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BACKGROUNDER

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The F-35A Fighter Is the Most Dominant and Lethal Multi-Role Weapons System in the World: Now Is the Time to Ramp Up Production

John Venable

Abstract

The U.S. Air Force's first F-35A fighter wing is now fully operational. The road to this point has been filled with insights on the aircraft, simulator, maintenance and logistical support, and operations that will apply to any service or nation flying the Joint Strike Fighter (JSF). This assessment is based on interviews with 30 F-35A combat pilots as well as senior operations and maintenance leaders at Hill Air Force Base in Utah. It follows a similar assessment from 2016 of 31 other highly experienced former fourth-generation fighter pilots, who were then flying the F-35A at two other Air Force locations. The collective perspectives confirm that, while the JSF is still several years away from realizing its full potential, even now, the F-35A is the most dominant and lethal multi-role aircraft in the world.

In February 2018, the Defense Department's F-35 Joint Program Office began to field the combat employment software for the F-35A. The software, referred to as Block 3F, or simply 3F, delivers the Joint Strike Fighter (JSF) program's full operational capability to the Air Force. The changes and enhanced capability this new software brings to the jet are significant, and while the potential for growth of this weapons system is still immeasurable, the F-35A can now be considered fully operational.

While insights and critiques on the individual elements of the F-35A program are interesting, any evaluation of this weapons system must include all four major components of the weapons system: (1) the aircraft, (2) the simulator, (3) maintenance and logistical support, and (4) operations.

Key Points

- The F-35A is the most dominant multi-role fighter aircraft in the world. Its demonstrated capabilities make it ready for the Department of Defense to approve full-rate production.
- Fighter pilots currently flying the jet believe the latest software update brought full warfighting capabilities to the F-35A and that it is virtually undefeatable. They rate the F-35A's handling and dogfighting characteristics above that of their previous jets.
- Air Force strategic plan execution to rapidly build maintenance experience and prepare for the expansion of the F-35A community has been exceptional. Now, the defense industry and the government must improve maintenance, supply, and scheduling.
- The Air Force has ingrained deep tactical experience in the pilots within its first operational F-35A wing. The looming ramp-up in production and bed-down of the F-35A will require the Air Force to balance that depth with the requirement to increase the number of experienced pilots as fast as possible.

This paper, in its entirety, can be found at **http://report.heritage.org/bg3406**

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This assessment is based on interviews with 30 F-35A combat pilots—21 of whom are also highly experienced former fourth-generation fighter pilots—as well as senior operations and maintenance leaders at Hill Air Force Base (AFB) in Utah, the Air Force's first operational F-35A location.[1] It follows a Heritage Foundation 2016, pre-Initial Operating Capability (IOC) assessment based on interviews of 31 other highly experienced pilots stationed at Luke AFB in Arizona and Eglin AFB in Florida.[2] The collective perspectives deliver a unique picture of both the extraordinary capabilities of this fifth-generation multi-role fighter, as well as areas that still need to be refined. It will take several more years before the F-35A begins to realize its full potential, but there is no doubt in the minds of those flying the F-35A at Hill AFB that, even now, this jet is the most dominant and lethal multi-role aircraft in the world.

The Aircraft

The F-35A has brought about a revolutionary change in the way pilots conduct fighter operations. In order to analyze the current weapons system, it is important to understand how the F-35A's sensors have changed basic fighter operations.

From their earliest days, fighter tactics have been designed to maximize lethality while simultaneously providing as much inherent visual mutual support to jets within a formation as possible.

Up until the late 1960s, air-to-surface munitions had very short lateral ranges, and most had to be delivered visually in order to have any level of precision. To overcome the inherent limitations of those weapons, pilots had to drive in close, often well within the range of concentrated and accurate anti-aircraft artillery (AAA), to destroy a target. That changed with the introduction of precision-guided munitions that allow jets to hit targets from level flight, more than four miles above the ground.

