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The Need for a Permanent Gun System On the F-35 Joint Strike Fighter

by

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Abstract

Historically, the United States Air Force (USAF) concentrates on advanced or future weaponry when it develops advanced/next generation aircraft like the Joint Strike Fighter (JSF). However, some legacy weapons, such as an internal gun system, continue to prove they are still viable and are absolutely necessary if we want our future aircraft to have the flexibility necessary for the wide range of missions we expect them to perform.

This point of view is far from being unchallenged. There are many individuals and organizations within the Department of Defense (DoD) and the within the aerospace industry that think the time for a gun on fighter aircraft is long over. These organizations/individuals primarily point to the advancements in modern weaponry to support their point of view. For example, the advancements in precision weapons have provided the USAF with the ability to target virtually any target, in any weather, at any time. Additionally, the requirement to design, install and maintain a gun system on an aircraft does not come without additional expense. Space and weight are always significant details when designing a new aircraft. These issues are magnified when designing a stealthy aircraft whose signature is negatively affected by any moving part and any opening on the aircraft's precisely designed fuselage.

However, many people agree that all of these negative attributes are overcome by the flexibility and insurance that a permanent internal gun system offers. These individuals believe a gun system is a reliable, low cost, small logistical footprint system that offers effects unachievable by other weapons. Not including such a weapon would

not only be imprudent but would potentially prevent the F-35 Lightening II from achieving many of the missions it will be expected to perform late into the 21st century.

JSF Requirements

The goal of F-35 Joint Strike Fighter Program is to affordably develop the next generation strike fighter weapons system to meet an advanced threat (2010 and beyond), while improving lethality, survivability, and supportability.[1] From the United States Air Force's perspective, the F-35 will ultimately replace all F-16 and A-10 aircraft and will be tasked to execute all the missions these two aircraft currently perform. Although little debate revolves around this decision, there is significant debate concerning the JSF's Concept of Operations (CONOPS) and exactly how the aircraft will perform these missions. Additionally, the weapons that the F-35 will utilize to achieve the effects the USAF desires is also far from resolved. A significant point of contention has been the decision to include an internal gun system on the USAF version of the F-35A (CTOL or Conventional Takeoff and Landing).

The F-35 Operational Requirements Document (ORD) currently requires the gun system to have an accuracy of $\leq$ 3.1 miliradians and it must have a Probability of Kill (Pk) of .35 against lightly armored and thin-skinned vehicles at 9,000 feet of slant range.[2] In layman's terms, this means the gun system must have an accuracy of approximately 3 feet for every 1000 feet of range from the target. At 9,000 feet of slant range this means the gun must be accurate to within approximately 27 feet. Additionally, the JSF is required to have a fully integrated, cockpit programmable fire control system that accounts for the effects of wind and aim wonder on long-range air to ground employment opportunity.[3] Within the DoD's Joint Munitions Effectiveness Manual (JMEM), a publication that deals with data and methodologies for conventional weapons, it is

suggested that lightly armored and thin-skinned vehicles be targeted using a .35 Probability of Kill. By performing a 30-45 degree High Angle Strafe (HAS) attack at 9000 feet of slant range, the JSF will be able remain above small arms fire while achieving the desired Probability of Kill against these types of targets.

Additionally, the gun system must have an air-to-air capability that exists throughout the operational flight envelope.[4] The system is required to provide the pilot with an all target aspect, heads-up, computed sight solution at within visual range (WVR) ranges.[5] The avionics to support these requirements already exists in the F-16C, one of the aircraft the JSF is designed to replace, and should be an easy addition to the JSF's arsenal.

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1. *Joint Strike Fighter Operational Requirements Document* (Joint Strike Fighter Program Office, March 2000), 1.
2. Ibid., 17.
3. Ibid., 17.
4. Ibid., 17.
5. Ibid., 17.

A Historical Perspective

From a historical perspective, pilots have been using guns since the first aircrafts were used for military purposes. However, it was during World War I that the real necessity to control the air was first realized and the first real attempts were made to use gun systems to achieve these ends. "Early on, Lewis and Parabellum machine guns were mounted in the rear cockpits of two-seaters on flexible mountings."[1] However, these gun systems proved largely ineffective for several reasons. First, the extra weight of the additional airman and large mounted gun system slowed the aircraft down significantly. This meant, "the plane had no hope of overtaking lighter aircraft and single seaters."[2] There were also attempts to move the propeller aft of the cockpit so that a single pilot could fire a mounted gun system from directly in front of him. However, these "pusher" aircraft could not overtake a conventionally mounted "tractor" or front mounted propeller aircraft and therefore could not bring their guns to bear.[3] Another significant problem that had to be overcome was the unreliability of all gun systems. "It was necessary to keep guns within the reach of the pilot so he could do in-flight maintenance (usually with a ball peen hammer) to get his weapon going again.[4] All of these factors drove designers to keep gun systems mounted directly in front of the pilots. However, it was not uncommon for pilots to shoot apart their own propeller systems. This problem led to several ingenious solutions. France's Roland Garros used deflector plates on his prop, became an ace, was shot down and captured by the Germans and lost his device to them.[5] Garros' design "inspired Anthony Fokker to go one step further and create a mechanical synchronizer to interrupt the gun fire at the propeller blades to solve this problem."[6] "The use of the synchronizer, though acceptable for the time, was not a perfect

solution."[7] The system slowed down the gun's rate of fire and its size and weight took the place of critical ammunition and slowed down the aircraft.[8]

After World War I, the pace of development of aircraft and their gun systems slowed to an almost glacial speed for almost twenty years.[9] However, after 1935 there was an explosion in aircraft design and a dramatic improvement in armament. "The next decade saw the replacement of the biplane with monoplane aircraft of vastly greater performance."[10] Similarly, aircraft gun systems evolved to cope with faster and tougher targets by developing larger caliber weapons and increased rates of fire.[11] "The US Army Air Force (USAAF) responded by increasing the number of guns on its fighters and placing them all on the wings and retaining the .50-caliber Browning to the end of the war (and beyond)."[12]

