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1. AGENCY USE ONLY (LEAVE BLANK)		2. REPORT DATE	3. REPORT TYPE AND DATES COVERED <i>STUDENT RESEARCH PAPER</i>
4. TITLE AND SUBTITLE <i>THE F-35 JSF: BEGINNING OF THE END FOR BLUE-WATER OPS?</i>		5. FUNDING NUMBERS <i>N/A</i>	
6. AUTHOR(S) <i>LIEUTENANT COMMANDER BRADY M. HATCHER, III, USN</i>			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <i>USMC COMMAND AND STAFF COLLEGE 2076 SOUTH STREET, MCCDC, QUANTICO, VA 22134-5068</i>		8. PERFORMING ORGANIZATION REPORT NUMBER <i>NONE</i>	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) <i>SAME AS #7.</i>		10. SPONSORING/MONITORING AGENCY REPORT NUMBER: <i>NONE</i>	
11. SUPPLEMENTARY NOTES <i>NONE</i>			
12A. DISTRIBUTION/AVAILABILITY STATEMENT <i>NO RESTRICTIONS</i>		12B. DISTRIBUTION CODE <i>N/A</i>	
ABSTRACT (MAXIMUM 200 WORDS) <i>WITH THE RECORD AND PROPENSITY FOR ENGINE FAILURE AND THE POSSIBILITY OF AN ENGINE BEING DAMAGED BY INGESTING DEBRIS, THE RESULT OF SWITCHING TO A SINGLE-ENGINE AIRCRAFT FOR THE NAVY'S PRIMARY FIGHTER, THE LOCKHEED MARTIN F-35 LIGHTNING II JOINT STRIKE FIGHTER, CAN ONLY RESULT IN DECREASED PROJECTION OF POWER ACROSS THE HIGH SEAS IN THE FUTURE.</i>			
14. SUBJECT TERMS (KEY WORDS ON WHICH TO PERFORM SEARCH) <i>STOVL, JSF, USMC, F-35, OMFTS</i>		15. NUMBER OF PAGES:	
		16. PRICE CODE: <i>N/A</i>	
17. SECURITY CLASSIFICATION OF REPORT <i>UNCLASSIFIED</i>	18. SECURITY CLASSIFICATION OF THIS PAGE: <i>UNCLASSIFIED</i>	19. SECURITY CLASSIFICATION OF ABSTRACT <i>UNCLASSIFIED</i>	20. LIMITATION OF ABSTRACT

United States Marine Corps
Command and Staff College
Marine Corps University
2076 South Street
Marine Corps Combat Development Command
Quantico, Virginia 22134-5068

MASTER OF MILITARY STUDIES

TITLE:

**THE F-35 JSF:
BEGINNING OF THE END FOR BLUE-WATER OPS?**

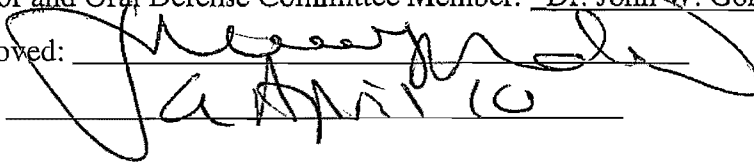
SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF MILITARY STUDIES

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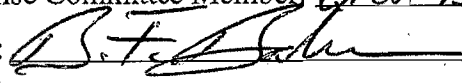
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Executive Summary

Title: The F-35 JSF: Beginning of the End for Blue-Water Ops?

Author: Lieutenant Commander Brady M. Hatcher, III, United States Navy

Thesis: Single-engine aircraft have long been considered unsuitable for Naval Aviation, but now the future of blue-water operations is dependent on the success and reliability of an aircraft powered by a single engine, the Lockheed Martin F-35 Lightning II Joint Strike Fighter.

Discussion: The future “tip of the spear” for Naval Aviation will be the Lockheed Martin F-35 Lightning II Joint Strike Fighter. Although this fifth-generation fighter has an impressive array of technology and attributes, it is hampered by the fact that it only has one engine. There are two engines currently being designed for the F-35. One is the F135 manufactured by Pratt & Whitney, and the other is the F136 manufactured by the GE Rolls-Royce Fighter Engine Team. The nature of Naval Aviation requires redundant systems to increase the reliability and survivability of its aircraft. However, the ability of the Navy to conduct blue-water operations and project power abroad will be hampered by an aircraft which has no redundancy to a very key component, the engine. The record of naval mishaps and accidents show that engine failure, whether due to a malfunction or the ingestion of debris, is inevitable and will occur. Therefore a single-engine aircraft will hamper the operability of the Navy using this platform.

Conclusion: With the record and propensity for engine failure and the possibility of an engine being damaged by ingesting debris, the result of switching to a single-engine aircraft for the Navy’s primary fighter, the Lockheed Martin F-35 Lightning II Joint Strike Fighter, can only result in decreased projection of power across the high seas in the future.

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Preface

I have always been interested in Naval Aviation. Even as a young boy growing up in rural Alabama, I would lie on my back in a field of grass and watch as jets would fly a low level route at 500 feet overhead. Years later I would fly that exact same route as a flight student and as an instructor, my dream to be a Naval Flight Officer came to reality.

I am very interested and concerned for the future of Naval Aviation. The dual-seat supersonic jet fighters currently in service are already reaching the end of their service life. Even now the choice is the Super Hornet FA-18F or nothing for us “double anchor” fighter types. Perhaps one day, the UAVs will replace us all, but I think not just yet. For now, we will place the future of Naval Tactical Aviation (TACAIR) to a single-engine, single-pilot aircraft and hope that technology will save us. That is if we can afford the jet at all.