While out of the AAA threat, those third-generation and fourth-generation aircraft were still vulnerable to enemy fighters and radar-guided surface-to-air missiles (SAMs). Radar warning and detection systems gave pilots an idea of where attacks were coming from, but detecting and then defeating an attacking enemy fighter or missile could only be done after visually acquiring the threat.

Throughout the history of aerial combat, the most vulnerable area of a fighter has been behind the aircraft's wing. Among other things, that entry allows attacking fighters to be in a firing position for a longer period of time, without being threatened by the aircraft they are attempting to destroy. With that in mind, every fighter pilot from World War I until the advent of fifth-generation fighters has been trained to constantly scan behind his own aircraft ("check six") for an attacker.

Still, any aircraft has areas that cannot be easily scanned or viewed from its cockpit. These blind spots are generally found behind an aircraft's wing. In order to cover this vulnerability, formations and tactics were designed to maximize both visual mutual support and maneuverability. Third-generation and fourth-generation fighters from Vietnam to today have flown line-abreast formations with one to three miles of separation between the other. This allows pilots to check the blind spots of the other, call out inbound threats, and to turn and quickly fire on an aircraft attacking their wingman.

The technology built into the JSF[3] has completely reshaped those vulnerabilities. The radar, Distributed Aperture System (DAS), and other passive sensors, coupled with the feeds from platforms in and around the air domain are fused together in F-35A cockpits to give pilots a 360-degree picture of both friendly and enemy aircraft around their jets. The broad coverage that the supporting network of systems provides coupled with the exceptional suite of sensors give F-35A pilots a high degree of situational awareness, and have instilled the belief that few (if any) enemy aircraft could sneak into a firing position without F-35A pilots knowing about it well in advance—without those pilots ever having to look outside.[4]

1. A breakdown of the experience level of the pilots interviewed for this *Backgrounder* can be found in Appendix Table 1.
2. John Venable, "Operational Assessment of the F-35A Argues for Full Program Procurement and Concurrent Development Process," Heritage Foundation *Backgrounder* No. 3140, August 4, 2016, https://www.heritage.org/defense/report/operational-assessment-the-f-35a-argues-full-program-procurement-and-concurrent.
3. The JSF program has three fighter planes—the F-35A, the F-35B, and the F-35C. The F-35A is a conventional take-off and land (CTOL) variant that the Air Force is fielding. The F-35B is a short take-off, vertical landing (STOVL) variant that the Marine Corps is fielding. The F-35C is the carrier variant (CV) designed to be operated from large-deck aircraft carriers and is being purchased and fielded by both the Navy and the Marine Corps.
4. No pilot interviewed for this assessment spoke of a need for visual mutual support, or expressed concern over the loss of the habit of "check six."

TABLE 1

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 radar cross section	Full

IR—Infrared guided NM—Nautical miles
SOURCE: Author's reasearch.

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Seemingly freed from the requirement to maintain visual mutual support, tacticians have designed tactics and formations that maximize the capabilities inherent to the JSF weapons system, a system that is optimized for flights of four or more jets. These formations take off, rejoin, fly to the tanker, and hold in formation until it is time to push into enemy territory. From that point on is where any similarity between fourth-generation and the current fifth-generation tactics ends. With the F-35A's situational awareness aids, pilots are no longer limited to flying visual formations in order to provide other flight members with mutual support, allowing formations to maximize the jet's system to locate and engage threats.

Finding and fixing the position of surface-to-air missile systems and other threat emitters relies on triangulation. When a single F-35A detects the emission of a threat, it records the azimuth to the signal from a designated point in space. As the jet continues on its flight path, it captures the azimuth to that same signal at a different point in space, allowing the jet to automatically calculate the geographic location of that threat based on trigonometry. As the math goes, the greater the angular difference between different azimuth traces, the higher the accuracy of the target location.

Flights of F-35As are linked through the system's multifunction advanced data link (MADL), allowing the azimuth traces of those detected threat emissions to be exchanged and paired, and their locations to be calculated automatically. The accuracy of the target location goes up markedly as the angular difference increases between those two points. That angular distance in a formation is created with the spread (distance) between F-35As in a formation. The wider the spread, the greater the azimuth angles, which deliver more precise geolocation.