After the many technological advances during World War II, there was little time for many more improvements to be made prior to the Korean War a mere five years later. However, the Korean conflict heralded in the jet age and the main air superiority fighter became the F-86 Saber armed with six improved Browning .50 caliber machine guns.[13] In fact, "all American fighters engaged in Korea came with .50-caliber weapons" until near the end of the war when the F-86F came into the inventory.[14] The F-86F was equipped with 20-mm weapons that were developed using German technology that had been improved upon since World War II. In any case, the dawn of the jet age did not change the basic gun attack tactic. The basic idea still involved "a stern attack using guns from as close a range as possible."[15] "Though the Korean War was fought with guns, the advent of the missile age was already afoot in the research and development community."[16]

"Research and development (R&D) on air-to-air missiles, both radar and infrared, commenced in the immediate postwar period and by the mid-1950s, such missiles were coming on line."[17] The first operational air-to-air missile was the Hughes AIM-4 Falcon, which came on line in 1956.[18] Soon after the fielding of the Falcon, the United States Navy developed the AIM-9 sidewinder and the AIM-7 Sparrow.[19] The AIM-9 is an Infa-Red (IR) missile that utilizes a target aircraft's IR exhaust emissions to lock on and home in on a target. The AIM-7, on the other hand, is a radar guided missile that guides to a target by locking onto the radar emissions generated by the host aircraft and reflected off the target. While early versions of the AIM-9 where only capable of being launched from the stern of a target, the AIM-7 gave fighter aircraft the ability to attack targets at all aspects. However, because of limitations in being able to identify (ID) targets Beyond Visual Range (BVR), the greater range of attack offered by a missile like the AIM-7 could not always be capitalized on.

During this same post war period there were advancements in gun design as well. The concept that showed the most promise involved building upon the Gatlin gun technology of the nineteenth century.[20] By using a multiple barrel design, engineers were able to achieve very high rates of fire while simultaneously spreading stress and increasing reliability.[21] This design ultimately evolved into the M-61 20mm Gatlin gun and soon became the gun system of choice on most of the century series aircraft. However, because of the massive retaliation strategy of this period, most aircraft were designed to either intercept high altitude nuclear equipped bombers or to deliver those weapons themselves. In both cases, most believed that because of the advancement in air-to-air missiles the gun was a weapon whose time had passed. Furthermore, this strategy

diverted funds from conventional programs and even led to the development fighter aircraft that had no gun systems at all.

Probably the most famous aircraft initially designed without a gun system is the McDonnell Douglas F-4 Phantom. Designed for the Navy and the Air Force, the F-4 was brought into the Air Force inventory to fill the air superiority role.[22] However, the close combat of Vietnam quickly highlighted the weak points of the Phantom.[23] Specifically, Sidewinder and Sparrow missiles had been designed to kill non-maneuvering targets not the agile North Vietnamese Mig-15, 17 and 21.[24] Additionally, the missiles were not instantly available to the pilot, they required a settling period before launch, and could not be utilized when the aircraft was pulling more than 2 to 2.5gs.[25] Perhaps worse of all, "the missiles had a minimum range of about half a mile before they armed themselves and began to guide."[26] This meant that aircraft inside of these ranges were immune from attack.[27] As a result, "the kill probabilities fell from a theoretical 80 percent to between 8 and 15 percent."[28]

To combat this shortfall, a 20 mm gun pod was developed that could be carried on the center pylon of the aircraft. However, this solution proved far from effective. Although a clean F-4 could stay with the much smaller North Vietnamese fighters, when the gun pod was hung on the center pylon it lost some of its performance advantages.[29] Furthermore, the gun pods were not nearly as accurate as the internally carried configurations.[30] To address these shortfalls, the Air Force developed the F-4E. The slatted winged F-4E had an internal gun system and better radar, which considerably enhanced its close combat capabilities.[31] However, the performance of air-to-air missiles

remained disappointing with only one out of every ten Sparrows and two out of every ten Sidewinders achieving a kill.[32]

"The participants in the Vietnam battles came away with many and varied ideas for the improvement of missiles, but an almost unanimous conviction that a gun would be required on air superiority fighters well into the twenty-first century.[33] As a result, "all USAF and USN fighters acquired since Vietnam have included a gun—all except the AV-8 and the A-10 have used the same M-61 Gatlin gun installed in the F-105 and the F-4E."[34] In fact the development of the F-15 and F-16, the backbone of the USAF fighter force since the 1980s, were designed to include a space for an internal M-61 gun system. These aircraft proved their worth during Operation Desert Storm in 1991. Although only 5% of the air-to-air kills accomplished during Desert Storm were accomplished using the gun, nearly half of the kills were still accomplished during Within Visual Range (WVR) engagements.[35] These results can largely be attributed to the lack of a completely reliable Combat ID system in addition to very stringent Rules of engagement (ROE). Furthermore, an analysis of the data indicates that it took slightly over 4.2 missiles to kill one target.[36]

Since Desert Storm, major advancements in missile technology, to include improvements to the Advanced Medium Range Air to Air Missile (AMRAAM), have increased performance and reliability. In fact, AMRAAM shots taken by USAF F-16s during Operation Southern Watch in 1992 and in Bosnia in 1994 represent the only air-to-air kills achieved by US aircraft since Desert Storm. Two points are worthy of note. First, both of these situations were accomplished by multi-role F-16s performing the air superiority mission. Upgrades made to the F-16 during the early 1990s, to include the

ability to carry AMRAAM and significant improvements to the aircraft's gun sight made it a very formidable air superiority aircraft. Second, all of these kills occurred during WVR engagements. Although this can also be attributed to very stringent ROE, the fact remains that USAF aircraft were not be able to utilize their BVR capabilities to their full extent.