Most of my research involved data obtained from online databases. It is difficult to find info on the impact of future blue-water operations for the JSF since predicting the future, especially the nature of war, is always elusive. However, I have gained insight on naval strategy from many published authors and have pieced together an opinion, base on the current and historical facts, on what is yet to come.

I would like to thank my mentor, Dr. John W. Gordon, for his guidance in every step of completing this thesis. Without his help and advice, this paper would not have been possible. I would also like to thank Col Damm, who as a single-engine F-16 pilot as well as a dual-engine F-4 and FA-18 pilot, was able to provide valuable insight to the safety and reliability of both platforms in a valuable personal interview.

And most of all thank you to my wife, Joanne, for her patience, love, and understanding during this year while I was a geo-bachelor at Marine Corps Command and Staff College.

Introduction

Naval Aviation has always striven to increase the safety, reliability, and survivability of its aircraft. The U.S. Navy is determined to decrease aviation accidents, or mishaps, and produce an organization that is virtually mishap free. Although achieving an accident free branch of the military is impossible due to human error and the great stresses placed on machines and systems, the overall theme of naval aviation safety is to find ways each year to improve upon safety, equipment, and training in order to decrease the number and severity of accidents compared to past years. One of the most dangerous aspects of Naval Aviation is blue-water operations. Blue-water, or "high seas," ops are the act of launching and recovering aircraft from a carrier in open seas. Some of these operations occur in locations that are too far from land for a damaged or disabled aircraft to be able to divert to a land-based airport. Though many single-engine aircraft have been employed successfully in the history of carrier aviation such as the A-4, A-7, and F-8, the last was the A-4 Skyhawk flown by Fleet Composite Squadron Eight (VC-8) retired at NAS Oceana on 23 August, 2003. As opposed to their obsolete predecessors, dual-engine naval aircraft typically have the ability to land aboard in single-engine mode with sufficient thrust to safely conduct a carrier arrested landing. Manned strike fighter aircraft could be replaced by Unmanned Aerial Vehicles (UAVs) if the performance of this next generation of aircraft is found lacking. Manned aircraft, however, offer flexibility and adaptability that endow certain cruciality to aviation that cannot be replaced by a UAV. Single-engine aircraft are undesired for carrier use due to their lack of redundancy during a single-engine failure, but the future of blue-water operations is dependent on the success and reliability of an aircraft powered by the single engine Lockheed Martin F-35 Lightning II Joint Strike Fighter.

The F-35 will be the world's most formidable fifth-generation strike fighter. A fifth-generation fighter is characterized by its capability to operate in a network-centric combat environment along with low radar signatures or stealth capability. Fifth-generation fighters also exhibit new developments such as thrust vectoring, composite materials, supercruise (the ability to cruise at supersonic speeds without afterburner), as well as integrated avionics to improve pilot situational awareness.¹ The F-35 will be more technologically advanced and more capable than any other strike fighter in the world, utilizing a "first look, first shot, first kill" mindset. A strike fighter is a dual-role tactical aircraft capable of conducting both air-to-ground (strike) and air-to-air (fighter) combat operations. However, designed from the start with affordability in mind and conceived as a relatively affordable fifth-generation strike fighter, the F-35 program has been plagued with issues that may result in a product that is incapable of performing all projected capabilities.

The Department of Defense states that the F-35 program "was structured from the beginning to be a model of acquisition reform, with an emphasis on jointness, technology maturation and concept demonstrations, and early cost and performance trades integral to the weapon system requirements definition process."² The F-35 will be bought in bulk by the U.S. Air Force, Navy, and Marines, along with nine other countries. The Lightning II is designed to replace a wide range of aircraft, including the Marine Corps AV-8B Harrier, Air Force A-10 Thunderbolt and F-16 Falcon, and Navy legacy F/A-18A/B/C/D Hornet. For the United Kingdom, the JSF will replace the Harrier GR7 and Sea Harrier.³ Eight allied countries are participating in the F-35 program under a Memorandum of Understanding (MOU) for the System Development and Demonstration (SDD) and Production, Sustainment, and Follow-On Development (PSFD) phases of the program. These countries include the United Kingdom,

Italy, the Netherlands, Canada, Australia, Denmark, Norway, and Turkey. Two additional countries, Israel and Singapore, are security cooperation participants that will also purchase the JSF.⁴

JSF Variants

The F-35 will be built in three different variations to meet the needs of three branches of the military. For the Navy, it is designed as a first-day-of-war strike fighter with high survivability to augment and eventually replace the F/A-18 Hornet. For the Air Force, it will be an air-to-ground fighter to replace the F-16 Falcon fighter and A-10 Thunderbolt attack aircraft and their corresponding missions. The F-35 will augment another fifth-generation fighter in the Air Force's arsenal, the F-22 Raptor. The F-35 will not be as stealthy as the F-22, nor will it be as capable in air-to-air combat. The Marine Corps is procuring the F-35B which will require the capability to conduct short take-off and vertical landing (STOVL) operations. The F-35B will conduct strike fighter missions and replace the F/A-18A/B/C/D strike fighter and the AV-8B vertical/short takeoff and landing (VSTOL) attack aircraft. The F-35 must be designed to provide all these capabilities to all three branches of the U.S. Military, as well as our allies, and become the "jack of all trades," (some would argue "master of none") world's primary strike fighter. While becoming the world's most advanced strike fighter, the JSF must conduct that role safely and reliably over the next three decades.