No longer tied to formations that deliver *visual* mutual support, the F-35A community has moved to fully take advantage of this weapons system by flying incredibly wide formations. While the standard distance between jets in a high-threat scenario is sensitive, in the words of one wingman, "the last time I have a visual on the other members of my flight is when we 'fence in' [leave a marshalling point and head down range toward the threat]. The next time I see them is when we rejoin for a battle damage check and the trip home."[5]

With that, and an understanding of the tacticians' preferred employment method of "detached mutual support" as a backdrop, one can begin to more fully evaluate the whole of the F-35A weapons system.

The F-35A now has the capability go to war anywhere in the world. The latest software and hardware upgrades (3F) give it a competitive advantage when engaging SAMs, which will be one of its primary roles during the first days of a fight with a near-peer competitor. The fused systems it uses to find, fix, and engage those threats are operating exceptionally well.

In 2017, Lt. General Chris Bogdan, then director of the F-35 Joint Program Office, testified before the House Armed Services Committee that the F-35A's AN/ASQ–239 electronic warfare (EW) system had performed well in testing,[6] and that the updates incorporated in 3F have the attention and affection of the jet's pilots. The detection range, Advanced Emitter Location (AEL), Enhanced Geolocation (EGL), and threat Identification (ID) performance and system response time now allow the jet to detect, find, and engage every element of layered defensive batteries of the SA-20 SAM system, one of the most dangerous SAM systems that Air Force jets face.

General Bogdan's testimony was reaffirmed by every pilot interviewed at Hill AFB. The target coordinates that the system can "pull" on those threats, coupled with the threat array images that the jet's synthetic aperture radar (SAR) builds, give pilots everything they need to target the threat.

> I would now take the F-35[A] to combat any day and anywhere in the world. To feel that way now is awfully powerful, but to think of what this system will be like in 20 years is mind boggling.[7]

The weapons portfolio the jet can use to prosecute those targets also expanded significantly with this latest modification. The F-35A can now carry the Global Positioning System (GPS)-guided small-diameter bomb and the (laser) guided bomb unit-12 (GBU-12) in its internal weapons bay. The former weapon doubles the number of air-to-surface targets that it can prosecute in a stealth configuration, and the latter offers a precision-delivery capability should the jet need to operate in a GPS-denied environment.

In the words of an F-16 weapons school graduate now flying the F-35A, the enhanced geolocation capabilities coupled with the new munitions makes this weapons system "a nail driver."[8]

The jet's 25 millimeter (mm) gun has also come to life with this latest version of software. The operational test and evaluation (OT&E) pilots are firing it at air-to-air targets, and OT&E as well as the operational units at Hill AFB are firing the gun on air-to-surface ranges.

While many dismiss the F-35A's gun as an antiquated and unnecessary hold-over, it is the one system that cannot be beat by stealth or other countermeasures, and making it operationally viable is critical.

Ground testing of the F-35A's 25 mm Gatling gun showed an incredibly tight bullet dispersion pattern (grouping), and pilots firing the gun on the range report tight groupings of round impacts. However, the sight and gun pairing do not currently allow pilots to put the rounds where they are aiming them.[9]

The complications associated with aiming a gun even with a fixed heads-up display (HUD) in a fourth-generation fighter are significant. Every canopy has variations of thickness that refract or distort a target's image as it works its way through the canopy's

5. Stated during an interview by a first-assignment F-35A pilot with 275 hours in the jet.
6. Lt. General Christopher C. Bogdan, USAF, "Military Services Fifth-Generation Tactical Aircraft Challenges and F-35 Joint Strike Fighter Program Update," hearing before the Subcommittee on Tactical Air and Land Forces, Committee on Armed Services, U.S. House of Representatives, February 16, 2017, p. 113, https://www.govinfo.gov/content/pkg/CHRG-115hhrg24678/pdf/CHRG-115hhrg24678.pdf (accessed January 13, 2019).
7. Quote from a highly experienced, former F-16 pilot, now an F-35A instructor pilot (IP) with 300 hours in the jet.
8. Quote from a highly experienced, former F-16 pilot, now an F-35A standardization/evaluation flight examiner (SEFE) pilot with 690 hours in the jet. SEFEs evaluate the proficiency of other pilots during check rides.
9. Each pilot interviewed who had fired the gun stated he had yet to consistently put bullets on target.

