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BACKGROUNDER

No. 3140 | AUGUST 4, 2016

Operational Assessment of the F-35A Argues for Full Program Procurement and Concurrent Development Process

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Abstract

The F-35A Lightning II's sensors, stealth, and overall capability have been defended by the government and industry, while pundits and politicians have concentrated on developmental issues, cost overruns, and maneuverability limitations. The F-35A is a generational leap beyond other multirole fighters, and thanks to concurrent development, its technology will be the freshest ever fielded. Its performance in an air-to-surface (attack) mode has been well accepted, but many have questioned the Lightning II's performance in aerial combat. Only the pilots who have flown the fighter actually know how well the Air Force version of the F-35 can perform, and the 31 who were surveyed for this paper expressed a high degree of confidence in this extraordinary fighter. The U.S. government should fulfill the entire programmed acquisition of the F-35A on its current schedule and apply the lessons learned from its concurrent development to every other major acquisition program in the future.

This paper will discuss benchmarks for classic fighter technology, maneuverability, stealth, and tactics. It will examine the F-35's faculties and compare them with the technology, performance, and cost of the generation of multirole fighters[1] that precedes it. That examination will reinforce the jet's faculties for the air-to-ground missions of all three F-35 variants:

- F-35A Conventional Takeoff and Land (Air Force);
- F-35B Short Takeoff/Vertical Landing (Marine Corps); and
- F-35C Aircraft Carrier-based (Navy).

This paper, in its entirety, can be found at **http://report.heritage.org/bg3140**

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Key Points

- The F-35 is an extraordinary air-to-ground platform. Its sensors outclass any other fourth- or fifth-generation multirole fighter, and the fusion of those sensors gives F-35 pilots unrivaled situational awareness in any mission arena.
- Even with current restrictions and G-limitations, experienced U.S. fighter pilots rate the overall air combat faculties of the F-35 as better than or equal to any other combat-configured fourth-generation generation fighter in the U.S. inventory.
- The F-35 is an expensive platform, but it is markedly more effective and in many cases cheaper than any other four-plus-generation multirole fighter in the world. DoD needs this system and needs to purchase the full Air Force program of record.
- Fighter and threat technology are growing faster than ever, and concurrent development is an exceptional method for fielding systems that keep pace with that growth. Program leadership is what needs to be overhauled.

All three are designed for different basing environments that affect the way each variant performs in the air combat arena. This paper will explore the handling characteristics and air-to-air performance of the Air Force version of the jet, based on the opinions of 31 experienced U.S. Air Force fighter pilots currently flying the Lightning II. Their depth of experience in front-line, fourth-generation fighters, as well as with the F-35A, delivers unrivaled perspective and confidence in this extraordinary fighter.

Evolution of Fighter Technology

The Department of Defense (DoD) has pushed the defense industry into a continuing quest for more speed, altitude, turning performance, and lethality of munitions—a quest that has defined the jet age. The lineage of jet fighters is generally classified in terms of five generations that are separated by significant leaps in the qualities of speed, weaponry, maneuverability, the ability to detect and engage targets, and/or the ability to mask detection by the opposition.

Global competitors are currently operating at near parity in fighter speed, as well as in range and lethality of weaponry. While follow-on generations of fighters may joust again in those two areas, this paper will concentrate on the remaining three categories: energy and maneuverability, detection of the enemy, and the ability to mask detection by the opposition.

Energy and Maneuverability (Em)

The ability to outaccelerate, outclimb, and outturn opposing aircraft has been a part of air combat since its inception. Jet engines were introduced in the 1940s, allowing the first generation of jet fighters to climb higher and fly faster than piston-engine aircraft. However, once those jets got in a turning engagement—or dogfight—their additional weight, coupled with the low thrust available from their archaic jet engines, was no more a match for the G-loads of aerial combat than their piston-engined predecessors were. As engine technology increased, so did aircraft weight, and while many second-generation fighters could fly faster than Mach 1, both first- and second-generation fighters were underpowered sports cars under the G-loading of a turning fight.

With the advent of longer-range missiles, beyond-visual-range (BVR) tactics came about that allowed fighters to engage adversaries before they merged, forgoing the need in many minds for turning fights. America entered the Vietnam War believing that the age of the missile was at hand, and many senior leaders thought the requirement for heady maneuvering and gun-toting aircraft was behind us.

It wasn't. F-4s were the first production fighters capable of Mach 2, but when paired against a poorly trained Vietnamese adversary flying often dated aircraft, the kill ratio was almost one-to-one in the early stages of the war. The services had removed much of the air-to-air dogfight training that pilots received, and the results were telling: The United States lost almost one fighter for every North Vietnamese kill that it claimed.

The U.S. Air Force and Navy moved immediately to hone air-to-air dogfighting skills and tactics that would change the kill-to-loss ratios considerably. By the end of the war in Vietnam, the need for skilled pilots and well-developed tactics was a lesson (re) learned. That lesson extended into the next series of fighter aircraft designs, which were centered on the ability to sustain high turn rates, requiring engines that delivered markedly higher thrust. Technological improvements, material, and weight reduction techniques delivered a fourth generation of aircraft with thrust-to-weight ratios that approached or exceeded one-to-one[2] in clean (non-combat) configurations.

Technology will continue to improve the ability of the United States to defeat adversaries' BVR. However, just as soon as it banks on the idea that capability removes the need for high energy and maneuverability, thinking enemies will respond. They will test the Air Force's mettle with counter tactics and technologies that cause us to endure a fate similar to the one we endured during Vietnam until they can catch up technologically.

1. Fighter aircraft designed and built to employ successfully in several different mission areas. The F-35A was designed for the missions of Defensive Counter Air (DCA); Offensive Counter Air (OCA); Intelligence, Surveillance, and Reconnaissance (ISR); Interdiction; Close Air Support (CAS); and Nuclear Strike (also known as Special Weapons).
2. "One-to-one" thrust-to-weight ratio refers to aircraft with motors that produce at least as much thrust (measured in pounds) as the aircraft weighs, allowing the aircraft to climb on a nearly vertical path and accelerate extraordinarily well.