This requirement for three different designs has placed restrictions due to funding and technology on the overall designs of the three different variants of the JSF. For the Air Force, a conventional field take-off and landing (CTOL) model, the F-35A, will be built that will also incorporate an internal gun. For the Marines, a STOVL version capable of operation from small deck carriers and amphibious assault ships is required. The F-35B and V-22 Osprey tilt-rotor

aircraft are crucial to achieving a long-term Marine Corps goal for fielding an all-VSTOL Marine Corps aviation capability. However, the added space and weight of the mechanics required for the STOVL operation will render it impossible for the Marine version to carry an internal gun. An external gun for the Marine variant is an option, but will greatly reduce the stealth capability of the fighter. And for the Navy, the F-35C will be procured and will be known as the CV variant. CV is the naval designation for aircraft carrier. The Navy version will be supplied with reinforced landing gear to survive repeated hard carrier landings along with a larger wing area. This larger wing area is very beneficial in achieving good slow speed maneuvering characteristics which is required for recovery on an aircraft carrier at sea. The Navy version will also incorporate an internal gun. All variants of the JSF will be powered by a single engine.

Initial costs for the JSF were predicted to be affordable with over 90% of the parts designed to be interchangeable between the three variants in order to keep the costs down.⁵ The latest estimate for the U.S. forces is a predicted \$112 million.⁶ As costs for the JSF rise, it is predicted that fewer tax payer dollars will be afforded to research and development in improvements of the JSF power plant. If the fly away cost of the JSF continues to rise, engineers may be forced to make cuts that will reduce the reliability of this single-engine fighter. The program is currently \$38 billion over budget and is operating more than two years behind schedule.

Past and Present Naval Aircraft

Over the past few decades, the Navy has preferred to employ an array of dual-engine aircraft. The dual-engine setup adds a layer of redundancy and safety to the survivability of an aircraft. This desired configuration is based on the possibility that one engine of the aircraft

could fail. This failure could be the result of either a mechanical malfunction, manufacturer defect, foreign object damage (FOD), or combat ballistic damage. FOD damage could easily result in any manner of material being inadvertently ingested through the intake, destroying critical engine components such as fragile turbine and compressor blades in the process. On many such occasions, a fire or major malfunction is the result of the engine being shut down or being rendered useless to supply enough thrust to keep the aircraft airborne. A dual-engine naval aircraft which experiences an engine failure and is therefore reduced to operating with only one engine is still capable of maneuvering and landing with the thrust of the remaining engine. This level of redundancy is vital during operations where a naval aircraft would likely be operating hundreds of miles from a location to land at an airfield. A single-engine aircraft experiencing an engine failure far from shore or carrier would force the pilot to eject from the aircraft, resulting in a high chance of injury to the pilot and a guaranteed loss of a multi-million dollar aircraft. The rapid and forceful ejection process has been known to break limbs or kill the ejected aviator, or collide with other parts of the aircraft. Once ejected, the aircrew must be concerned with surviving the landing and water environment until they are rescued. Many times, naval aircraft operate over water temperatures that would allow human survival for only a few minutes.

This desire to avoid the loss of aircraft and lives has resulted in the use of dual-engine aircraft for their nature of safety and survivability. The current and former strike fighter naval aircraft were both dual-engine. The current model is the F/A-18C Hornet and F/A-18E/F Super Hornet. The Navy's former premier strike fighter aircraft, the Grumman F-14 Tomcat, was retired in 2006 and was also powered by either two Pratt and Whitney or two General Electric engines. The Navy shifted engine selection for Grumman F-14B/D fighters from the Pratt & Whitney TF30 to the General Electric F110-GE-100 for several reasons. The General Electric

engine was more powerful and less likely to stall than the Pratt and Whitney. But the major reason was that not only was the GE 110 a more powerful and reliable engine, it was also cheaper. As a result of an Air Force decision to award 75% of a one-year alternate fighter engine program contract to General Electric for the GE F110, high production rates for the new engine drove the prices down.⁷ The change to the alternate engine provided the F-14 with engines that were more powerful, reliable, less prone to stall, and cheaper than the Pratt and Whitney engines. This premise of providing a more reliable and safer engine alternative accompanied with lower cost through the competition between two companies will be an important factor for the single-engine F-35.

The argument for the safety and survivability of a dual-engine fighter can be defended by data from the Naval Safety Center. For FY09, there were two naval aviation safety incidents that resulted in a Class A mishap that could have resulted in the loss of the aircraft had the mishap aircraft been a single-engine variant. A Class A mishap is defined as an accident where the total damage is estimated as \$1,000,000 or more and/or involves destroyed aircraft and/or fatal injury and/or permanent total disability. The first mishap occurred with VX-9, the Navy's Aviation Test squadron. An EA-18G Growler, the electronic attack version of the F/A-18 Super Hornet, was nearly destroyed by a left engine fire during flight in 2009. The aircraft was able to secure the one engine that was on fire and land safely at Nellis AFB with the remaining engine without any injury to the aircrew. At VFA-122, the Navy's west coast Super Hornet training squadron, an F/A-18F also experienced an engine fire. The starboard engine was secured and the remaining engine allowed the aircraft to land safely at China Lake NAWS. In both instances, there were no fatalities, injuries, or ejections. If the same engine fire emergencies were to occur in the F-35, the

result would likely have been total loss of the aircraft, along with possible injury or death of the aircrew from the violent process of ejection or crash.⁸