two inches of Plexiglas. To solve this problem, different optical corrections were calculated to adjust the image—as well as the associated aiming required for a pilot to put bullets on target in every individual jet. Those aiming complications are put on steroids when the gunsight is no longer displayed on a fixed HUD, but projected on to the visor in a fighter pilot's helmet, which moves in all three dimensions. The move to actively strafe is a big step for the jet, but the system will require significant testing—and refinement—before the F-35A can reliably put 25mm bullets on target.

Maneuver Restrictions

Under previous versions of software, the JSF was restricted in maneuvering based on fuel weight and, under the best of conditions, the F-35A was limited to seven gravitational force equivalents (G-forces), simply called "Gs." This forced pilots to artificially pad or limit their turns, so as not to "over-G" the aircraft. In a defensive engagement for example, pilots looking over their shoulder at the aircraft prosecuting them would underplay their "G" loading to ensure that they did not place too much stress on the jet ("over-G") and force an untimely end to their sortie.

Those restrictions are now completely gone, and even with a full internal weapons load-out and fuel, pilots can pull back as far as the stick will go and let the jet limit loadings to nine Gs anytime the jet is capable of generating that kind of turn. As discussed below (under "The Weapons School Standard"), that same finesse is what fighter pilots have always referred to as energy management, and it can only be learned through multiple, regular air-to-air training repetitions—which are currently not taking place.

F-35A Dogfight Performance

The energy 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 (bomb racks, 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,[10] or missile rail is permanently affixed,[11] adding significant weight, drag, and radar cross section (RCS) that cannot be jettisoned in flight.

If 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 HARM Targeting System (HTS)[12] pods will remain and generally restrict jets to eight Gs or less. While most fighters still perform adequately in those post-jettison configurations, air combat EM performance suffers considerably.

A Direct Comparison. Fifty-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[13] 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.[14] 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.)

10. In this instance, "rack" refers to Munitions Adapter Units (MAUs) and other missile rails that are bolted to fighter airframes and cannot be jettisoned by the pilot in flight.

11. "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 re-mate them to aircraft after removal, forcing most organizations to leave them on all the time. Others (such as the HARM Targeting System or HTS) provide such high levels of situational awareness that pilots would never fly in combat without them.