However, the development of stealth technology stands as a staunch challenger to the idea that WVR engagements will continue to occur in the battles of the future. The F-22A was specifically designed to replace the F-15C as the USAF's premier air superiority fighter. To accomplish this mission, the F-22A relies upon stealth, super cruise, super-maneuverability and acceleration.[37] While stealth and super cruise will offer the F-22A the ability to see and shoot adversary aircraft long before it is vulnerable to their weapons, the requirements for advanced acceleration and maneuverability concede that aircraft designers and USAF pilots accept that it will occasionally find itself in a visual fight. In fact, if you examine the current F-22A concept of operations (CONOPS), pilot training program and currency requirements it is obvious that WVR fighting is expected to continue to occur. According to Lt Col Craig Baker, F-22A pilot, "its not an environment we want to be in, nor is it an environment we expect to be in that often, but we know that it will continue to happen and we have to be prepared."[38] Because of this, it should not be a surprise that the F-22A is equipped with the same M-61 cannon that has proven to be such an effective weapon for many of our legacy fighter aircraft. All of these factors suggest that regardless of technological improvements to aircraft, missiles and Combat ID systems, WVR merges will continue to happen.

Up to this point, our discussion has largely focused on the historical air-to-air uses for a fighter gun system. However, the significant role that fighter gun systems played in the air-to-ground role cannot be over emphasized. Strafing enemy positions began in World War I and with the birth of Close Air Support (CAS) in World War II the gun became a prominent air-to-ground weapon. Although advancements in bombs and rocket systems continued to make these weapons the premier ground attack weapon of the day, gun systems allowed fighter to continue to attack valuable targets long after their load of bombs and rockets had been depleted.[39] This persistence led to the destruction of many valuable targets in both theaters of war.[40]

During the Korean conflict, strafing ground targets continued to be an important tactic. While most of the attention went to the first dogfights of the jets age, bombing and strafing ground targets by propeller driven aircraft continued to be an important aspect of air-to-ground combat.[41] The Vietnam conflict saw a similar situation unfold. While the importance of a gun on the F-4 during air-to-air combat has already been discussed, the gun became a complimentary weapon against ground targets too.[42] Although increases in ground threats drove commanders to raise the minimum operating altitudes above those useable for strafe operations unless troops were in contact, "when ground forces were involved, and needed support, pilots pressed their attacks as low as possible to get the job done."[43] In short, pilots found the gun a godsend for lower threat ground target environments.[44]

Though limited, air-to-ground gun operations continued during the conflicts the United States found themselves involved in after Vietnam. From Operations Desert Storm to Enduring Freedom (OEF) and Iraqi Freedom (OIF) air-to-ground gun attacks

have continued to prove they are a critical tactic whose future is far from over. One example from Desert Storm occurred on when Major Jay Lindell used the M-61 gun system on his F-16 to suppress Iraqi regular army troops engaged with a compromised, nine-man, Special Operations Forces (SOF) team.[45] "Lindell cited the gun as the only weapon left at a time and place where time critical ordnance was needed on target to stop advancing Iraqi regular troops."[46]

A similar situation occurred during Iraqi Freedom in the winter of 2005. Captain Jon Vargas, a F-16 pilot with the 555th Fighter Squadron, used his gun to attack a moving vehicle loaded down with insurgents who were fleeing the scene of a brutal attack on Iraqi civilians. Because of the proximity of civilian structures/personnel and the target was moving at a reasonable rate of speed, the gun was the only option Captain Vargas had.[47] The attack disabled the vehicle, killed the insurgents inside, and caused no collateral damage.[48] In fact, during OIF and OEF the number of air-to-ground strafe attacks by US aircraft has increased significantly. For example, during a four month period in the winter of 2005, the 555th Fighter Squadron expended over 3,500 rounds of 20 mm High Explosive Incendiary (HEI) on ground targets in the Iraqi theater of Operations.[49] For an aircraft that can carry over 500 rounds of ammunition and can sustain a rate of fire of approximately 100 rounds per second that may not seem like very many employment opportunities. However, several things must be kept in mind. First, this data represents only one fighter squadron and only during a four-month period of time. During this same period of time, there were at least four USAF fighter squadrons operating within the Iraqi Theater of Operations and all of them were employing the gun with approximately the same frequency. Second, every gun employment opportunity

represents a tactical situation in which there were few, if any, other options. Although it may be impossible to determine the actual number of lives saved or the number of enemy killed, each of these situations represents a are very significant accomplishment for a weapon system considered out of date and out of touch with today's modern digital battlefield.

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42. Todd E. Denning, A Case Joint Strike Fighter, 61.
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45. Ibid., 37.
46. Ibid., 37.
47. Major John Vargas, Interview by author, United States Air Force Weapons School, Nellis Air Force Base, Nevada, 14 December 2006.
48. Ibid
49. Lt Col George Uribe, Telephone Interview by author, Tyndall Air Force Base Florida, 12 February 2007.

Current Status of the F-35 Gun System

Regardless of your opinion on whether of not the F-35 should have a gun system, the current status of system is anything but stable. Currently, Lockheed's plan for fulfilling the USAF's requirements involves installing a 25 mm gun systems (GAU-22) designed by General Dynamics. General Dynamics, formally known as General Electric, designed both the GAU- 8 30 mm gun system for the A-10 Warthog and the GAU-12 25 mm gun system for the AVVV-8B Harrier. Both of these gun systems have proven to be very reliable and have proven themselves during combat operations.

Although the original plan for the F-35 was to incorporate a 27 mm gun system, the system proved to be cost and weight prohibitive.[1] Therefore, in 2003 the decision was made to adapt the 25 mm GAU-12 for the JSF. However, this decision was far from trouble free and meeting the Joint Requirements Document (JRD) specifications has been tougher than expected.

The first issue that must be overcome concerns the systems accuracy requirements. As mentioned earlier, the gun system must have an accuracy of 3.1 mils (or 3 feet of dispersion for every 1000 feet of slant range). The problem is that total system accuracy is determined by several factors: the accuracy of the gun itself; the dispersion caused by the aircraft canopy; the dispersion caused by the pilot's Helmet Mounted Display (HMD); and the dispersion caused by the avionics projected on the HMD. To this point, the biggest limitation has revolved around the HMD. The F-35 will be the first jet fighter aircraft that does not incorporate some form of a Heads Up Display (HUD). As a result, all avionics that would normally be displayed on a HUD must be incorporated into the HMD. The HMD will project this information onto its visor and

will allow the pilot to see the information regardless of the position of his head. The problem is that any movement of the helmet on the pilot's head will cause the avionics to move from their actual position in space and lead to a reduction in the gun systems accuracy. Fortunately, Lockheed engineers and subcontractors continue to work the accuracy concerns. In fact, as of this writing, the HMD has made tremendous improvements and provides the pilot with a very secure, snug and comfortable fit.[2]

However, accuracy is not the only area of concern. The other aspect of gun system performance involves the air-to-ground Probability of Kill (Pk) specifications mentioned earlier. Currently, the F-35 Joint Program Office (JPO) is planning to certify the PGU-20 Armor Piercing (AP) combat round with a Depleted Uranium (DU) penetrator in order to meet Pk requirements. This decision was made because conventional 25 mm rounds do not meet DoD requirements.