JSF Design

There are currently two engines being developed for the F-35. Both engines are designed to be the most powerful of their type in the world. Both engines are in varying stages of research and development, and neither design has fully reached completion. Both designs are expected to produce over 40,000 pounds of thrust, making the F-35 the most powerful single-engine fighter ever.⁹ This requirement is primarily due to the Marine STOVL variant. The 40,000 pounds of thrust goal is based on the weight of the aircraft, crew, fuel, and average ordinance load. The only engine currently in the design phase that is fit for flight testing is the F135. The F135 engine, designed by Pratt and Whitney, consists of a 3-stage turbofan, 6-stage compressor, annular combustor, single stage high-pressure turbine, and a 2-stage low-pressure turbine. The alternate engine, which has always been a controversy for its feasibility and cost, is the F136 made by the Fighter Engine Team (FET) of General Electric and Rolls-Royce.¹⁰ The FET entry is a 3-stage turbofan, 5-stage compressor, a 3-stage low-pressure turbine section, and a single stage high pressure turbine. The F136 engine is very early in the System Development and Demonstration (SDD) phase.

The reason for the controversy surrounding the alternate power source for the F-35 is the tremendous added cost of designing an alternate engine. The \$430 million dollars needed to continue the development of the FET engine has been approved and is part of the 2010 Fiscal Year Department of Defense spending bill.¹¹ But the added initial cost to design an alternate engine will be offset by the savings experienced over the lifetime of the aircraft. The alternate engine is being designed to increase reliability, to lower costs, and to promote a competitive

condition between two manufacturers to produce the best and most reliable engine available. History has shown that the competition between two companies producing engines for an air frame will reduce overall long range costs an average of 20 percent.¹² The competition in the areas of research and development between the two companies would also be good for aviators wanting the best engine the Navy could afford, and not one just built by the only bidder.

Pratt and Whitney claims that the development, testing, and production of the F135 have been successful enough that an alternate engine is not feasible. The problems that caused the engine failures in 2007 and 2008 have been identified and fixes were implemented. Therefore, there should not be any technical problems that should arise which would render the need for an alternate engine.¹³ However, without hundreds and thousands of operational flight hours to back up these statements, Pratt and Whitney is relying on their engine being the only obtainable propulsion source for the Navy to conduct blue-water operations over the next three decades.

This alternate engine program is an important element of the future of blue-water operations. History has shown that companies competing for customer support over a particular product attempt to produce a better product at a better price. In the 70's and 80's, Pratt and Whitney, the same company that is submitting the F135 engine for the JSF, developed an engine for the F-16 Falcon known as the F100. This engine, however, was not well regarded by aircrews or aviation mechanics and was plagued by unreliability. At the time, the Pratt and Whitney engine was the only propulsions source in existence for the Falcon. As a result of poor performance and reliability, Pratt and Whitney was asked by Congress and the Department of Defense to rectify the shortcomings of the power plant for the Air Force's premier air-to-air single-engine fighter. However, the company was slow and reluctant to resolve the problem. They were so slow, in fact, that Congress asked another company, General Electric, to design a

new and improved engine. The result was what is to become known as the “Great Engine Race” between the two competing companies. The goal of the race was to design the best power plant for the Falcon in cost, reliability, and performance. General Electric is currently the world’s leading producer of small and large jet engines for civilian and military aircraft. At the end of the Great Engine Race, General Electric was able to produce a more reliable engine at lower costs, known as the GE F110. Another added benefit, the GE F110 engine was also used in other airframes such as the F-15 Strike Eagle. This increased the number of purchased engines and resulted in a decreased cost due to the American taxpayers.

The F-35 could also benefit from this healthy competition between companies. The resulting combined efforts put into the F135 and F136 engines could lead to a more reliable power source for the JSF. This added reliability is deeply needed by the single-engine fighter that eight countries are investing the current and future defense of their nation.¹⁴ Even with the troubled economy in the U.S., it would be of benefit to the tax payer and the aviator to have two companies competing for the best engine in price, performance, and reliability. According to GE, the F136 engine is on schedule and on budget, and should continue to be developed to make sure the best engine is available for the F-35 for decades to come.

It is interesting to note that the senior ranking officer of the Navy, the Chief of Naval Operations, Admiral Gary Roughead, is against the alternate engine plan. The basis of his argument was noted at the July 28, 2009 rollout of the first Pratt & Whitney F135-powered F-35C carrier variant. “I’m in the one engine camp,” said Admiral Roughead. “On a carrier, space matters.”¹⁵ While space on an aircraft carrier is extremely important and precious, the prospect has already been addressed by combining the EA-6B Prowler and F/A-18F Super Hornet into one airframe. As the Prowler is phased out and the EA-18 Growler is implemented, the space

from combining the Growler and Super Hornet in the same airframe and therefore using the same engine will provide space for alternate engines. Also, it is unlikely that the aircraft in a single F-35 squadron will be powered by different engine variants. For the F-14 Tomcat, which was powered by either Pratt & Whitney or a General Electric engines, entire squadrons utilized the same engine and therefore only needed one type of replacement during deployment. Even in the case of two Tomcat squadrons deploying on a single carrier, both squadrons utilized the same engine as in the case of VF-11 and VF-143 in their 2002 and 2004 deployments.