Detecting Enemy Fighters

Fighters use many different methods to detect other aircraft. Passive detection systems are becoming more and more prevalent, but the technology used most commonly to detect enemy aircraft is a fighter's onboard radar. Radar has been around since the opening stages of World War II, but the first radars mounted in jet fighters were very limited in their capability.

Radar. First-generation jet fighters had no real radar detection capability. The F-86, made famous during the Korean War, relied on ground-based radars and controllers to guide pilots to a point where they could pick the targets up visually—a process known as Ground Controlled Intercept (GCI). Onboard radars were capable of providing precise range data for computed gunsights, but little more.

Second-generation air-to-air fighters were designed to intercept high-flying nuclear bombers, and the best of them could detect and lock onto fighter-sized targets at 15 miles. Detection ranges for third-generation F-4s and Russian MIG 21s were a bit longer and included the capability to fire radar-guided missiles, but both relied heavily on GCI to find the enemy, and most successful gun or missile engagements were tail aspect shots: attacking from behind an aircraft.

Fighters enjoyed significant improvements in detection range and clutter[3] resolution with the fourth generation. Aircraft like the F-15C realized detection ranges on fighter-sized targets in excess of 50 miles and could readily engage aircraft flying well below their altitudes for a true look-down-shoot-down capability.

In the late 1990s, Active Electronically Scanned Array (AESA) radars entered the fight, delivering contact ranges in excess of 100 miles. Fighters so equipped have a huge advantage over those with dated pulse-Doppler radars, and when mated with a medium-range air-to-air missile, they deliver quite a leap in capability. Having an AESA radar alone does not elevate a fighter to the fifth generation, but fourth-generation fighters that possess it along with one or two other improvements are often referred to as four-plus-generation fighters. Among "other" improvements, some four-plus-generation fighters possess unique passive detection capabilities.

Passive Detection. Aircraft of all types emit several different types of detectable noise. It makes sense that without care, radar emissions from an aircraft can be detected by opposing aircraft at least as far away from the source as the transmitting aircraft can detect enemy fighters. The Russian AA-10E Alamo missile is designed to exploit this by using passive radar homing to follow radar emissions from enemy fighters all the way to the source without relying on active radar returns from the firing aircraft from launch to impact.[4] What this implies is that the launching Russian fighter has at least a limited ability to "see" and launch on opposing fighters without emitting any radar emissions of its own.

The other sources of detectable noise are less well known, but with the radar example, they begin to come into view.[5] Two-way radios, some navigational aids, data-links, engine or airframe heat—anything that emits radio, radar, heat, or traceable light can be used by enemy radar sites, fighters, and surface-to-air-missiles (SAMs) to find, fix, and target aircraft. The three factors that determine the ability (and advantage) that one fighter has to detect another in any one of those arenas are:

- *Sensor* sophistication and sensitivity,
- *Sensor fusion* of detection sub-systems into a display that pilots can rapidly understand and digest, and
- *Stealth* and the target's ability to mask its own emissions or returns.

Sensors. Modern fighters have several sensors and sub-systems at their disposal. In addition to radar, they include radar warning receivers (RWR); Infra-Red Search and Track (IRST) systems; and passive coherent location systems (PCLS).

3. Fighter-generated radar signals bounce off the ground, and their returns create "clutter" that makes it hard for third-generation fighters to lock on to and engage aircraft flying below them.
4. Carlo Kopp, "The Russian Philosophy of Beyond Visual Range Air Combat," Air Power Australia *Technical Report* No. APA-TR-2008-0301, updated 2012, http://www.ausairpower.net/APA-Rus-BVR-AAM.html (accessed July 16, 2016).
5. David Axe, "7 Secret Ways America's Stealth Armada Stays off the Radar," *Wired*, December 13, 2012, https://www.wired.com/2012/12/steath-secrets/ (accessed July 13, 2016).

Radar warning receivers were developed following the first several U.S. aircraft losses to Soviet-made SA-2 missile systems in Vietnam. Pilots could see the missiles respond to the movements of targeted aircraft, so engineers designed a detection system for the radars that guided those missiles to their targets. They mounted archaic-radar warning systems on fighter aircraft and displays inside their cockpits. Once the systems were on board, aircrews developed tactics that would allow appropriately warned pilots to outmaneuver the missiles.

Initially, RWRs were directional and would merely tell pilots which clock position they should search for the inbound missile. Over time, engineers developed methods for estimating the range of known threats, and pilots and engineers working together developed methods to triangulate and bomb the location of SAMs. Anti-radiation missiles were developed, and the pairing was given to SAM-hunting units designated as Wild Weasels. That capability improved with the HARM[6] Targeting System (HTS) of the fourth-generation F-16CJ.

The HTS allows F-16CJs working in flights of two or more jets to triangulate and fire on SAM systems more rapidly by linking and processing the collective data of the formation of jets. The target location solutions that the HTS offers are so precise and timely that missile systems can frequently find and destroy enemy SAMs even after the sites shut down their radar emitters on word of inbound missiles. The HTS gives its pilots markedly elevated levels of situational awareness from both SAM and air-to-air threats, but it comes at a cost. The HTS "pod" is an external, un-jettisonable[7] modification to the F-16 that adds weight and a significant amount of drag to the jet's sleek lines.

Fourth-generation F-15Cs are now being modified for a next-generation electronic warfare suite called Eagle Passive/Active Warning Survivability System (EPAWSS). EPAWSS reportedly will give the Eagle sophisticated jamming, geolocation, target-identification, infrared threat-detection, and decoy capabilities[8]—a modification that is postulated to give the F-15C several fifth-generation faculties.[9]

The details of the F-35 threat-detection system or RWR are classified, but interviews of pilots who have flown both the F-16CJ and the F-35 state that a single F-35 has the ability to locate, identify, and triangulate emitter locations faster and with greater precision than can a flight of three F-16CJs that surround the emitter.[10] The associated systems work against air-to-air threats just as well and are all internal to the F-35, forgoing the need for external pods or stores that would slow down the jet or give it a larger radar cross section (RCS).[11] This system alone helps to make all three versions of the F-35 standouts in the air-to-ground mission sets of the multirole fighter community.