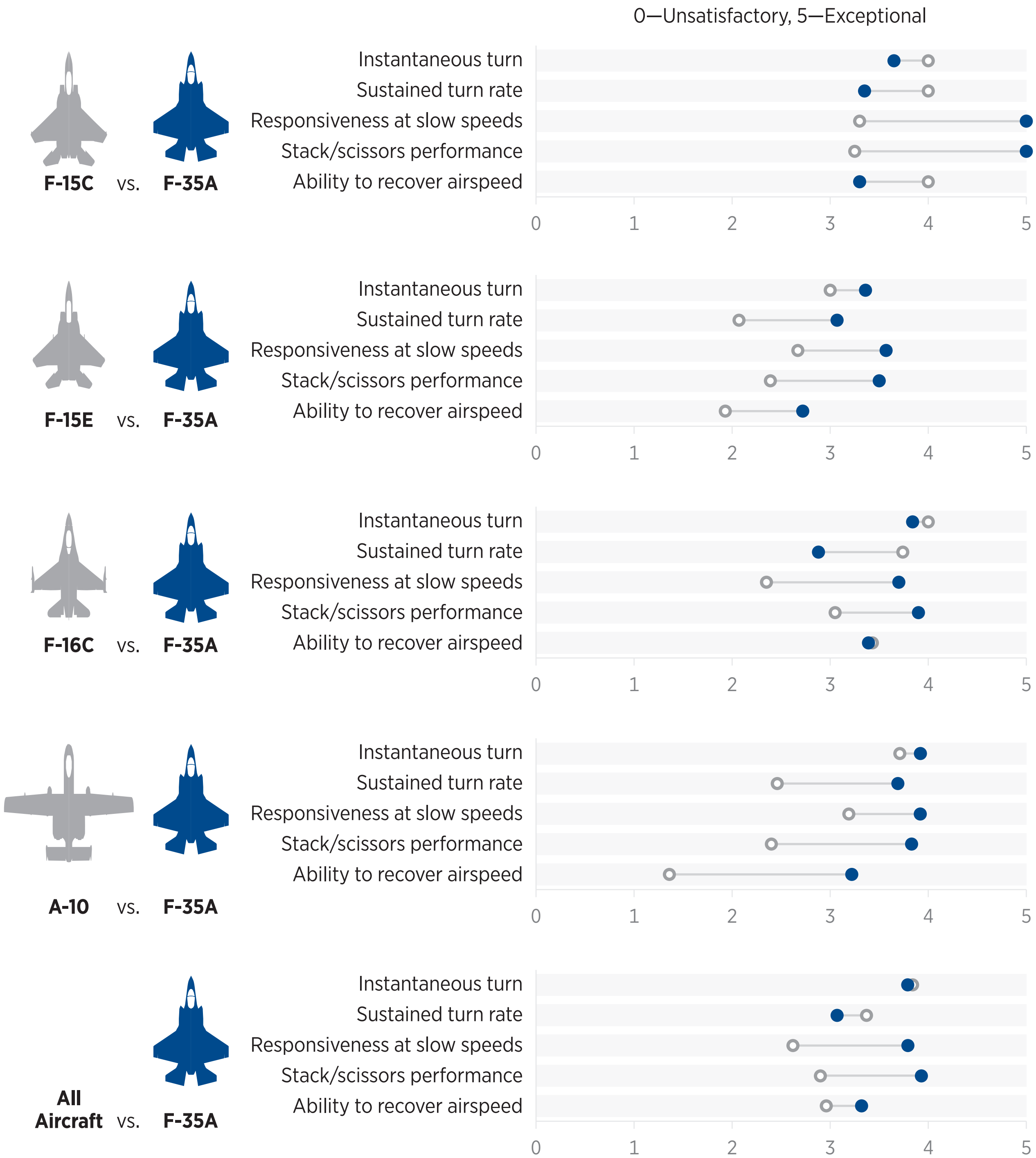
12. HARM stands for High-speed Anti-Radiation Missile.

13. "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 with an enemy fighter. For the F-16, this would leave the HTS pod, the infrared (IR) Targeting Pod, the electric countermeasure (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.

14. 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.

CHART 1

How Pilots Rate Fighter Jet Maneuverability



SOURCE: Author's survey of 51 former fourth-generation and a single fifth-generation pilot currently flying the F-35A. The former F-22 pilot rated the F-35A fours in all areas and the F-22A all fives. F-22A assessment numbers are included in the "all pilots surveyed" depiction. See Appendix for details on those pilots. See footnotes 13 and 14 for details on the fighter aircraft configuration for this comparison.