Money for the development of the F136 engine by Rolls Royce/GE has been approved for 2010. The Appropriations bill included \$465M for FY 2010 and was approved by Congress and signed by President Obama. This marks 15 years in a row that Congress has shown support for competing engines, and four years of support for the JSF project. The GE designed F136 has completed 550 hours of testing, with over 1000 hours projected by the end of 2010. Like the competing F135 engine, the F136 will be able to power all variants of the Lightning II. The F136 is a derivative of the F120 engine originally developed to compete with the F119 engine for the F22 program. The F135 is an engine that is derived from the F119 that Pratt and Whitney had already developed for the F-22 Raptor.¹⁶ President Obama and Secretary of Defense Gates initially wanted to cut the funding of the alternate engine due to budget deficits and rising defense costs.¹⁷ But, with the compelling historical proof of the advantages of an alternate engine, the facts have allowed the promising program to be funded for another year.

Major General David Heinz, former Director Joint Strike Fighter Program, said that he favors continuing production of the General Electric/Rolls-Royce F136 alternate engine, despite its added costs. "I believe that part of the debate that has to occur - and is occurring - is there an operational risk that we are accepting by having just a single engine manufacturer?" he says. "I

simply think that we focus too much of the discussion about the cost." The F-35 replaces the Lockheed F-16, Boeing F/A-18C/D and AV-8B fleets. A single safety-critical issue affecting the F135 could cause the Pentagon to ground most of its tactical airpower fleet, according to General Heinz and he expects the rivalry to lead to lower prices and encourage technology upgrades.¹⁸ General Heinz, however, was fired by Defense Secretary Robert Gates on 1 February, 2010, due to cost overruns and program delays.¹⁹

Comparison of JSF and Other Designs

It is no longer a question of if the Navy will accept a single-engine striker fighter for blue-water operations, for that decision has already been made. The Navy will purchase and utilize the F-35C version and replace the F/A-18C with this single-engine variant. But the switch will come with it some disadvantages for the naval aviators. When flying a single-engine aircraft that suffers from engine damage or failure, an aircrew only has a few seconds to troubleshoot a failed engine before having to make the decision to eject resulting in total loss of the aircraft. And in the case of the F-35C, that is an over \$100M decision that needs to be made under extreme duress. For a dual-engine aircraft, that split second decision can be transformed or delayed into a much more lengthy time period. While one engine can easily maintain stable flying characteristics, the other engine can be secured and diagnosed as to the cause of the malfunction through engine instruments and indications. An added benefit of a dual-engine aircraft is its capability of also safely landing on the carrier with only one engine, and having available thrust to climb away from the carrier for a missed approach, or "bolter." Such options do not exist with the single-engine F-35, where either the engine must be restarted almost immediately, or a violent ejection process and total loss of aircraft will quickly result.

It is the nature of the F-35 program to be forced to meet certain compromises. The F-35 is to be built in three different variants for the Air Force, Marines, and Navy. Lockheed Martin came to a conclusion that the only way to meet all requirements for all three variants was by employing a single-engine design. According to Steve Weatherspoon, Lockheed Martin's Deputy Test Verification officer for the F-35 Integrated Test Force, Lockheed has strived to increase the reliability of the F135 by improving the design of the sub-systems surrounding the engine. One of such sub-systems is the F-35's Integrated Power Package. The IPP and several other control systems provide constant backup power to the F-35. Similar redundancies are found throughout the aircraft to minimize risks. Lockheed and Weatherspoon are quick to point out that the reliability of single-engine fighters has significantly improved in recent years while mishap rates have gone down. Unfortunately, the mishap rate of the F135 in an operational capacity will not be determined until the engine is paid for, in the aircraft, and being launched off of a pitching deck into combat with one soul on board.

Single-Engine Comparison

While single-engine aircraft have come a long way with regard to reliability, there are certain conditions where no amount of research, development, or reliability is sufficient. On many occasions the loss of an engine due to external causes is inevitable. No measure of reliability or redundancy of systems or subsystems such as the Integrated Power Package will be sufficient to prevent an engine failure from external forces such as FOD or enemy fire. The single-engine aircraft, such as the F-16 Falcon, will always suffer from this vulnerability to external forces, no matter how technologically advanced and redundant its components are. Due to take off weight and emergency divert fuel requirements, naval aircraft will aerial refuel more

often than a land based aircraft. Therefore there is an increased risk of engine FOD during this hazardous evolution where two aircraft come in contact.

Another real and likely event is a precautionary engine shutdown. There are times when engine's instruments indicate that the engine is operating outside of normal parameters. The engine could also be showing signs of near or imminent failure by mechanically reacting abnormally, vibrating, or emitting unusual sounds. In a dual-engine design, the abnormally operating engine can be evaluated and secured if necessary. The single malfunctioning engine can be shut down and the problem diagnosed while the aircraft continues to aviate normally. If an engine with abnormal indications is not shut down, it could result in catastrophic engine failure, fuel leaks, and fire. With a single-engine design, there is no option for shutting down of one engine, only reducing power output to a minimum level to resume safe flight. At that point, the aviator is totally reliant on those internal advancements and redundancies that the engine designer has installed in his single-engine craft, and there is no option to secure the engine before catastrophic failure occurs.

The argument has been made that a single-engine carrier aircraft is just as safe, reliable, and survivable as a dual-engine carrier aircraft. The argument can also be made that the U.S. Navy has used single-engine aircraft in carrier aviation before, with varying levels of success. For example, the U.S. Navy employed the A-7 Corsair II and the A-4 Skyhawk into combat during the Vietnam War. Another fact is that both of these airframes, however, were replaced by a dual-engine aircraft such as the F/A-18 Hornet and F-4 Phantom. The consensus for going to two engines was increased survivability in case one engine was damaged from enemy fire or other damage such as FOD. Therefore, it would appear that reverting back to a single-engine fighter would be reverting back to a less redundant, less survivable system.

