounds above any other fighter aircraft. In the joint battlespace, the US relies on rapid communication to maintain the leading edge of lethality. The F-35, with its vast array of information gathering technology, operates on a datalink known as Multi-function Advanced Data Link (MADL). The stealth F-22 operates on

Inflight Data Link (IFDL). The majority of other combat assets, both air and ground, operate on a network known as Link-16. These differing communication networks offer limited interoperability and compatibility between networks. A stealthy 5th generation F-22 can't openly communicate with a stealthy 5th generation F-35 and both fighters are built by the same company.[41] Link-16 enabled fighters can't openly gather targeting information collected by F-35s. In order to operate effectively in a joint environment, tactical military machines must have rapid communication compatibility and be able to share time critical information to harness the US military's full potential. Several options are being developed to provide a link between platform communication suites.

As a multi-role fighter platform, the F-35 is also lacking in one major area – weapons load out. Its design incorporates the use of an internal weapons bay as well as external pylons that can be mounted underneath the wings for additional "hardpoints."[42] Regrettably, the internal weapons bay is only capable of carrying two air-to-air missiles and two air-to-ground bombs.[43] In order to take advantage of its maximum combat payload, the F-35 must sacrifice its stealth and maneuverability by mounting weapons underneath the aircraft wings. This modification gives the aircraft two additional stations for missiles, and four additional stations for bombs. However, the downside of additional weapons is the time consuming maintenance associated with stealth parametric tests and configuration upload and download times. As a comparison, the USAF's premier multi-role fighter, the F-15E, is capable of carrying fifteen air-to-ground munitions along with four air-to-air missiles.

Much like the issues with compatibility, the F-35's commonality was drastically reduced throughout its development. Once boasted as a 70-90% common airframe between the A, B and C variants, has realistically evolved into a 30% commonality as seen in Figure 3.[44] Each variant has morphed from service requirements changing the overall dimensions and internal components. The USMC variant, with its VTOL requirement is the most drastic of variants incorporating a shaft-driven lift fan and full variable rear nozzle to enable vertical take-off. Each F-35 shares mirror commonality and "cousin" commonality between each other. The takeaway is the regions shaded in green which are common between all variants.

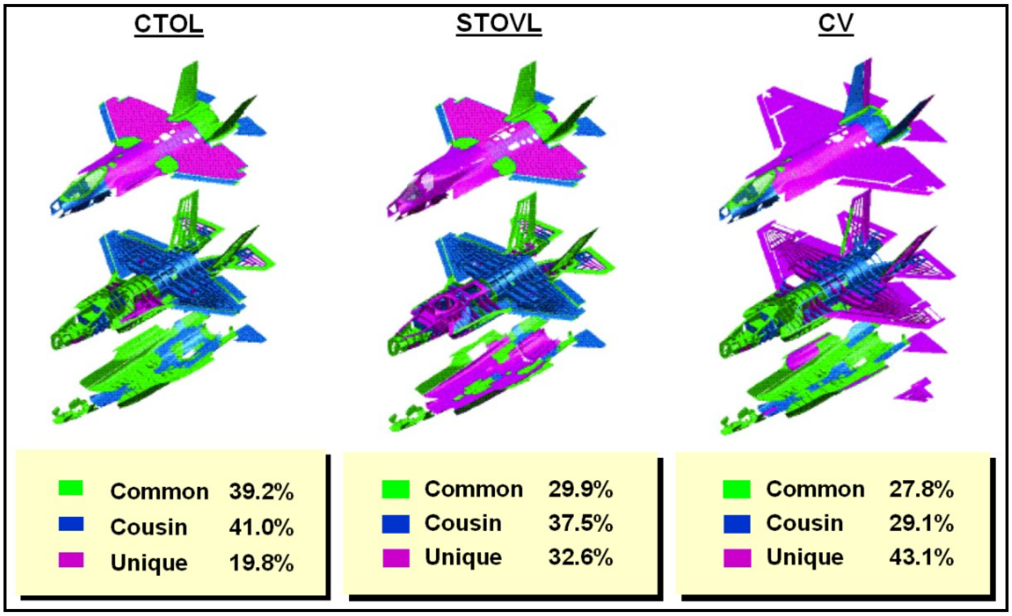

Figure 3. Commonality Comparison

The F-35 operational testing programs also identified more major causes for concern to include ejection seat issues for pilots under 135 pounds; redesigned bulkheads due to cracking on the F-35B; a catastrophic engine fire resulting in $50 million in damage; fuel over-pressurization problems; and slow software development.[45] Additionally, the bulk of technological development went into the F-35 as an integrated weapons system but the F-35 needs updated air-to-air missiles and air-to-ground bombs. As concurrency testing continues, F-35 program managers and designers must identify issues that arise from testing and also proactively engage in the development of advanced integrated weaponry to maximize its potential.