Infra-red Search and Track systems were developed for fourth-generation platforms. IRST systems search and even scan the forward hemisphere of equipped fighters for the infrared emissions of threat aircraft. Some systems incorporate a magnified optical sight system to help pilots visually identify target aircraft at significant distances. The Eurofighter Typhoon's PIRATE IRST reportedly can detect unshielded, subsonic fighters approaching at high aspect (head on) at 30 nautical miles.[12] These systems possess equipment and algorithms that can provide the range to detected threats but are significantly hampered by weather and atmospheric conditions.

The F-35 Distributed Aperture System (DAS) is an IRST system with six ports that stare simultaneously in all directions. The DAS system is projected within and slaved to the Helmet Mounted Display (HMD), allowing pilots to perform near-

6. High-speed Anti-Radiation Missile.
7. "Un-jettisonable" equipment is equipment that the pilot cannot jettison from the aircraft in flight, including the HTS pod, Targeting Pod, Electronic Countermeasures (ECM) Pod, and bomb and missile rails.
8. Kris Osborn, "Air Force Updates F-15 Fleet's Radars, Sensors," *DoD Buzz*, March 13, 2014, http://www.dodbuzz.com/2014/03/13/air-force-updates-f-15-fleets-radars-sensors/Military.com (accessed July 13, 2016).
9. EPAWSS is housed in an enormous external pod that will add considerable weight, drag, and RCS to the F-15C.
10. Personal interviews with three former F-16CJ pilots, each of whom stated this same line almost verbatim.
11. Radar detectability factor, measured in square meters of radar cross section.
12. Reinhard Zmug, "Der Eurofighter 'Typhoon' (VII)—Radar und Selbstschutz," *Bundesheer*, Folge 306, Ausgabe 6/2008, http://www.bundesheer.at/truppendienst/ausgaben/artikel.php?id=807 (accessed July 13, 2016).

spherical visual scans even when looking "through" the F-35 with 20/40 clarity, day or night. The DAS is enhanced by the Electro-Optical Targeting System (EOTS) that provides precision air-to-air scan and track, as well as a solid air-to-surface targeting capability. EOTS retains the aircraft's stealth and is linked to the jet's integrated central computer through a high-speed fiber-optic interface.

The two IR systems will automatically detect and display threats on cockpit LCDs and in the pilot's HMD. The IR spectrums associated with particular aircraft and missile systems are stored within the jet's algorithms, allowing the jet, in conjunction with other passive and active sensors,[13] to positively identify aircraft and/or inbound missiles from all directions, without limit to the number of targets simultaneously tracked.

Passive coherent location systems and systems with similar capabilities encompass a class of radar systems that detect and track objects by processing reflections from non-cooperative and perhaps unintended emission sources in the environment, such as commercial broadcast and communications signals.[14] With the right equipment and a powerful processor, equipped platforms can determine the location, heading, and speed of aircraft.[15] It is believed that high-end, fourth-generation fighters incorporated some form of PCLS in their systems,[16] and it would be a bad bet to wager against any fifth-generation fighter having this capability.

While each of these active and passive systems can significantly increase a fighter's advantage, there are drawbacks. Each system may well offer independent methods for finding and identifying target aircraft, but trying to incorporate several separate onboard system displays in a pilot's cross-check[17] and correlating that information can be a nightmare. Then there are the off-board feeds from aircraft within the formation and systems like Joint Surveillance, Targeting and Reconnaissance System (Joint-STARS); RC-135 Rivet Joint; and the Airborne Warning and Control System (AWACS). This is where sensor fusion becomes critical.

Sensor Fusion. Coupling the products of off-board feeds with a fighter's active radar, RWR, IRST, PCLS, and/or other passive detection systems into a single, correlated display can be a godsend for a pilot's situational awareness. It reduces cockpit cross-checks and delivers the kind of confidence that few fourth-generation platforms incorporate. While many four-plus-generation fighters incorporate sensor fusion, the magic within the F-35's fusion is the middle-ware that sits between the sensors and the displays. Once any sensor detects a threat, it will move to learn everything it can on the contact by cross-referencing every other onboard, off-board, and overhead sensor to identify (ID) it.

Coupling or fusing the ID signatures from each of the complementary systems into a reliable declaration of friend or foe will significantly reduce pilot workloads. It will also allow the United States and its allies to relax their rules of engagement, freeing pilots to engage enemies earlier and with greater effect. Bringing even some of that fusion into an HMD will give the associated pilot an advantage that will be hard to overmatch.

Those who are not read into its classified faculties can only speculate as to the specific components of and feeds within the F-35's system of systems, but the experiences of the pilots who were interviewed for this paper are telling. All but three of the 31 pilots interviewed noted "ghosts" (multiple display images for the same threat) and other glitches in sensor fusion, but all 31 expressed high confidence in the software and engineering modifications and improvements that they had witnessed to date. Each pilot also expressed confidence in the individual F-35 system components and the belief that sensor fusion was months away from delivering a remarkable system.

Stealth. Situational awareness (SA) is a pilot's real knowledge of the tactical situation around him

13. "In conjunction with" refers to sensor fusion, discussed in the next section of this paper.
14. GlobalSecurity.org, "Passive Coherent Location (PCL)," last modified November 7, 2011, http://www.globalsecurity.org/military/world/stealth-aircraft-vulnerabilities-pcl.htm (accessed July 16, 2016).
15. Tyler Rogoway, "Here's the First Shot of the F-15C Pod That Will Change How the Air Force Fights," Foxtrot Alpha, December 30, 2015, http://foxtrotalpha.jalopnik.com/here-s-the-first-shot-of-the-f-15c-pod-that-will-change-1750314539 (accessed July 13, 2016).
16. Defense Industry Daily Staff, "F-22 Raptor: Capabilities and Controversies," *Defense Industry Daily*, November 13, 2013, http://www.defenseindustrydaily.com/f-22-raptor-capabilities-and-controversies-019069/ (accessed July 13, 2016).
17. "Cross-check" refers to the visual scan that pilots make between multiple sensor displays, wingmen, threats, or any combination thereof.