F-16 Comparison

There is a compelling argument that the new JSF only needs one engine to complete its mission. Some data refutes the argument that two engines are safer than one. The single-engine F-16 actually has a lower Class A mishap rate than the twin-engine F/A-18. The loss rates for the single-engine F-16 and the dual-engine F/A-18 Hornet have historically been essentially identical. One airframe typically experiences a few more or less mishaps than the other airframe year after year. For example, the single-engine F-16 has an average of 3.9 Class A mishaps for every 100,000 flight hours. The dual-engine F/A-18 Hornet has actually a slightly higher accident record at 4.2 Class A mishaps per 100,000 flight hours. Though the differences are very minute, it does show that a single-engine aircraft can operate safely and reliably without significantly higher losses of jets and aviator lives. A very important and pertinent fact that is left out; however, by those arguing for the case of single-engine safety and advocating the accident rate of the F-16 Falcon have forgotten is the nature of blue-water operations. An F-16 will never be catapult launched from the pitching deck of an aircraft carrier. Such an attempt would sheer the nose gear off, as it is not sturdy enough to withstand the tensile forces applied to the structure during a catapult launch. And an F-16 cannot survive a carrier arrested landing. Such an attempt would render the F-16 landing gear crushed under the weight and strain of a hard arrested landing. The F-16 landing gear components are designed for gentle flared landings and not the hard compression landings experienced repeatedly by an FA-18. So even though the F-16 has a comparable accident record, there are many other contributing factors such as salty, corrosive, and damaging environment the F/A-18 must endure for months at a time, which must be taken into consideration. In general, the F-16 operates in a much safer environment while Navy and

Marine aircraft should always have a higher mishap given the more hazardous environment that they operate in.

Lockheed Martin is required to complete a 5,000 sortie test program for the JSF by the end of 2013. As of July, 2009, it had only completed 100 sorties. Twelve more aircraft are set to be added to the test fleet and to start flying 144 flight hours and 12 sorties per month in 2011.²⁰ The F-35A, F-35B, and F-35C are scheduled to achieve Initial Operational Capability (IOC) in March 2013, March 2012, and September 2014, respectively; therefore, the Marine STOVL variant will be the first F-35 to be operational.²¹ The program is currently 30 months behind schedule, and only just entering the research and development tests and flight tests of the F-35B version. If history is any indicator, the program will most likely be plagued with more issues and fall further behind schedule along with added costs.

The question has been argued that a single-engine design actually decreases the probability that an engine failure will occur. The basis for this reasoning is focused on the fact that in a dual-engine aircraft, there are twice as many engines, thus twice the possibility that one of the engines will fail. Along with the second engine, there also comes along another set of components including fuel pumps, fuel lines, hydraulic lines, hydraulic pumps, engine control modules, fire detection system, and a variety of many other parts and components that must be added to the aircraft to support the extra engine. Not only does this add extra components along with their possibility of failure, but it also results in added weight. In the case of the F-35, it would also sacrifice much needed internal space. These added components for a second engine would affect the complexity, weight, cost, and internal volume of the aircraft and would render it unacceptable to the requirements set forth by the U.S. and the partner nations of the JSF program.

Dual-Engine F-35

A dual-engine F35 would utilize valuable space inside the fuselage. The stealth capability of the F-35 is dependent on keeping the fuel tanks and weapons internal to the aircraft in order to reduce the radar cross section and decrease the ability to acquire the F-35 on radar. The engine would replace area that could be utilized for fuel and/or weapons. One of the criteria the Navy was interested in when submitting requests for a new strike fighter was the need for maximum operating radius. By having a single engine, the F-35 can utilize the space for added internal fuel, thus maximizing range while maintaining the weapons and fuel internally to maintain the F-35's stealth characteristics. External fuel tanks will increase the radar cross section and eliminate the stealth characteristics of the F-35. As a carrier based asset, the F-35C requires enough fuel to achieve the range necessary to reach valuable targets located far inland. Therefore, the JSF will only have one engine, and a dual-engine configuration is not an option.

Impact on Blue-Water Operations

History has shown that converting between single and multi engine aircraft for Navy operations requires a change in tactics and employment. During the Korean War, some pilots switched over from fuel sipping, slow moving, more forgiving single-engine propeller aircraft to faster, fuel thirsty jet aircraft with less range and greater fuel consumption. These pilots, especially reserve aviators, switched over from single-engine WWII piston driven planes to twin-engine F2H Banshee and F3D Skynight jet fighters. They put themselves in unsafe situations since they were inexperienced with employing the new technology.²² Therefore when there is progress in technology the human element is required to learn how to employ the new tool to maximum efficiency.

The future of blue-water operation is extremely dependant on the success of the F-35. Chairman of the Joint Chiefs of Staff, Navy Admiral Michael Mullen told the Senate Armed Services Committee (SASC) during a fiscal year 2010 budget hearing that "we're in a real time of transition here in terms of future aviation. There are those that see JSF as the last manned fighter, bomber, or jet," Mullen said. "I'm one that's inclined to believe that. I don't know if that's exactly right. But this all speaks to the change that goes out...obviously decades, including how much unmanned we're going to have and how it's going to be resourced."²³ If the JSF turns out to be unsuccessful and unreliable, it will further fuel the fire on the argument for increasing the use of UAVs.