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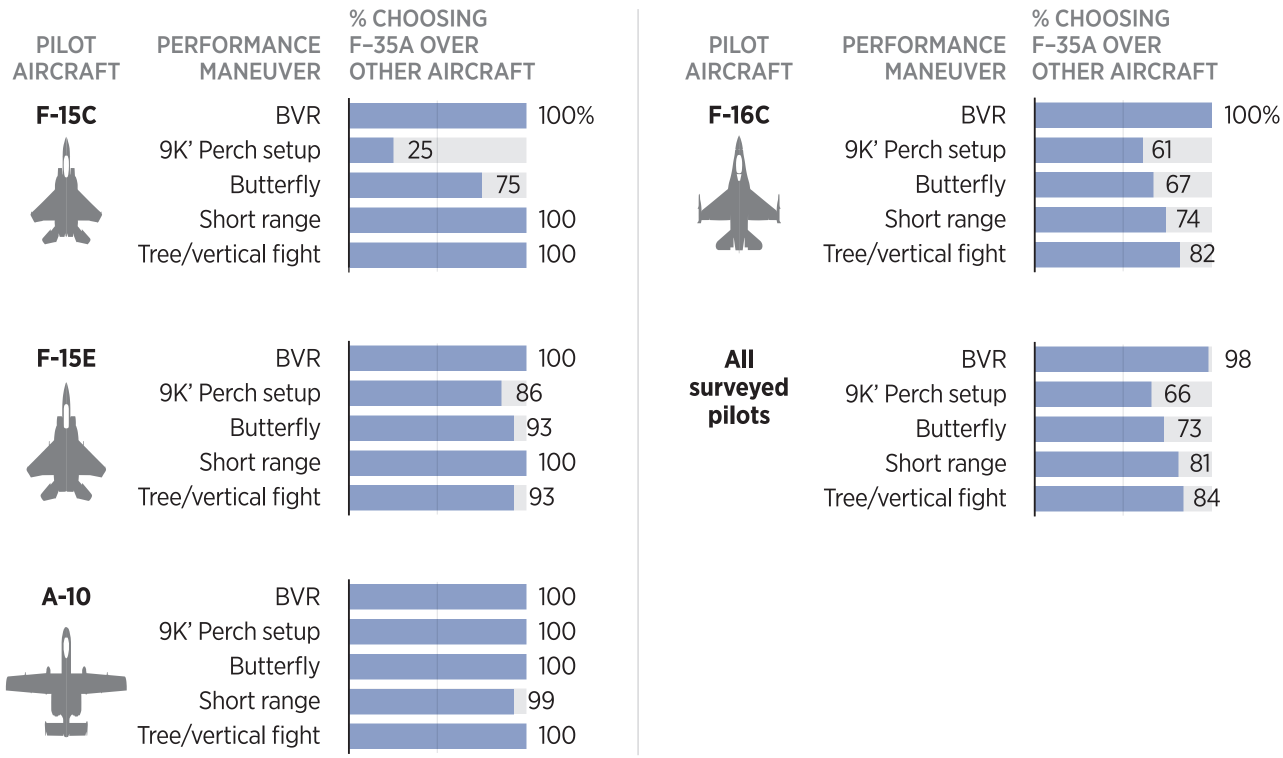
CHART 2

Former Fourth-Generation Fighter Pilots Prefer Flying the F-35



BVR—Beyond visual range 9K'—9,000 feet

SOURCE: Author's survey of 51 former fourth-generation and a single fifth-generation pilot currently flying the F-35A. The F-22 pilot now flying the F-35A selected the F-22A over the F-35A in every performance maneuver category. F-22A assessment numbers are included in the "all pilots surveyed" depiction. See Appendix for details on those pilots. See footnotes 13 and 14 for details on the fighter aircraft configuration for this comparison.

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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 set-up, for example, he felt he could outperform a pilot of equal abilities in the F-35A. Former fourth-generation pilots selected the F-35A 100 percent of the time in beyond-visual-range situations, and more than 75 percent of the time in visual dogfights where energy and maneuverability are critical to success.[15] The number one reason pilots selected their previous fighter over the F-35A in any one of the four visual fight scenarios was the fact that their previous fighter had an AIM-9X missile for those fights, and the F-35A did not. The scenario that each pilot was given included aircraft configurations for the early stages of a war where stealth was required for the F-35A. There, the jet has no external stores, and since the AIM-9X missile can only be carried externally, that missile was not available.