A DU round is primarily used to defeat armor and works by utilizing kinetic energy penetration and by creating after-armor spallation. However, because DU rounds don't fragment like conventional rounds, they are ineffective against softer targets, such as aircraft, unarmored vehicles, and enemy personnel. The second area of concern involves the availability of DU rounds. The USAF does not currently own any DU rounds and the US Navy only has approximately 200,000 rounds.[3] Furthermore, the DU production line was shut down in the 1980s and there are no plans to restart its fabrication. Additionally, because of environmental concerns only one of the eight partner nations considers DU an acceptable option.

As a result of these concerns, the F-35 JPO has been forced to consider other types of ammunition. After a trade study in which five different rounds were considered,

the JPO seems to be leaning towards a Frangible Projectile (FRAP).[4] The FRAP round under consideration utilizes a tungsten penetrator and is dual-purpose (it can be used in the air-to-air or air-to-ground role). Also, because this type of round is being used in its 20 mm variant by some of our allies, it is considered to be a low risk option.[5] Just as importantly, the 25 mm FRAP round has the potential for a 5 percent and 25 percent increase in lethality versus armored and airborne targets respectively when compared to PGU-20.[6] The main reason for this improvement is a significant increase in the muzzle and sustained velocity that the FRAP enjoys. Additionally, this round removes the concerns of JSF partners because unlike DU and HEI rounds, it can be used on virtually any training range. The bottom line is that FRAP round offers an excellent option to mitigate current concerns about the DU and HEI rounds while simultaneously improving weapons effects against all targets, with the exception of personnel in the open.[7]

Another issue of concern involves the number of rounds the F-35 will be able to carry. During the development of any new aircraft, space and weight is always at a premium. Currently, Lockheed engineers claim that due to limited space there is only room for approximately 180 rounds for the 25 mm gun system. This is a significant reduction when compared to current fighters. For example, the F-16 can carry 510 rounds for its 20 mm gun system. Furthermore, the ORD requires that the "rounds carried must be sufficient to provide at least three operationally effective gun employment opportunities."[8] Lockheed is confident that by utilizing some advanced employment modes they will be able to meet the ORD requirements with only 180 rounds. For example, in the air-to-ground role this can be accomplished by offering an automatic employment mode. By locking the aircrafts sensors onto a target, the aircraft

avionics can then provide wind corrected steering and open fire cues to the pilot.[9] Avionics improvements like this will undoubtedly improve efficiency and lethality and will help mitigate the issues that such a small number of rounds present.

All of these factors -- system accuracy, round effectiveness, and the number of rounds carried-- offer challenges that Lockheed and the JPO must overcome if the F-35 gun system is going to be a viable weapon. While all of these issues are far from completely solved, the current road map appears to offer a plan that will allow Lockheed the ability to field the JSF with a gun system that meets or exceeds the DoD requirements established in the ORD.

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2. Ibid
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8. *Joint Strike Fighter Operational Requirements Document* (Joint Strike Fighter Program Office, March 2000), 17.
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US Navy and USMC Variants

Initially, the F-35 ORD had a specific "objective" requiring the Carrier Variant (CV) to have an internal or missionized gun and the United States Marine Corps (USMC) Short Takeoff and Vertical Landing (STOVL) variant to have an internal gun that is easily removed/installed and doesn't impact aircraft handling qualities/vertical landing performance when removed and doesn't impact internal/external weapons employment when installed.[1] Within the DoD Acquisition community there is a significant difference between a requirement that is labeled as a "threshold" requirement and one that is labeled as an "objective" requirement. A threshold requirement translates directly into a specification that the contractor will be graded on during the test and evaluation phase. An objective requirement, on the other hand, represents a capability that the contractor will do its best to accommodate. Objective requirements are not translated into specifications and are not generally measured during the test and evaluation phase. However, meeting objective requirements may lead to higher award fees for the contractor. Although the USAF lists an internal gun system as a threshold requirement, the US Navy and USMC listed their gun system as an objective requirement. From the beginning, the US Navy and Marine Corps seem to have attributed significantly less significance to an internal gun system that the USAF had listed as an objective requirement.

In any case, issues that appeared during System Development and Demonstration (SDD) led the Navy and Marine Corps to change their requirements. SDD for the STOVL variant were plagued with issues surrounding the weight of the aircraft. For any

STOVL type of aircraft weight is a driving factor in the aircraft's ability to perform the short takeoff and vertical landing maneuvers that give it its name. In fact, in 2004 weight issues with the STOVL became so severe that there was a real threat that the variant might be cancelled.[2] During several extensive weight reduction efforts the USMC agreed to modify it objective requirement and instead settle for a podded system that could be carried externally and removed or added depending upon mission requirements. Simply put, the USMC had to make significant capability trade offs in order to save the STOVL variant of the F-35.

A podded gun system offers one key advantage for the Marine STOVL variant. Simply put, a gun pod helps solve the weight problem the aircraft was suffering from. When the aircraft is operating off of Marine vessels and needs to be able to perform its STOVL functions, the gun pod can be removed if the aircraft's gross weight is to high for safe operations. When launching and recovering from land base airfields or when the aircrafts gross weight is not a factor, the gun pod can be added to the centerline station of the aircraft.

The US Navy, on the other hand, has mostly given up on the F-35 gun system for the CV. Although the gun system was originally only an objective requirement, issues with weight and space have largely caused the gun system to be abandoned. The US Navy's current plan is to utilize the gun system the USMC will use on the STOVL variant.