UAVs

Regardless of the success of the JSF program, the future of manned supersonic jet fighters may come to an end. Many aviators and scholars believe that is not the case and there will always be a role in manned tactical aviation. Dr. Colin Gray states that the person behind the machine is more important than the technology itself and that manned aircraft is too useful not to continue to be utilized.²⁴ Dr. Gray also states that people rather than technology are important and that the human dimension is the integral part of the weapon system.²⁵ Col Raymond Damm, a fighter pilot with over 4200 flight hours of experience, believes that "There will always be a place for some manned airplanes." Col Damm is a carrier aviator with firsthand experience with the dual-engine F-4 Phantom and F-18C Hornet as well as the single-engine F-16 Falcon. He states that single-engine fighters can be used in blue-water operations, but as with all aviation there is some risk involved. "The problem is the blue-water recovery piece," stated Col Damm. During an aircraft recovery cycle with no suitable divert in range of an aircraft with a failed or failing engine, the margin for error for recovering the aircraft along with the other aircraft trying

to land onboard the carrier presents a small window of opportunity which will increase the risk involved. However, single-engine aircraft have been employed by the Navy before, and it has been proven it can safely be done. As Col Damm stated, "You can do it, but there is a risk."²⁶

One factor that UAVs offer that a manned aircraft cannot is a guarantee of safety to the operator. The American public does not condone the loss of even one of its sons or daughters in combat, and the use of UAVs provide casualty free aviation operations. Also in consideration is the added cost and time of training a naval officer from flight school to combat operations, which could be greatly reduced by using UAV operators. "The nice thing about unmanned airplanes is there is no loss of life with UAVs and the cost," according to Col Damm.²⁷ The boom in the UAV industry has many aerospace companies across the globe coming up with new and innovative products in an attempt to gain the government contracts for supplying nation's military. The cost benefit and safety margin will be a significant point in the argument for replacing all manned fighters with UAVs.

Trying to predict the future reliability of the F-35 is difficult at best. The testing and development of the engines to date has not proven to be encouraging. Though the program is two years behind schedule, the F-35B, using the F135 Pratt and Whitney engine is actually capable of exceeding the thrust requirement to accomplish its mission. The requirement set forth for the F-35 to complete its mission, giving internal fuel and ordnance load was 40,550 pounds. The F-35 STOVL variant in tests has been shown to generate 41,100 pounds of thrust, thus barely exceeding the required minimum by only 550 pounds, even though it is the most powerful fighter jet engine ever. STOVL users will include the U.S. Marine Corps, the United Kingdom Royal Navy and Royal Air Force, and the Italian Navy and Air Force.²⁸

Other critics of the JSF have issues other than single-engine blue-water operations. At the time this paper was written, the JSF has yet to fly but 100 sorties of a 5,000 mission flight test program. And the JSF program is currently 30 months behind schedule, over budget, and an estimated 2,300-4,800 pounds above the initial empty weight goals. These delays and shortcomings do not bode well for the future of the F-35. If the program is having all these troubles now, how will the airframe fare once put into a harsh combat or carrier based environment?²⁹

Armament

Not only does the F-35 need to provide survivability, but it also must have lethality and the capability to project the force necessary to destroy or incapacitate the enemy. This leads us to another shortcoming of the F-35, the armament. The JSF does not carry as many missiles as some of its competitors such as the Eurofighter Typhoon or Sukhoi Su-35. The JSF is also inferior in speed and agility. For a fighter that will be the only U.S. air-to-air interceptor in the near future, this is not comforting news. The subject of the added protection of the stealth capability of the F-35 also comes into question. New radar systems currently under development, such as VHF radars, are being designed to detect stealth targets such as the F-35. These advanced radars may render the added cost of affording the JSF a low radar cross-section a complete waste of money and resources.³⁰

JSF Inlet Duct

An important design feature and vulnerability of the JSF is the inlet duct. The inlet duct for all three variants of the aircraft uses a bifurcated design. This version has inlets on both sides of the fuselage that merge together into a single inlet and then lead directly into the engine. The two inlets surround a large fuel tank on the CTOL and CV variants. Therefore, if the aircraft was

fired upon during combat and struck in the inlet area, the resulting ballistic damage would likely result in a fuel leak into the inlet. The leaking fuel from the fuel tank would be sucked down the inlet and ingested directly into the engine. Dumping any amount of fuel into the inlet of a jet engine is extremely hazardous, as fuel is not added to the air flow until after the compressor and turbine stages of a turbojet engine. The result is a rather explosive and disastrous effect. For a single-engine aircraft such as the F-35, this scenario is particularly dangerous. There was a series of tests conducted at China Lake to test the fuel ingestions tolerance of the JSF engine. The tests revealed that fuel ingestion through the inlet duct would have devastating results. Therefore, a liner that would seal a fuel leak in case of projectile damage was designed. After several phases of testing on various liner designs, one was actually developed that met the requirements of the airframe. However, the design was too heavy, and the entire plan had to be terminated.³¹ Therefore the F-35 design still suffers from survivability from being fired upon by anti-aircraft and small arms fire, which was of great concern and caused the loss of many aircraft during the Vietnam War. Since the specific characteristics of each war are different, the potential for ballistic damage to the F-35 in future conflicts could prove to be a limitation.