TABLE 1

Fighter Jets More Detectable than Records Show

Jets use radar to track enemy fighters. Detectability is measured in square meters of radar cross section (RCS). Many fighter aircraft require external stores to conduct combat missions, so their commonly published RCS is generally much lower than their RCS in combat.

RCS IN SQUARE METERS, BY AIRCRAFT

Aircraft	Commonly Published	Actual Combat Configuration
B–52	100	Well above
F–15 (4th gen.)	25	Higher
F–16C (4th gen.)	1.2	Higher
Bird	0.01	n/a
F–35	0.005	0.005
F–117	0.003	0.003

SOURCE: GlobalSecurity.org, "Radar Cross Section (RCS)," http://www.globalsecurity.org/military/world/stealth-aircraft-rcs.htm (accessed July 18, 2016).

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or her. The quest to maximize your SA while denying an opponent's is unending. Denying an adversary's SA of what is happening in the air can be accomplished by using overwhelming numbers, cloaking, and maneuver/deception/subterfuge.

The U.S. gave up on the idea of flooding an opponent's radar (or air defense system as a whole) with mass numbers of fighters many years ago, choosing instead to use advantages in leading-edge technology and tactics and training to defeat the enemy. If either is accomplished effectively, fighters get nearly unlimited, unchecked moves while their opponents try to discern where they may have gone after the last maneuver they believe they witnessed. This is particularly valuable for multirole platforms tasked with the Weasel mission of suppression of enemy defenses or interdiction in a denied-access (heavily defended) area.

One way to do that is by denying enemy aircraft sensors the opportunity to detect other aircraft. For radar, the detectability factor is measured in square meters of radar cross section (RCS). RCS can be lowered by using special materials, construction, and fabrication techniques, but the process is extraordinarily complicated and expensive, and most stealth systems are very hard to maintain.[18]

It is important to realize that stealth is limited by an aircraft's initial design. Many fighters require external stores to conduct any combat mission, and the RCS of a clean jet[19] (the number commonly published for aircraft) is not the same RCS that those same jets will have when flying into combat. The RCS for combat-equipped fighters is generally much higher.

When it works, stealth is a game changer that will give those that have it a big advantage against the opposition. In mock dogfights, F-35As have repeatedly gone completely undetected by their fourth-generation adversaries, resulting in impressively high kill ratios. When stealth is incorporated into every surface and component on and within a jet, the effects upend the generational chart, rendering every non-stealth platform equivalent to the detection and engagement faculties of (at best) a second-generation fighter.

As of this writing, every fourth-generation or four-plus-generation fighter that faces the F-35A may hold the energy and maneuverability of high-end platform, but each will be left with the situ-

18. The fragile nature of the stealth exterior of the F-117A, F-22A, and B-2 required that each of those aircraft be hangered, and their care and continual maintenance requirements limited flying time and combat turn capabilities. The research and development that went into the stealth skin of the F-35 alleviates those requirements and limitations.
19. The term "clean" fighter refers to the airframe alone, with no additional external stores, fuel tanks, rails, racks, or missiles. Most fighter-sized targets in the 1960s and 1970s had radar cross sections (RCS) of six square meters or more.

TABLE 2

The Evolution of Fighter Aircraft

LEVEL COMPARABLE TO 5TH GENERATION

	1st Generation	2nd	3rd	4th	4th+	5th
Era	Korea	1955–1965	1965–1975	1975–1995	1995–present	2005–present
Speed	Subsonic jet	Mach 1+	Mach 1–2+	Mach 1–2+	Mach 1–2+	Mach 1–2+
Weaponry	Gun only	Gun and IR tail aspect missile	Gun and all aspect radar missile	Gun and all aspect IR + radar missile	Gun and all aspect IR + radar missile	Gun and all aspect IR + radar missile
Engagement	</= 1,500 feet	1–3 miles (tail only)	Limited all aspect	All aspect look down	All aspect look down	All aspect look down
Energy and Maneuverability	Low energy, high maneuverability	Low energy, low maneuverability	Low energy, low maneuverability	High energy, high maneuverability	High energy, high maneuverability	High energy, high maneuverability
Detection of Enemy Fighter	None	>/=10 NM	>/=20 NM	</=50 NM	>/=100 NM	>/=100 NM
Sensor Fusion	None	None	None	None	Limited	Full
Stealth	None	None	None	None	Reduced RCS	Full

IR—Infrared guided NM—Nautical miles

SOURCE: Author's reasearch based on rough estimates and orders of magnitude.

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ational awareness of a GCI-less, second-generation fighter. Over time, GCI capabilities will grow, allowing ground-based radar controllers to vector enemy fighters toward the F-35s, but those pilots will be left to pick up their opponents visually, just as fighters did in the Korean War. They will do that until their own breakthroughs allow the fielding of operational stealth fighters and/or their sensors can be tuned to detect an F-35 in time to be tactically effective. While this technological advantage will likely be with the U.S. and its allies for many years to come, the U.S. cannot allow fighter energy and maneuverability or our tactics to wither.

F-35A Dogfight Performance

Much has been written about the F-35A's performance in an air combat environment, and while it is important to see how well it stacks up against its fourth-generation predecessors, there are some important facts to keep in mind in any comparison. The F-35A is still under development, and incremental design restrictions limit the G-loading that pilots have to 7.0 Gs. The fly-by-wire design is predicated on software control laws (CLAWs) that act as a governor to limit pilots from max-performing the jet in a way that could cause it to go out of control.[20] For purposes of this paper, those limitations were taken as is, and pilots were asked not to speculate about

20. As the Air Force and Lockheed-Martin complete the concurrent development flight testing associated with different fuel and munitions loading, some of the CLAW limits may soften. The associated changes will be released in a software version called "3F" that is due to be fielded in August 2017. Once it is released, the F-35A will be able to fly at 9.0 Gs as soon as the landing gear is in the well (up).

how the jet will perform when those restrictions are lifted.

The energy and maneuverability (Em) performance of fourth-generation fighters is very often exaggerated by the idea that these fighters fly combat missions in absolutely clean "airshow" configurations. No fourth-generation jet in the U.S. inventory (or any other) goes into combat that way, and most will carry significant external stores (munitions, fuel tanks, and targeting pods) in order to accomplish their mission. When pilots know they are about to enter a dogfight situation requiring the best Em their jets can deliver, they will jettison fuel tanks and unexpended bombs, but almost every pod, rack,[21] or missile rail is permanently affixed,[22] adding significant un-jettisonable weight, drag, and RCS.