However, the gun pod solution has several disadvantages. First, the gun is not currently a primary weapon system and its not expected to be in the future. In other words, none of the CONOPS associated with the F-35 involve using the gun as its

primary weapon in any environment. In both the air-to-air and air-to-ground environment there are is no shortage of very capable weapons the aircraft will be able to employ in order to achieve the effects that are desired. The point is that the gun system is a weapon whose use is usually unexpected and often times the last and only option. For example, during the USAF's most recent conflict, Operations Iraqi Freedom, aircraft have used their gun systems to attack targets that could not have been attacked with other weapons.[3] Many times, due to collateral damage concerns and the proximity of friendly forces or non-combatants, even precision bombs cannot be used. Although the introduction of the Small Diameter Bomb (SDB) has helped to mitigate these concerns, and has been used in situations where older precision bombs could not have been utilized, these issues have not been eliminated. The gun, on the other hand, is a precision weapons that can be used in very close proximity to friendly forces, protected structures and non-combatants. The point is that you don't know when you will need the gun system and planning to only carry it "when its needed" is not practical.

The second reason that a podded gun system is not a good solution concerns the accuracy of such a solution. Historically, podded gun systems have not performed well. For example, as mentioned earlier, the F-4 was not originally designed with an internal gun system. One of the intermediate solutions to this problem was to design a gun pod. However, while it served to fix the tactical problem of not having a gun at all, the external carriage of the pod brought about increased parasite drag affecting the energy and maneuverability of the aircraft along with significant system inaccuracies.[4] Similarly, a 30 mm gun pod was designed for external carriage on the F-16 during

Operation Desert Storm. However, the gun pod was quickly abandoned because of a lack of accuracy and a lack of utility.[5]

A third concern revolves around the signature of the F-35. The F-35 is being designed to survive and operate on the battlefield of 2010 and beyond. The key to the aircraft's ability to perform in the challenging environment of the future is its low Radar Cross Section (RCS). For this reason, the aircraft is designed with two 2,000-pound class internal bays in which it can carry its primary air-to-air and air-to-ground weaponry. When anything is carried outside of the internal bays, it increases the aircrafts RCS making it more vulnerable to Surface to Air Missile (SAM) systems and other aircraft. Although engineers as Lockheed and General Dynamics are confident they can design a low RCS gun pod, many people within the USAF are unconvinced. In fact, as of this writing, no advancements have been made that would make the gun pod's RCS insignificant.[6]

Finally, the logistical impacts of a gun pod must be considered. While an internal gun pod requires very little additional logistical support, except for ammunition and the device used to load the system, a podded system creates additional logistical concerns. Current logistic requirements require that a 24 aircraft squadron have logistics footprint $\leq$ 8 C-17 equivalent loads.[7] Between the gun pods themselves and the additional equipment required to load/unload the pod, additional strain will undoubtedly be put on this requirement and the ability to maintain and sustain the force.

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1. *Joint Strike Fighter Operational Requirements Document* (Joint Strike Fighter Program Office, March 2000), 17.
2. Joseph Manion, Interview by author, Headquarters Air Force A3/5R, Pentagon, Washington, DC, 20 October 2006.
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4. Todd E. Denning, *A Case for the Joint Strike Fighter Gun (*Army General Command and Staff College, Fort Leavenworth, Kansas, 1996), 61.
5. Ibid., 106.
6. Joseph Manion, Interview by author, Headquarters Air Force A3/5R, Pentagon, Washington, DC, 20 October 2006.
7. Joint Strike Fighter Operational Requirements, 23.

An Air-to-Air perspective

Regardless of the historical record, the question of whether or not there is a still a need for a gun system on the F-35 must be answered. The USAF has prematurely attempted to burry the gun many times in the past and does not want to make the same mistake again. However, is there really a need for a gun system on such an advanced aircraft? Do we really expect to be "dog fighting" in the battle space of the future? Doesn't the advancements in missile technology and stealth technology make the gun obsolete within the air-to-air environment? All of these questions must be addressed if we are going to make informed decisions about the need for such a legacy weapon on such an advanced aircraft.

As defined by the ORD, the F-35 must be able to participate in a wide variety of operations from Military Operations Other Than War (MOOTW) to Major Theater War (MTW), including peacekeeping operations.[1] Specifically, the ORD requires the F-35 to be able to conduct the following missions; Attack Operations/Air Interdiction (AI), Offensive Counter Air (OCA), Close Air Support (CAS), Strategic Attack, Suppression of Enemy Air Defenses (SEAD), and Defensive Counter Air (DCA).[2] The air-to-air missions specified by the ORD, OCA and DCA, require the F-35 to be able to search, detect, track, ID, prioritize, and successfully engage up to six airborne targets simultaneously.[3] In order to accomplish that mission, the F-35 will carry several types of air-to-air weapons. Specifically, the F-35 will carry the future versions of the AMRAAM, the AIM-9X and an internal gun.

Although the AMRAAM is a very effective missile, capable of destroying targets BVR and WVR, a typical air-to-ground weapons load will only allow the F-35 to carry two AMRAAMs within its internal bays. However, if tasked solely in the air-to-air role, the aircraft is capable of increasing the number of internally carried AMRAAMs to four. The F-35 also has the ability to carry two wingtip mounted Aim-9X missiles that significantly improve its WVR capabilities. However, this increase in capability comes with the potential for negative impacts to the aircraft's RCS. Like the gun pod, engineers are confident that they can mitigate the negative impacts to the aircrafts signature, but these promises have yet to be realized. Ultimately, cost benefit analyses of carrying the Aim-9X will have to be made based on the specifics of each mission.