Cost

The F-35 program has an unfortunate trend of growing more expensive over time. For a plan that started out as the most affordable fifth-generation strike fighter available, it has only grown more expensive. Through FY2009, the F-35 has received an estimated \$44 billion in funding including \$37 billion in research and development and \$6.9 billion in procurement funding. As of 22 December, 2009, the estimate for the average procurement unit cost (APUC) divided by the currently planned for 2,443 production aircraft equals about \$112 million in FY2010 dollars.³² This is a considerable increase from the originally estimated \$30 to \$38

million for each aircraft. As the cost of procuring the aircraft increases, the concern for safety and survivability comes into question as the cost cutting measures start to whittle away at quality. Instead of getting the best parts, the program may end up with the parts with the best price.

Impact on Naval Strategy

By placing the future of naval strategy on the F-35, the U. S. Navy is reducing its capability by reducing the safety, reliability, and redundancy of a key component. According Dr. Colin Gray, “It is not possible to predict with total confidence the character of future warfare.”³³

This uncertainty on the character of future engagements places the reliability of the JSF in question. There is a possibility that some new technology or weapon could severely affect the application of a single-engine aircraft. Dr. Gray also mentions that one of the six potential factors that could weaken airpower contribution in war fighting is “inappropriate air assets,” which a single-engine aircraft in blue water operations very well could be.³⁴ Although the role of UAVs will continue to increase, especially in the area of surveillance and reconnaissance, the manned fighter will continue to be utilized for decades to come. According to Strategic Studies professor Dr. Colin Gray, “the manned aircraft is just too flexible, and therefore too useful, to be phased out of the defense posture.”³⁵

Future Carrier Air Wing (CVW)

According to some experts, the future of naval operations will depend on the restructuring of the Carrier Air Wing (CVW). In order for the Navy to meet predicted future obligations, there will need to be more strike capable aircraft on board each carrier. Currently, each carrier employs approximately 50 strike aircraft, but the possibilities of operations with China-Taiwan and North Korea call for a more robust number of air superiority aircraft such as

the JSF.³⁶ There is also a requirement for enhanced surveillance by both manned and unmanned systems. As of today, a carrier conducting blue-water ops lacks the capability to conduct long range Intelligence, Surveillance, and Reconnaissance (ISR), collect Communications Intelligence (COMINT), and provide full motion video.³⁷ This gap in situational awareness could prove to be a weakness in naval capability if not filled by an appropriate asset.

The primary role of the Navy, according to Admiral Malcolm W. Cagle, former Chief of Naval Education and Training, is not to support the land battle but the control of the sea.³⁸ For this purpose, it is crucial that the JSF be capable of operating in a blue-water environment. The Navy has been assured by the JSF program that advancements in technology will make the JSF engines more sophisticated and safer than previous ones. This assurance does not coincide with testing failures and delays associated with these “new technology” engines. According to Dr. Gray “the use made of technology is more important than is the technology itself” and “technological advantage tends to be fleeting.”³⁹ The stealth technology of the JSF may be advanced now, but new radar systems are being developed to counter this capability. Over time, new weapons and new systems will be added to the JSF. The increased weight will put more stress on the engine and therefore decrease the safety margin that this new technology is supposed to provide. In order for the JSF to be the tip of the spear of Naval Strategy, it needs to be able to meet the demands of future combat, and a single-engine will place limits on this critical component.

Conclusion

The Joint Strike Fighter program has been plagued by myriad problems over the course of its development. If costs continue to rise and issues continue to appear, it is questionable if the F-35C will ever see blue-water operations. The nature of future conflicts more than likely

consist of operations in remote areas of the world fought against non-state actors. For this purpose, the U.S. Navy must be ready with a blue-water capable fleet with the world's most capable strike fighter at the tip of the spear. If this spear tip turns out to be unreliable and unable to fulfill its mission, the primary role of the Navy to project power against foreign combatants will be compromised.

Even though Pratt and Whitney and others claim that technology has risen to the point that one engine can be relied upon to power an aircraft, history and the test record for the F135 engine do not support these claims. Numerous failures during the testing of the F135 engine have placed the program years behind timeline. The F135 is designed to put out more thrust than any engine of its size in history. The added stress to the components of the engine to produce this power has not shown to be up to the task during the design and testing phase. If a manufacturer's defect or fault in the F135 occurs, there is the distinct possibility that the entire fleet of strike fighters for the U.S. Air Force, Navy, and Marine Corps along with eight or more of our allied nations will be grounded. This is too much of a risk to put on a single component that affects so many.

The single-engine design in the F-35 Lightning II is a step back in safety and combat reliability, and a step forward in "buying in bulk" and saving money. Past single-jet naval aircraft have been replaced with multi-engine designs due to the amount of combat ballistic damage inflicted during Vietnam and later conflicts. The F-35 is a step forward in compromise because the design must meet the demands of the Army, Navy, and Air Force. It is a selection derived from the goal to get three branches of the armed forces to buy a single airframe that meets all of their requirements. The resulting single-engine design will be the limiting factor in the years to come.

However, as stated, single-engine fighters were embarked aboard aircraft carriers for decades, and they can be again. The Navy will need to learn how to employ the new capabilities of the JSF to reap all of the technology and benefits that it offers. The use of UAVs onboard carriers will also increase. UAVs provide a long range and loiter time to the ISR mission that manned aircraft cannot match. The compromise was made and the engine weight and internal space was traded for additional technology and fuel. But the manned fighter will continue to be a part of blue-water operations, and the Navy's mission to project power abroad will continue.

Endnotes

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