If stores and weapons are jettisoned prior to hitting air-to-ground targets, pilots will fail in their primary (multirole) tasking. Even post-jettison, the G-restrictions associated with targeting, forward looking infrared (FLIR), and HTS pods will remain and generally restrict jets to 8.0 Gs or less. While most fighters still perform adequately in those post-jettison configurations, air combat Em performance suffers considerably.

A Direct Comparison. Thirty-one experienced pilots currently flying the F-35A were asked to rate the energy and maneuvering characteristics of their previous fourth-generation fighters in a combat configuration throughout the dogfighting maneuver envelope in a combat configuration[23] after jettisoning their external stores. They were then asked to rate the performance of the F-35A using the same scale, with fuel and internal munition loads associated with a combat loadout[24] under their current G and CLAW restrictions.[25] The F-35A compared well to the four other fighters (F-15C, F-15E, F-16C, and A-10) in most every regime. (For the total results and responses from the pilots of each respective fighter, see Chart 1.)

Each pilot was then asked to select which fighter he would rather fly in combat if he were to face a clone flying the other jet in six different air-to-air situations. (See Chart 2.) If the pilot selected an F-15C in a short-range setup, for example, he felt he could outperform a pilot of equal abilities in the F-35A. Pilots selected the F-35A 100 percent of the time in beyond-visual-range situations and over 80 percent of dogfighting situations where energy and maneuverability are critical to success.

The F-35A was not designed to be an air superiority fighter, but the pilots interviewed conveyed the picture of a jet that will more than hold its own in that environment—even with its current G and maneuver restrictions. In the words of an F-16C Weapons School Graduate and instructor pilot now flying the F-35A, "Even pre-IOC,[26] this jet has exceeded pilot expectations for dissimilar combat. (It is) G-limited now, but even with that, the pedal turns[27] are incredible and deliver a constant 28 degrees/second. When they open up the CLAW, and remove the (7) G-restrictions, this jet will be eye watering."[28]

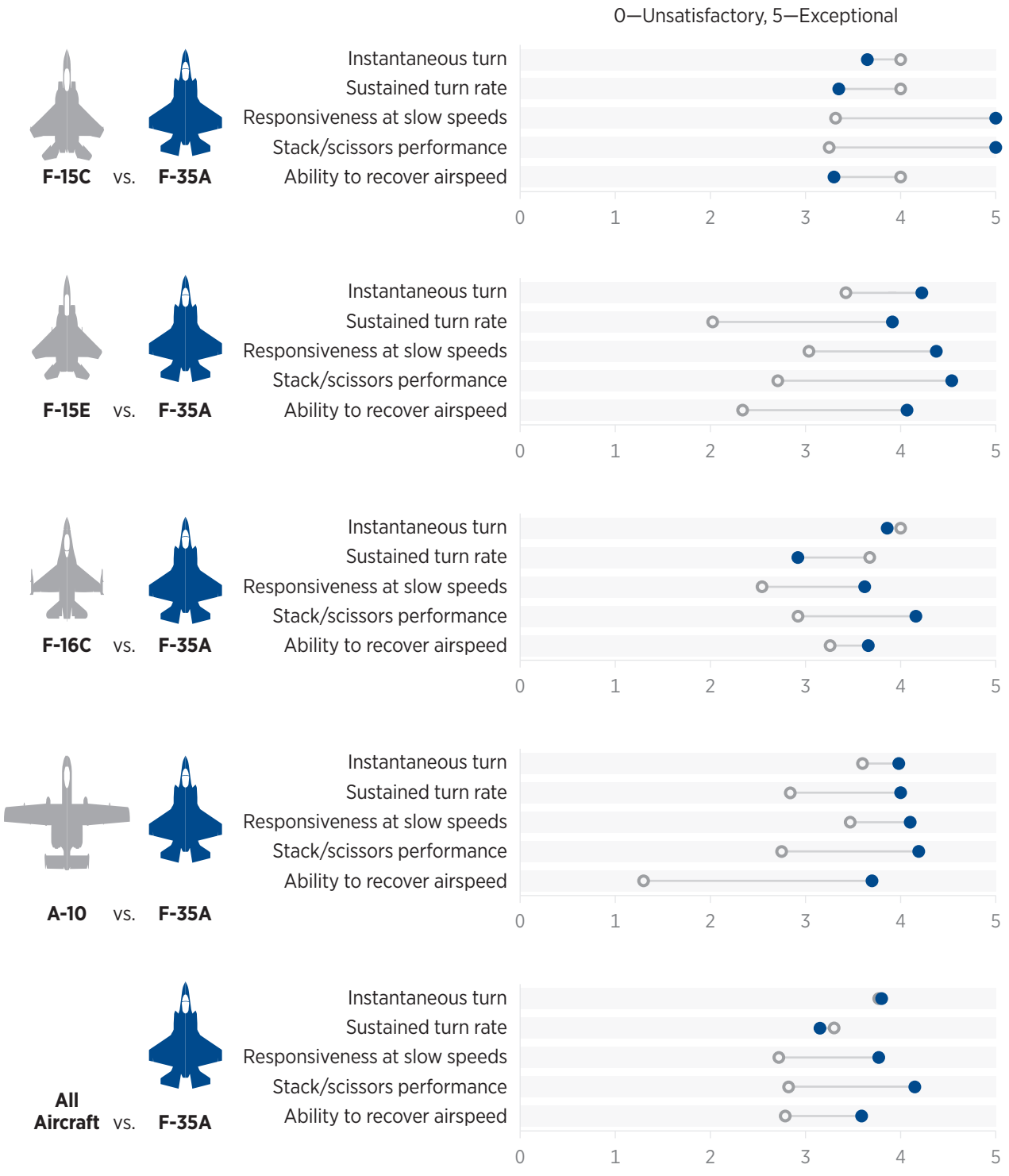
Concurrent Acquisition and Program Management

While the F-35A is on the path to becoming an extraordinary multirole fighter, the road has been