Therefore, in its most optimum air-to-air configuration the F-35 will be equipped with four AMRAAMs, two AIM-9Xs, and its internal gun. There is little doubt that this weapons load, the F-35's advance sensors/avionics and its RCS will provide it with the first launch and first kill capability in most environments and against most other aircraft. However, it is not hard to imagine situations where the F-35 does not detect or kill all the adversary aircraft it may encounter. The primary reason for this is that air-to-air missiles do not have a 100% Probability of Kill. Obviously, when faced with a reasonable number of low-tech adversaries the F-35 may achieve a kill with every BVR AMRAAM shot it takes. However, against advanced low observable adversary aircraft equipped with advanced Electronic Counter Measures (ECM), it is not hard to imagine a scenario where it requires multiple missile shots to achieve one kill. Furthermore, it is not hard to imagine a scenario in which the aircraft's missile supply is simply overwhelmed by a significant number of low-tech adversaries. If the F-35 uses all of its AMRAAMs in the

BVR environment and does not kill all the adversary aircraft, it must then decide whether to egress the area or engage in the visual environment. It's noteworthy that the F-35 does not enjoy the ability to super cruise or achieve the high top end speeds that its brother the F-22 enjoys. Currently, the F-35 ORD requires the aircraft to be able to accelerate from .8 Mach to 1.2 Mach in less than 55 seconds at 30,000 feet.[4] In addition, the aircraft's required top end speed is 1.0 Mach at sea level and 1.5 Mach $\geq$ 30,000 feet.[5] While these performance parameters are nothing to scoff at, they do not guarantee the jet the ability to egress from all fifth generation threats.

If the F-35 cannot egress away from a threat, then it must stay and fight in an environment where its stealthy signature is severely mitigated. Within the visual environment, the AIM-9X provides the F-35 with a formable capability. The AIM-9X is a lethal all aspect IR missile, especially when combined with the F-35's HMD, but like the AMRAAM it does not have a 100% Probability of kill. Like any missile, the Sidewinder is susceptible to countermeasures and defensive maneuvers and killing an advance adversary with one shot is undoubtedly a difficult task. Furthermore, once the JSF finds itself maneuvering against an enemy aircraft in a visual environment, it will be very easy to end up inside the minimum range of both AMRAAM and Sidewinder.[6] The type of WVR fighting the JSF is expected to pursue amplifies this situation. Because of the development of HMDs /Helmet mounted cueing systems and the abundance of High Off Bore Sight (HOBS) missiles, most visual engagements will result in aircraft remaining relatively close to one another. This is because the combination of these technologies frees the pilot from having to point the nose of his aircraft at his adversary in order to fire a missile. Even with advanced missiles, remaining close to your

adversary mitigates his ability to maneuver his aircraft in a position that is acceptable for a missile shot. According to Major Craig Baker, a F-22A pilot, "if you are fighting an aircraft with a HMD and a HOBS missile you've got to keep the fight close and look for a missile or gun shot."[7] Given all of these considerations, it's not hard to imagine the F-35 finding itself in an environment where it is out of missiles or not within missile parameters and completely dependent upon its gun system to defend itself and complete its mission.

However, it is not just the limited number of missiles and lack of acceleration/top end speed that may lead the JSF to find itself in a situation where it needs a gun system. As mentioned earlier, the F-35 CONOPS requires it to perform OCA and DCA. While performing both of these missions it is completely feasible that the F-35 may find itself in a situation where it is defending other assets, air and ground, which it cannot simply egress or run away from. In these situations, the aircraft may be required to stand and fight regardless of the number or type of enemy aircraft present. In these situations, you can never have enough air-to-air ordnance.[8] The internal gun system provides the F-35 with additional employment opportunities and may be just the extra firepower necessary to complete its mission.

Moreover, the F-35's gun system gives it a very reliable and effective counter air weapon. As it has been alluded to, air-to-air missiles are far from being 100% reliable. Although this can be due to several factors, missile reliability, counter measures and maneuvers, there are other factors to consider. Both the AMRAAM and the Aim-9X require other aircrafts systems in order to be employed. The AMRAAM, for example, will be cued to air targets utilizing the F-35s on board radar or Electro-Optical Targeting

System (EOTS). If the aircraft finds itself in a situation where either or both of these systems are degraded or not working properly, the ability to employ AMRAAM will be severely degraded if not impossible. Similarly, the Aim-9X requires either the aircrafts radar, EOTS or HMD in order to be cued to the desired target. Failures in any of these systems can significantly mitigate the pilot's ability to employ the missile. It's also important to note that several of these supporting systems impact the employment of both of the aircrafts primary air-to-air weapons. For example, if the F-35 loses it's on board radar or HMD, the ability to employ both the AMRAAM and the Aim-9X are seriously impacted and may make their use impossible.

The F-35's gun system, on the other hand, is not predicated on other systems and is extremely difficult to defeat. Although the HMD will make gun employment much more precise and accurate, it is not required for the pilot to employ the system. All that is required for an air-to-air gunshot to be effective is for the attacking aircraft to be in range, in lead, and in the same plane of motion as its target. Once the F-35 finds itself in the visual environment, being in range for a gunshot is dependent upon many factors such as both aircraft's speed, the aspect of the target aircraft and the type of ammunition being fired. However, with the proposed 25 mm gun system, it's safe to say that the F-35 will be within air-to-air gun range when it's within 5,000 feet of its target. Putting the F-35 in lead and in the same plane of motion as the target requires flying maneuvers that all JSF pilots will be trained to perform. However, it is worth noting that unlike the F-22, the JSF does not have an engine that utilizes vectored thrust. This will make it more difficult to maneuver to a position from which a gun employment opportunity can be taken. If the

F-35 was dependent upon a gun pod, the impacts on maneuverability would further complicate this situation and make a gun employment opportunity even more difficult.

Once the problems of range, lead and plane have been solved all that is required is that the JSF pilot put the aircrafts HMD gun sight on the target. The only way to defeat a gun shot like this is for the target aircraft to maneuver in such a way that it causes the bullets to miss. However, with today's advance predictive gun sights this is much easier said than done. The bottom line is that all the modern technology in the world cannot protect an enemy aircraft from the oldest weapon in air-to-air warfare. The gun is simple, efficient, effective and always available.