Defending the Way Forward - Conclusion

Humans are naturally resistant to change.[46] Psychological and social uncertainties make us want to maintain our comfort zones. The problem with this natural resistance comes the inability to see how constructive change can be. Instead humans sometimes approach change with an extreme eye of scrutiny, shedding negative light on the unknown as it is compared to the known. This mindset can lead one to reject not just change, but innovation, and the F-35 is proving to be the innovation that many don't see eye to eye with.

According to the University of Wisconsin – Milwaukee (UWM), there are several factors as to why people resist change. Those factors include unclear guidance, changing established patterns, lack of communication about change, unknown benefits of change, and unknown organizational changes.[47] Furthermore there are characteristics of innovations that affect its acceptance in an organization; in this case, innovation being the F-35 and the organization being the US military branches. As related to the F-35, those characteristics include relative advantage, simplicity, trial, measures of effectiveness, and expense.[48] So you may pose the question, "What does human behavior have to do with the F-35?" The answer is simple, if the characteristics of an innovative product are unknown, doubt is cast with regard to the feasibility of its procurement.

When it comes to the characteristics of innovation, the F-35 receives multiple venues of negative media attention which provokes the general population to question the government's feasibility in defense spending. Without a solid background in tactical fighter aviation, it is challenging for civilians and congressional delegates to see "relative advantage."[49] UWM states that innovations with relative advantage must be viewed as making a "significant improvement" over current applications. In other words, the benefit of the F-35 must be so great that it is undoubtedly worth its associated costs. With federal budgets and known US deficits, the F-35 program is more often perceived as a money pit with insignificant gains.

With budget implications on the forefront, the F-35's simplicity, trials, and measures of effectiveness also come under question. As mentioned in its history, the F-35 is a melting pot of advanced programs that date into the early 1990s. Its complex roots in multiple program cancellations and continued procurement complicates its simplistic presentation to congressional delegates and the DOD. An innovative product must be "easy to understand" otherwise it is critically viewed as too complicated causing supporters to lose enthusiasm.[50] Simplistic views also tie into ease of trials and measures of effectiveness. The F-35 program experienced several setbacks to spark causes for concern to Congress and the DOD. These setbacks portray the aircraft as a trial and error procurement process; as one problem is fixed another arises. It makes proving its measure of effectiveness more challenging as it faces public discredit and scrutiny.

Lastly, the most criticized characteristic of innovation that routinely makes negative press is the expense of the F-35 program. The cost of technology is always a challenging hurdle to cross, not only from the price of procurement, but also from the cost saving measures that accompany it. Making budget cuts from one program to bolster another can bring negative attention; this is where aircraft like the A-10 garner support. The current war on terrorism showcases the A-10s relative advantage, its simplistic employment capability, and proven track record of effectiveness. When compared to the F-35, the A-10 is drastically inexpensive.

What must be remembered is that the F-35 is not for today's fight, but tomorrow's uncertainties. It is capable of executing beyond the front lines of battle undetected. Although designed with a limited weapons load out, it makes up for it with information collection and sensor fusion. The F-35 makes better utility of other platform's weapons with precise information sharing. Aircraft that are unable to locate ground targets, or unable to identify air threats can now be tasked with precise targeting coordinates to maximize the probability of destruction on the first strike. Operational planners must bring this view into planning cells when determining an effective force ratio of 4^{th} and 5^{th} generation fighter integration. Much like the F-22A and F-15C/E fighter integration tactics, the F-35 should be tactically and operationally integrated to best utilize its sensor fusion technology in a stealthy configuration while sharing time sensitive targeting information to other fighters. Planning considerations should include a risk assessment of utilizing the F-35 as a breacher in high threat arenas to target integrated air defense nodes in order to enable the flow of follow on forces. The practicality of using the F-35 with external ordnance should be considered only in environments where stealth capability is not required. Future conflicts with near peer aggressors will stress the need for every possible advantage, making stealth and sensor fusion a higher priority than bulky external munitions. The F-35 is well equipped to "quarterback" in an environment of enemy concealment, denial, and deception.