21. In this instance, "rack" refers to non-jettisonable Munitions Adapter Units (MAU) that are bolted to fighter airframes.
22. "Permanently" means that it must be removed by a maintenance team on the ground. Some targeting pods require a great deal of maintenance and troubleshooting to remate them to aircraft after removal, forcing most organizations to leave them on all the time. Others (like the HTS) provide such high levels of SA that organizations would never fly in combat without them.
23. "Combat configuration" refers to an aircraft with stores that remain after pilots drop or jettison everything they can drop or jettison before going to a merge. For the F-16, this would leave the Harm Targeting Pod (HTS), IR Targeting Pod, ECM pod, MAUs, rails, and air-to-air missiles; for the F-15C, the fuel tank racks; for the F-15E, the Targeting Pod, MAUs, rails, and air-to-air missiles; for the A-10, the IR Targeting Pod, ECM pod, and enough racks and rails from which to hang a city's worth of meat.
24. Combat configuration for the F-35A: 13,000 pounds of fuel to replicate retaining internal munitions and roughly half internal fuel. The F-35A will have no external stores during any anti-access, high-threat environment.
25. "Current G and CLAW restrictions" refers to the jet "as is," with the CLAW as currently programmed and the 7.0 G restriction.
26. Initial operating capability, the first major step that a combat system must take before it can be declared fully mission capable (FOC).
27. Turns assisted by the heavy application of the aircraft's rudder.
28. Personal interview with former F-16C pilot currently flying the F-35A, April 18, 2016.

CHART 1

How Pilots Rate Fighter Jet Maneuverability



SOURCE: Author's survey of 31 fighter pilots. See appendix for details.

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filled with controversy about its concurrent development acquisition program. Like any other system that relies on technology, fighters have technically viable lifespans, and the clock of utility begins well before the system is ever fielded. A case in point was the air-to-air variant of the Royal Air Force's Tornado F-3. The technology that went into its design had been proven before the fighter was built. There were no technological leaps, no real risks assumed in the design or acquisition process, and by the time it was fielded in the 1980s, it was virtually obsolete. The F-3 served the RAF for over 20 years, but it was never considered a first-rate fighter or even one that would perform well against the threats of the era.

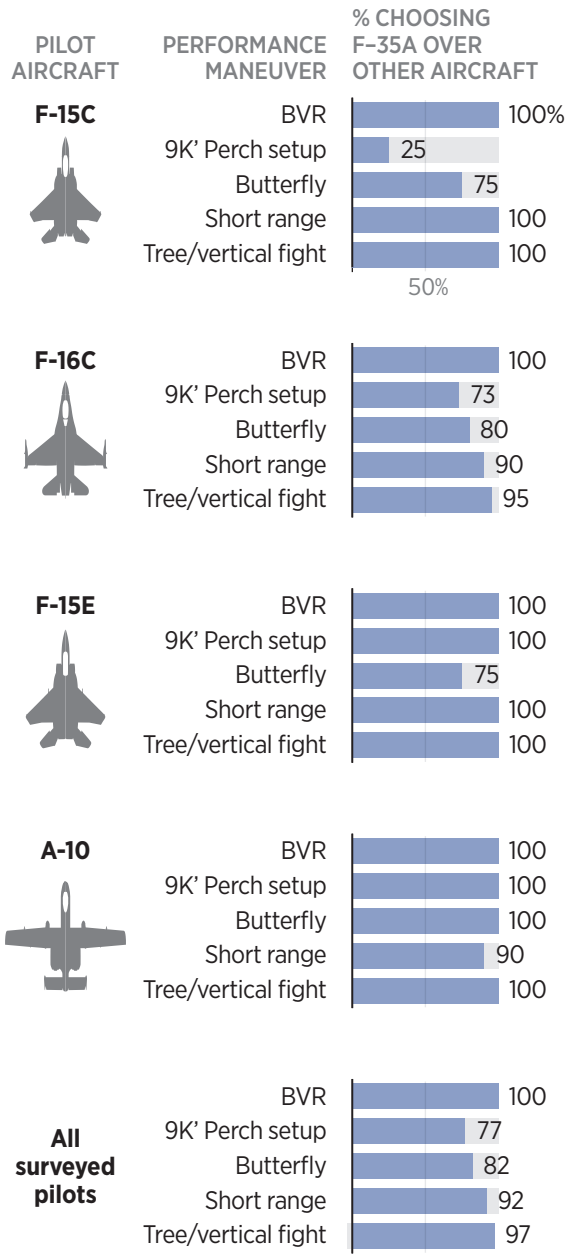
The requirement for the Joint Strike Fighter (JSF) came about when technology was growing so rapidly that it would be hard to field a jet that was not already approaching obsolescence. DoD agreed on an approach that would combat that challenge by moving to acquire a system while many components of the aircraft were still undergoing some level of research and development. That concurrent development brought with it a level of risk that by its very nature will be present throughout the course of the F-35's initial fielding.

Component, sensor, and airframe development were (and still are) all happening at the same time, and even small changes in the weight, size, performance, and schedule of any component could affect the weight, size, performance, and schedule of the entire system. While some believe the risk associated with portions of the F-35 concurrent development program equate to acquisition malpractice,[29] the benefits are potentially enormous. The risks of developmental delays and cost overruns were accepted to mitigate an even bigger risk: that the United States would field its own version of the Tornado F-3. The costly risk of delays was known, and only extraordinary leadership could mitigate it. That should have been factored into the whole of the acquisition process, but it wasn't.

No matter how much legislation is put forth or how many more lines are added to the Federal Acquisition Rules (FARs), any major acquisition program will falter without consistent, competent leadership. The F-35 is the biggest acquisition program in the

CHART 2

Pilots Prefer Flying F-35A



SOURCE: Author's survey of 31 fighter pilots. See appendix for details.

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29. Frank Kendall, Undersecretary of Defense for Acquisition, Technology, and Logistics, "The Acquisition Implications of the DOD Strategic Guidance and the FY 2013 Budget," remarks delivered at the Center for Strategic and International Studies, Washington, D.C., February 6, 2012, https://csis-prod.s3.amazonaws.com/s3fs-public/event/120206_FY13_event_transcript.pdf (accessed July 14, 2016).

history of the United States.[30] If concurrent development is coupled with a program of this size, the single biggest requirement for acquisition becomes competent, long-tenured leadership.