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1. *Joint Strike Fighter Operational Requirements Document* (Joint Strike Fighter Program Office, March 2000), 2.
2. Ibid., 2.
3. Ibid., 11.
4. Ibid., 21.
5. Ibid., 21.
6. Major Craig Baker, Interview by author, Headquarters Air Force A3/5R, Pentagon, Washington DC, 20 October 2006.
7. Ibid
8. Ibid

An Air-to-Ground perspective

Although utilizing the F-35's gun system in an air-to-air role is very plausible, the advantages a gun system offers in the air-to-ground role is even more beneficial. As we have seen, the gun has been a primary air-to-ground weapon since aviations conception. However, with the advent of more advanced bombs and missiles the gun has lost some of its prominence. The biggest factor in this change was due to the development of precision-guided munitions. Laser guided bombs and Global Positioning System (GPS) aided weapons have increased the accuracy, reliability and efficiency of air-to-ground weapons. On the other hand, there are many tactical situations in which the gun may not only be a good alternative, but the only viable option.

As previously mentioned, the F-35 has two internal 2,000 pound class weapons bays. Although the JSF can carry a wide range of weapons, a typical load-out will include two GBU-31s (2,000 pound GPS aided weapons), two AMRAAMs, and a fully loaded internal gun. Once the primary mission is accomplished and the two GBU-31s have been dropped, the only remaining air-to-ground weapon remaining is the 25 mm gun system. Should the F-35 encounter any other targets or be called upon to further contribute to the ground war, it would be completely unable to participate if not for the gun system. This situation is not hard to imagine. In fact, this exact situation has occurred many times during Operations Desert Storm, Enduring Freedom and Iraqi Freedom.[1]

However, it's not just the fact that the gun system provides the F-35 with additional air-to-ground weaponry that makes it such an important component to its

overall lethality. Another important consideration concerns the gun systems accuracy, lethality, and collateral damage control. It is often overlooked, but important to note, that like a laser guided or GPS aided munitions, the gun is also a precision weapon. In fact, because of its limited blast/fragmentation the gun can be used in many circumstances where other precision weapons would be prohibited or ill advised. In fact, gun employment has not been an uncommon event during the urban warfare often encountered during Operation Iraqi Freedom.[2] Concerns about the proximity of friendly forces or non-combatants and due to collateral damage issues, the gun has often times proven to be the only weapon that coalition aircraft can utilize.[3]

Furthermore, in many instances, the gun is the only appropriate weapon for specific targets. For instance, the USAF currently has very few effective weapons for attacking moving targets. Although the AGM-65 Maverick is ideally suited for attacking moving targets, it is not carried by all ground attack units and it is not well suited for many of the other targets encountered in urban warfare. Therefore, USAF ground attack aircraft rarely carry the Maverick Missile and must depend upon their gun systems to achieve the desired effects against moving targets. Additionally, a gun system equipped with High Explosive Incendiary (HEI) bullets is ideally equipped to attack enemy troops, especially when there are additional collateral damage concerns. In fact, attacking enemy troops and moving vehicles, such as Vehicle Born Improvised Explosive Devices (VBIEDs), with HEI bullets has become common during Operations Iraqi Freedom and Enduring Freedom.[4]

Furthermore, it is important to note that an aircrafts gun system can also be used to suppress rather than kill a target. In many circumstances, the desired effect is to

suppress an enemy's action rather than destroy a specific target. For instance, it is not uncommon to have difficulties identifying a target and confirming that it meets all the requirements required to perform an attack. However, if some sort of action must be taken in order to protect friendly forces or assets, a gun system allows an aircraft to make a "warning shot" in order to suppress the actions of potential enemy forces. During Operation Iraqi Freedom, members of the 555th Fighter Squadron found that "warning shots" were very effective at preventing potential enemy suspects from fleeing areas of violence and allowing ground forces to detain/arrest the individuals.[5]

Another important aspect to consider during this discussion is the reaction time that a gun system offers pilots. Although employing other types of precision weapons can be accomplished in a reasonably quick manner, they do not compare to the rapid fashion in which the gun can be used to attack a target. Laser guided bombs, for example, require the pilot to find the target within its targeting system, confirm that there are no obstructions that may inhibit the flight of the bomb or interfere with the laser, position itself for the attack, and then continue to laze the target throughout the bombs time of flight. In addition, weather or battlefield smoke and haze can prevent a successful laser guided bomb attack. When utilizing GPS aided munitions, unless the coordinates of the target is previously known, the pilot must either go through the process of generating the coordinates for the target using his targeting pod or wait for another off-board source to generate them for him. 'Self-generating" coordinates utilizing a targeting pod is not a lengthy process but it is not currently the most accurate method and tends to generate the most error. If a precision attack is required for success, an off-board source is the most accurate method. This method, however, can take anywhere from

several minutes to several hours depending on the ability to communicate with assets equipped with the proper equipment and capable of performing the required functions.

A gun attack, on the other hand, can be preformed in a manner of seconds. Once the pilot has acquired the target, either visually or with the aid of his targeting system, he can role in and attack almost immediately. Obviously, there are many targets that guided bombs and missiles can successfully attack, but on which a gun simply will have very little effect. However, when dealing with targets that are susceptible to gun attack, reacting quickly can undoubtedly prevent targets from escaping attack and will most definitely save friendly lives, ROE permitting.

It must also be pointed out that an air-to-ground gun attack can be performed without the aid of other on-board avionic systems. Like air-to-air missiles, air-to-ground bombs and missiles are dependent upon other systems in order for them to succeed. Laser Guided Bombs (LGBs), for instance, must be employed utilizing an on board targeting pod/system. The F-35 will use its EOTS to employ LGBs. If the F-35's EOTs is not functioning properly, it will be impossible to employ any type of LGB without help from another aircraft or some type of ground based laser designator. GPS aided munitions, like JDAM, are dependent upon the Global Positioning System in order to achieve the level of accuracy usually desired to achieve the desired effects. If the aircrafts GPS system malfunctions or the GPS signal is being successfully jammed or interrupted, JDAMs will not be able to be employed with any degree of precision. The F-35's gun system, on the other hand, only requires the aircraft's HMD to be functioning properly in order for it to be employed with precision.