In order to assist in the adoption of innovation, Lockheed Martin must maintain an open dialogue with DOD F-35 program managers as to the status of the aircraft. They must demonstrate the need for the F-35 and its applicability. If a need is demonstrated, people will gradually become more accepting of the technology. Additionally information must be presented in a manner that coincides with federal budgetary discipline. A strict timeline must be maintained in order to keep costs as close to projection as possible. If the aircraft experience unforeseen delays and setbacks, potential buyers could back out if they perceive inevitable issues or increased costs associated with development. Finally, the aircraft must prove itself. Quite often the DOD is reluctant to put its most capable asset at the tip of the spear. Once the services declares the F-35 operationally capable, it must be quickly integrated into combat operational planning to bolster its credibility and capability.

The F-35 experienced multiple setback from financial surprises to technology glitches. Nonetheless, the F-35 has grown into a 5th generation fighter that is unmatched by any competitor. The F-35 program offices maintain strict accountability with government contracting and further aircraft development. As of December 2015, Lockheed Martin delivered its 45th F-35 to the DOD: 26 –USAF, 8 – USMC, 8 – USN, 1 – Italian AF, and 2 – Royal Norwegian AF. General Joseph Dunford, USMC, Chairman of the Joint Chiefs of Staff, declared IOC for the USMC's F-35B squadron, VMFA-121, in July 2015. The USAF is still on track to declare IOC by August of 2016 and the USN is set to be IOC between August 2018 and February 2019.

Undoubtedly the F-35 receives criticism from all angles. The high visibility of its budget woes the general public and makes headlines for defense spending. Although comparisons of the F-35 have been made against the F-4 program and the A-10's capability, the F-35 continues to set performance records incomparable to legacy fighters. Its unique integration of avionics creates a machine that reduces pilot workload while accurately assessing its own environment. Pilots claim that the aircraft is easy to fly and incorporates a sensor fusion that is easy for transitioning pilots to get accustomed to. The once highly trained Harrier pilots learning to fly in the highly sensitive STOVL configuration of the AV-8B are a thing of the past. F-35B pilots in the USMC simply push a button to enter STOVL mode, pushing forward on the stick sends the aircraft down, pulling back brings it up. According to former Harrier pilot Captain Jonathan Thompson, "The F-35B is designed to be very intuitive in hover mode…the F-35B hover technique is just as easy to learn and just as easy to become second nature."[51]

Throughout all the negative press attention that the F-35 receives, it truly reveals itself as an unmatched 5th generation fighter. The complex roles of legacy aircraft being replaced will be distributed across the DOD to ensure that specialized missions are unhindered. The F-35's digital interoperability and sensor fusion give US warfighters the upper hand in both air-to-air and air-to-ground combat. F-35s will make once cumbersome and time consuming tasks, like locating an unknown threat, a thing of the past. At one time in history, F-4s flew low altitude reconnaissance missions in Vietnam in search of surface to air missiles (SAMS) below 100 feet, at speeds in excess of 600 knots only to come back with little or no results. A-10 pilots today, fly below 500 feet between 250-300 knots visually looking for the direction from which artillery fire is pinning down friendly forces. Once the F-35 enters the battlespace, those once white knuckled fighter pilot tactical tasks become a thing of the past. The F-35 will autonomously locate the sneaky SAM operators, it will instantly display and classify the unknown artillery system and it will pinpoint the exact location of friendly forces it's supporting. Critics say what they'd like, and although not combat proven yet, the F-35 will pave the way for 5th generation capability and capacity for years to come. As quoted in October 2015 from the House Armed Services Subcommittee on Tactical Air and Land Forces, "Modernization is critically important to our Air Force…Air Forces that fall behind the technology curve fail, and in modern warfare, if the Air Force fails, the Joint force fails."[52]

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