In its first 18 years of existence, the JSF/F-35 program office had nine different directors—one every two years—and no matter how bright an individual may be, it takes at least a year to become familiar with the interwoven complexities of such a program.[31] The tenure for the leader most critical to program success was driven more by the expected timing and progression of general officer career paths than it was by the requirements of the biggest acquisition program in history.

It was only after delays and cost overruns aroused the ire of Congress that the Air Force put Lieutenant General Chris Bogdan at the helm of the program. In his four years on point, Bogdan has brought energy, honesty, and the kind of leadership that the program has needed for years. His time on point has not been without controversy, but he has proven that competent, stable leadership in that position is critical, and he has brought the F-35 to the precipice of the kind of technological success for which DoD and industry have been hoping—but at what cost?

Cost and Capability

At full-rate production, every F-35A that leaves the Lockheed-Martin facility in Fort Worth is projected to cost $80 million–$85 million.[32] When one considers the technology and cost of this system, it compares favorably with other recently fielded fighters.

- **The F35A Lightning II** is a fifth-generation fighter conceived in the 1990s. It began concurrent development in the mid-2000s and was declared IOC on August 2, 2016. The jet incorporates full stealth; an AESA radar; internal 360 degree IRST (DAS); an internal IR targeting system (EOTS); and other passive detection systems that are coupled through sensor fusion. In a combat configuration, all munitions, fuel, and targeting sensor and designation capabilities are carried internally, giving it a 9G capability throughout its operational envelope. Estimated full-rate production cost: $80 million–$85 million.

- **The Eurofighter Typhoon** is a four-plus-generation multirole fighter conceived and designed in the early 1980s and introduced into operational service in 2003. The jet itself has a reduced RCS, an AESA radar, internal forward looking IRST, and other passive detection systems that are coupled through sensor fusion. In a combat configuration, the targeting pod, external tanks, and weapons are all carried externally, affecting range, RCS, maximum G, sustained G, and maneuverability. Full-rate production cost: $119 million.[33]

- **The F-15K Strike Eagle** is a four-plus-generation multirole fighter conceived, designed, and initially fielded in the 1980s. This version of the jet is built for (and largely by) South Korea, offers no stealth or reduced RCS, and has an AESA radar and an IRST passive detection system. In a combat configuration, the targeting pod, fuel tanks, and weapons are all carried externally, affecting range, RCS, maximum G, sustained G, and maneuverability. Full-rate production cost: $108 million.[34]

- **The Rafale B** is a four-plus-generation multirole fighter conceived in the 1970s, designed in the 1980s, and initially fielded in the mid-2000s. The jet itself has a reduced RCS and infrared signa-

30. The F-35 program is not replacing a single or even three different fighters (one for each service). Individual service acquisition plans that might have replaced the F-16C, F-15E, A-10, F-18C, and AV-8s have been combined into a single acquisition program. The F-35A is comparable in cost to any other four-plus-generation fighter on the market today; the sheer numbers of fighters being replaced are what make this a record-setting move.
31. Bryant Jordan, "F-35 Program Chief: Longer Program Assignments Needed for JSF Fix," Military.com, April 26, 2016, http://www.military.com/daily-news/2016/04/26/f35-program-chief-longer-program-assignments-needed-jsf-fix.html (accessed July 14, 2016).
32. Defense-Aerospace.com, "F-35 Engine Unit Costs Continue to Grow Even As Production Increases," April 28, 2015, http://www.defense-aerospace.com/articles-view/feature/5/163182/f_35-engine-unit-costs-continue-to-grow.html (accessed July 13, 2016).
33. Bundesministerium der Verteidigung, "Haushaltsausschuss billigt Bundeswehrprojekte," June 17, 2009. Converted to 2014 U.S. dollars.
34. Aerospaceweb.org, "McDonnell Douglas (now Boeing) F-15E Eagle Fighter Bomber," last modified March 17, 2012, http://www.aerospaceweb.org/aircraft/bomber/f15e/ (accessed July 13, 2016).

ture. It has been retrofitted with an AESA radar and possesses an internal IRST and other passive detection systems that are coupled through data/sensor fusion. In a combat configuration, the targeting pod, external tanks, and weapons are all carried externally, affecting range, RCS, maximum G, sustained G, and maneuverability. Full-rate production cost: $98 million.[35]

- **The F-18E Super Hornet Block II** is a four-plus-generation multirole fighter based on a design initially conceived in the mid-1990s. The refined aspects of the Block II were designed and fielded in the mid-to-late 2000s and include an AESA radar but no stealth or reduced RCS. In a combat configuration, the targeting pod, external tanks, and weapons are all carried externally, affecting range, RCS, maximum G, sustained G, and maneuverability. Full-rate production cost: $78 million.

- **The JAS-29C Gripen** is a fourth-generation multirole fighter conceived in 1979, designed in the 1980s, and initially fielded in the late 1990s. The jet has a pulse-Doppler radar and offers no stealth or reduced RCS. In a combat configuration, the targeting pod, external tanks, and weapons are all carried externally, affecting range, RCS, maximum G, sustained G, and maneuverability. Full-rate production cost: $69 million.[36]

While the prices of these six fighters can be debated, none of the fourth-generation or four-plus-generation jets can compete with the air-to-ground capabilities of the F-35. In its air-to-ground roles, the F-35A can find, fix, target, and drop on ground threats or targets more quickly and more accurately than any other fighter in the world and without the need for external stores—all in a denied-access (high-threat) environment.

Nor would other fighters fare well if pitted against the F-35A in aerial combat. In an air-to-air BVR situation, the F-35 can locate and target every other combat-configured jet before their pilots become aware of the F-35's presence. Even if one of the other fighters survived a BVR engagement, the external (un-jettisonable) pods, racks, and rails of each opponent would give a completely clean, combat-configured F-35A a distinct advantage.