A final important note revolves around the cost benefit analysis of carrying a gun system. As it has been discussed, the F-35 Lightening II will be the USAF's next generation multi-role fighter. Currently, the only true multi-role weapon that the F-35 will carry is its internal gun system. Although this weapon will most likely never prove to be the primary weapon in either the air-to-air or air-to-ground role, it is without a doubt a weapon that has an important role in both mission areas. Additionally, when compared to these other primary weapons, the gun system proves to provide the most benefit for the least amount of investment. For instance, a Laser guidance kit can cost upwards of $55,000 a piece and GPS guidance kits can cost approximately $18,000 a copy.[6] Air-to-air munitions, on the other hand are much more expensive with an AMRAAM or Aim-9X costing over $300,000 a copy.[7] The cost of the F-35s gun system, on the other hand, is included in the overall development cost of the aircraft itself. Moreover, sustainment costs for a gun system are minimal and typically only involve routine upkeep and inspections. Furthermore, the costs of bullets are nominal, especially when compared to the cost of the targets they are used to attack. Therefore, even if it is rarely unutilized, its hard to argue that from an economic perspective the gun system provides "more bang for the buck" than virtually any other air-to-air or air-to-ground weapon. For practically a one-time investment, the USAF will enable its F-35 fleet the flexibility and capability to attack virtually any target at anytime.

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2. Lt Col George Uribe, Telephone Interview by author, Tyndall Air Force Base Florida, 12 February 2007.
3. Ibid
4. Joseph Guastella, Telephone Interview by author, Operation Iraqi Freedom A3, Al Udeid Air Base, Qatar, February 2007.

5. Lt Col George Uribe, Telephone Interview by author, Tyndall Air Force Base Florida, 12 February 2007.
6. Air Force Link Library, The Official Website of the United States Air Force, http://www.af.mil/factsheet/factsheet_print.asp, February 2007.
7. Ibid

Conclusions

"The gun" has a long and storied history within the annuals of military aviation and, in one form or another, has been present since military pilots first took to the air. From simply using their own handguns to shoot at enemy aircraft, to today's modern Gatlin gun systems, the gun has proven to be an effective, efficient, and dependable air-to-air and air-to-ground weapons system.

Within an air-to-air environment, the F-35 may find itself within a myriad of situations. Although the USAF has spent a significant amount of money ensuring the F-35 will have a signature which provides it with the "first look, first launch" opportunity, there are undoubtedly situations in which the aircraft will find itself fighting within the visual arena. Within the visual arena, the aircrafts low RCS is largely mitigated and the aircraft will find itself on much more even footing with older or less technologically advanced aircraft. Although the AMRAAM and Aim-9X have significant WVR capabilities, the number of missiles the aircraft can carry and their inability to ensure success within the extremely close quarters expected to be present during future dog fights, makes an permanent, internal gun system more of a necessity than an option.

Furthermore, a F-35 gun system will be even more important within the air-to-ground arena. Although the development of laser guided bombs and GPS aided munitions have significantly increased the accuracy of air-to-ground munitions, there is still a significant limit on the number of weapons a stealthy aircraft can carry. Additionally, there will always be situations in which the F-35 needs a fast acting, precise

and low collateral damage weapon that only a gun system offers. Furthermore, in both the BVR and WVR environments, a gun system offers an offensive weapon that will be available regardless of the status of other aircraft systems. In short, the gun offers the F-35 an extremely reliable and simple to use "point and shoot weapon" that is always available to the fighter pilots of the future.

Recommendations

Historically, the USAF concentrates on the development of advanced or future weaponry when it develops advanced/next generation aircraft. However, some legacy weapons, such as an internal gun system, continue to prove they are still viable and are absolutely necessary if we want our future aircraft to have the flexibility necessary for the wide range of missions we expect them to perform.

When writing the F-35's Operational Requirements Document (ORD), the USAF went to great pains to specify all the capabilities the aircraft would require in order to perform in the future battle space. As of this writing, the Joint Program Office acknowledges it faces significant challenges in order to meet the requirements specified by the Service's in the ORD. Although many argue these challenges will be too costly or difficult to overcome, most within the Air Force's requirements community understand the importance of preserving the internal gun system on the F-35.

In order for this to happen the USAF should take the following steps: 1) "Hold the line" on the gun requirements currently outlined in the F-35 ORD. Regardless of the opinions of the USMC, USN or Joint Program Office, the USAF must not become dismayed or discouraged by the difficulties in achieving the capabilities it has determined it requires. Within the air-to-air and air-to-ground environments, the gun has proven to be a reliable and irreplaceable weapon. Even if Lockheed officially declares it will not be able to fully meet the requirements and specifications the USAF desires, disallowing requirement relief sends a strong message that the capabilities offered by the gun are not negotiable. 2) Direct the Joint Program Office to invest in the development of a 25mm

FRAP round. Although the USAF will most likely have to accept a conventional round when the F-35 achieves Initial Operating Capability (IOC), the advantages offered by the FRAP round can not be overlooked. Additionally, the FRAP round enables Lockheed to come much closer to achieving the requirements defined by the USAF and will make the gun system a much more capable weapon. The bottom line is that FRAP ammunition is a proven technology, is currently available, and should be utilized for the F-35. 3) Continue to fund Research and Development (R & D) for new forms of ammunition. Even when utilizing the FRAP round, the limited number of rounds the F-35 will be able to carry is undoubtedly a major weakness for the gun system. Although many of the advanced avionics capabilities the F-35 will possess will help mitigate the problems associated with carrying such a limited amount of ammunition, there are still other options available to the Air Force. For example, there is little doubt that future technologies, such as telescopic ammunition, will offer the F-35 the ability to carry many more rounds within the limited space it can currently attribute to ammunition storage. Improvements such as these will only make the F-35 an even more formable threat and must be investigated.

Finally, the USAF must not be timid or reluctant to continue to make its case for including an internal gun system on the F-35. Historical precedent, as well as careful analysis of the F-35's CONOPS, makes it abundantly clear that a gun system is not only required weapon, but also an absolutely necessary if the aircraft is reign supreme on the battlefield of the future. Without a doubt, any and all of the negative attributes discussed is this paper are overcome by the tactical flexibility and indemnity that a permanent internal gun system offers. Furthermore, there is no uncertainty that an internal gun

offers a reliable, low cost, difficult to defeat, fast acting, small logistical footprint system that provides tactical effects that are unachievable by other weapons. It would be completely imprudent for the USAF to pass up the opportunity to field such a weapon on the aircraft that will ultimately represent the backbone of the United States' combat Air Force.

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