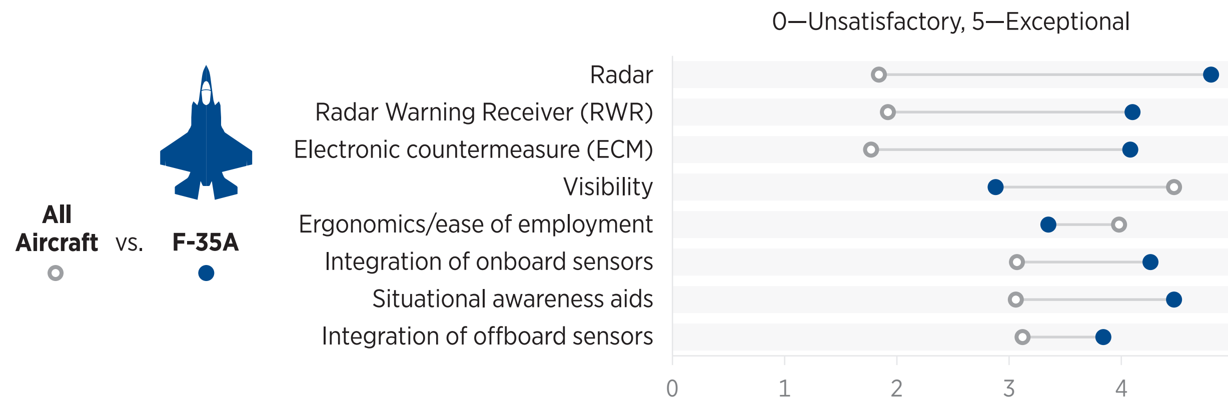
Sensor Fusion and 3F

One of the most significant complaints by pilots flying jets with pre-3F software was how the jet syn-

15. A former F-22 pilot now flying the F-35A was interviewed and chose the F-22A over the F-35A in every engagement category. That pilot's assessment was included in the "All Aircraft vs. F-35A" and "All Surveyed Pilots" assessment figures; however the limited sample size was not worthy of additional aircraft summary charts or tables.

CHART 3

How Pilots Rate Fighter Jet Avionics and Sensors (All Aircraft)



SOURCE: Author's survey of 51 former fourth-generation and single fifth-generation pilot currently flying the F-35A. See Appendix for details on those pilots. See footnotes 13 and 14 for details on the fighter aircraft configuration for this comparison.

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thesized or fused the data it received from the jet's multiple sensors and other off-board sources. The target location depicted by the radar, the distributed aperture system (DAS), the Electro-Optical Targeting System (EOTS), and other onboard systems and off-board platforms often varied enough for the jet's multifunction displays to depict multiple images for the same aircraft. This "ghosting" was mentioned as an irritant by every F-35A pilot interviewed in 2016.[16]

Although multiple sensors feed the F-35A displays, the jet's active electronically scanned array (AESA) radar is the primary sensor anytime it is pointed in the direction of a target. When the pilot turns away from a threat, the passive internal sensors and other external feeds are aggregated and displayed to give the pilot situational awareness of what he will face once he turns the jet toward the threat.[17]

The geolocation of the threat by those disparate feeds has inherent biases that may cause the jet to display more than one image for a single threat. Any multiple images are rectified once the jet's radar (or that of any other networked F-35A) acquires and refines the target location and the target track is centered on the most accurate feed—the radar track.

By all accounts, the issues with ghosting are all but a thing of the past, and the jet is performing at a level most pilots have been hoping for since they gained a seat at the F-35A table. Every pilot expressed great confidence in the jet, as well as in his ability to successfully employ it in high-threat environments.

While readily acknowledging that this new version of the software is everything they were promised, almost every fighter pilot interviewed at Hill AFB for this *Backgrounder* added a caveat, often downgrading his assessment of individual aircraft systems based on what he believed the jet was capable of in the future. This idea, and the culture of the community behind it, was summarized by one fighter pilot's comment that he is "a huge fan of the F-35[A], but it is six to nine years away from full maturity—and I won't give a top grade for the jet or any one of its sub-systems until it gets there." For how all 52 experienced pilots rated the F-35A's system and subsystem performance compared to how each assessed the fighter he previously flew, see Chart 3.