The F-35A and the other fighters may be comparably priced, but the F-35A is a full generation ahead of any other multirole fighter nearing production. Nevertheless, there are valid questions that remain:

- How long will this advantage last, and

- How will the United States counter the threat when hostile nations begin to catch up with this leap in technology?

The Fleeting Edge of Technology

For the better part of 30 years and the first three generations of jet fighter aircraft, the United States kept a slight lead on both adversaries and allies in technology and/or tactics. This changed with the advent of stealth, and that technological leap put the U.S. 10–15 years ahead of the threat. Nations that fall behind fight for parity by developing better tactics or fielding greater numbers until they can once again compete technologically.

The enemy is and always will be a thinking being, and even a slight change in dated equipment, coupled with novel tactics, can sometimes be a game changer. The F-117A was developed in the 1970s and entered service in 1983. With it came the age of stealth, and the U.S. Air Force (much as it had in the 1960s in response to the age of the missile) felt that it was all but untouchable. That proved to be valid during Operation Desert Storm in 1991. In 1999, however, the Yugoslavian air defenses were composed of dated systems, one of which was the SA-3 GOA, a SAM system fielded by the Soviet Union in 1961. The Serbs used clever tactics and a nearly 40-year-old system to shoot down an F-117A.

35. *Projet de loi de finances pour 2014 : Défense : équipement des forces et excellence technologique des industries de défense* [Finance Bill 2014—Defense: Equipment Forces and Technological Excellence of the Defense Industry], French Senate Legislative Report No. 158, November 21, 2013, http://www.senat.fr/rap/a13-158-8/a13-158-8.html (accessed July 13, 2016). Unit cost (excluding development costs) of €74M 2013 for the Rafale B (110 aircraft); €68.8M 2013 for the Rafale C (118 aircraft); and €79M 2011 for the Rafale M (58 aircraft). Converted to 2014 U.S. dollars.

36. News release, "Stark milstolpe av Gripenprojektet" [Strong milestone by the Gripen project], Mynewsdesk, November 28, 2006, http://www.mynewsdesk.com/se/forsvarets_materielverk__fmv/pressreleases/stark-milstolpe-av-gripenprojektet-258602 (accessed July 14, 2016). Converted to 2014 U.S. dollars.

The U.S. Air Force had become complacent when it sent that F-117 into what it believed to be a low-threat environment with no electronic countermeasures support from any other U.S. platform. With no internal jamming system of its own, it relied wholly on stealth for self-protection, and this was not enough. When arrogance takes hold of the technologically advanced, laggard nations can use tactics to level the playing field until they catch up with the technology.

Both the Russians and the Chinese are working to field a viable fifth-generation stealth fighter, but even holding leaked or pilfered classified U.S. data, they are discovering just how challenging stealth can be. Nevertheless, the Air Force F-35A's superior technology, energy, and maneuverability will give this platform a dominant edge for some time to come. Its stealth is remarkable, and its package of internal electronic countermeasures can detect and electronically blind the newest enemy sensors and SAM and radar systems without highlighting itself to a threat.

What Should Be Done

The United States Air Force will begin the slide back into its own Vietnam (or Yugoslavian) level of ineffectiveness the moment senior leaders and industry representatives use technological dominance to reduce flying time, tactics training, and integrated operations. To prevent that from happening, the Air Force must revitalize its flying hour and tactics training programs to give every fighter pilot the time in the air that he or she needs to dominate the skies when stealth is no longer ours alone.

With this in mind, there are at least four specific actions that Congress and the Department of Defense should take:

- **Move forward with the purchase of the full Air Force program of record of 1,763 F-35A fighters.** Even now, the sensors and sensor fusion of this platform outclass any other fourth- or fifth-generation fighter currently in the air. Experienced pilots rate the air combat faculties of the F-35 as better than or equal to any other combat-configured fourth-generation fighter in the U.S. inventory—even with the jet's current restrictions and G-limits.

- **Fully fund DoD's requested baseline budget and the overseas contingency operation budget.** The edge that the F-35A brings in the air-to-ground world is incredible, and its price is comparable to those of jets that would never stand a chance against it in the air. The Air Force is currently deferring the purchase/cashing in on F-35As to pay for other critical needs that have gone unfunded or underfunded by Congress. That practice needs to end immediately.

- **Continue concurrent development for platforms and systems requiring leading-edge technology.** There are risks associated with concurrent development, but the gains and contracting lessons gleaned through the F-35A program are significant and need to be applied to systems that are susceptible to fielding obsolescence.

- **Solidify acquisition leadership for all major (Cat I) acquisition programs by mandating four-year tenures for the heads of all program offices.** The complexities of any such program are incredibly high, and the only way to deliver excellence on time and within budget to make the program fully mission capable is through extraordinary, stable leadership.

Conclusion

The F-35 is an expensive platform, but it is notably more effective and in many cases cheaper than any other four-plus-generation multirole fighter in the world. No other nation's fielded fighter would fare well in an engagement against the F-35, and no other multirole fighter currently on the market would survive, much less thrive, in a modern-day high-threat environment. The United States needs to fulfill the F-35A's complete fielding and look at the concurrent development process that brought it to fruition as a model for similar rapidly growing systems and technologies.

*—**John Venable,** a former F-16C pilot with 3,000 hours of fighter time, is Senior Research Fellow for Defense Policy in the Center for National Defense, of the Kathryn and Shelby Cullom Davis Institute for National Security and Foreign Policy, at The Heritage Foundation.*

Appendix

APPENDIX TABLE 1

Breakdown of Pilots Interviewed

		NUMBER OF PILOTS			
Aircraft Piloted	**Average Flight Time (hours)**	**Top Gun/ Test Pilot***	**Instructor Pilot Plus****	**Instructor Pilot**	**Total**
F-16	1,441	6	3	11	20
F-15E	1,850	2	1	1	4
A-10	1,420	1	2	2	5
F-15C	1,085	1	0	1	2
Total	**1,467**	**10**	**6**	**15**	**31**

* Top Gun is a Weapons Instructor Course graduate. Test Pilot is a Test Pilot School graduate.
** Instructor Pilot Plus—Instructors with higher level certifications (Package/Strike commander, Sandie, etc.)

SOURCE: Author's survey of 31 fighter pilots.

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