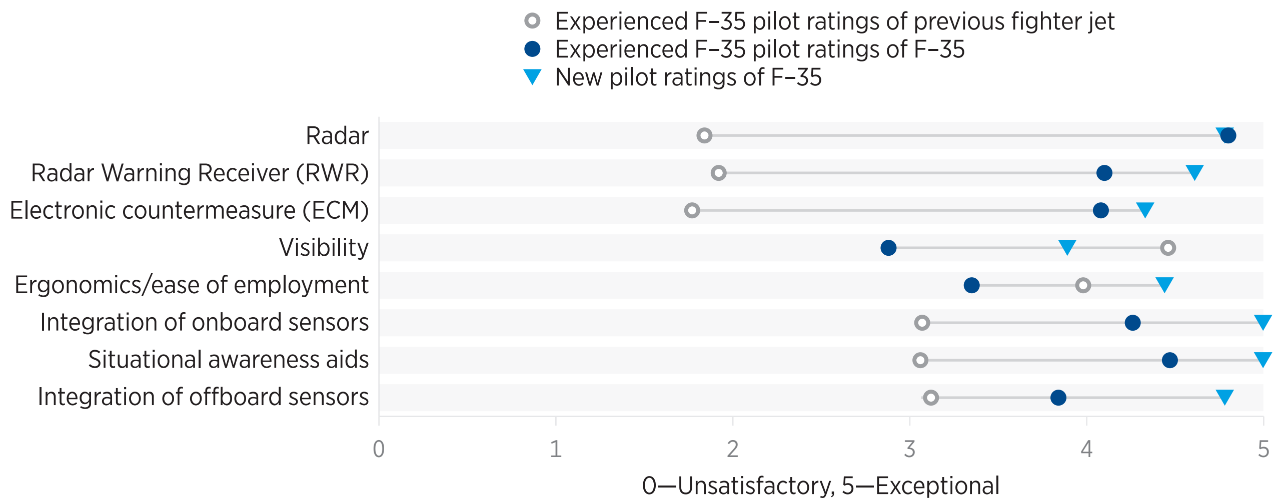
Every man and woman interviewed at Hill AFB voiced full confidence in this weapons system if called to employ the F-35A in the highest of threat environ-

16. Venable, "Operational Assessment of the F-35A Argues for Full Program Procurement and Concurrent Development Process."

17. Interview with J. R. McDonald, Vice President of Government Affairs–Joint Strike Fighter, Lockheed Martin Corporation, February 26, 2019, Orlando, FL.

CHART 4

How Experienced and Less Experienced Pilots Rate the F–35



SOURCE: Author's survey of nine pilots currently flying the F–35A who have never flown another fighter, and of 52 former fourth-generation and fifth-generation pilots currently flying the F–35A. See Appendix for details.

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ments. Its stealth, suite of sensors, and weapons portfolio will allow it to engage and destroy most threats before they are aware of the F-35A's presence. It has become the system that was envisioned when the JSF program was first established in the 1990s. However, there are sub-systems that are not up to speed, and while they do not appear to hinder employment, they heighten the stress levels and risk of what would be considered ordinary, administrative tasks for another fighter at night.

Night Operations

The majority of operational F-35A combat sorties will likely be flown at night. Almost every fourth-generation fighter pilot flying in that environment now uses some version of night vision goggles (NVGs or "nogs") to assist in everything from flying formation to spatial orientation and target identification. The view when looking out of the cockpit is generally excellent with NVGs, and the visual acuity they offer has improved over the years to slightly better than 20/40.[18] While they significantly increase a pilot's overall situational awareness (SA), NVGs do come with limitations that make their employment somewhat cumbersome.

One of the first irritants is that cockpit instruments, maps, checklists, and flight data cards cannot be read through NVG lenses, and pilots must shift their gaze under their nogs when referencing something inside the cockpit. NVGs are mounted directly on the front side of the helmet, adding four-inches of metal that pilots must consciously keep clear of the canopy when looking left or right. While the kits have gotten lighter over the years and modern versions now weigh just over a pound, their position on the helmet gives that pound quite a bit of leverage during a four-G or five-G turn, and if left in place during a combat ejection, the nogs will cause serious injury to the pilot.

The good and bad attributes of NVGs were taken into account during the design of the F-35A's helmet-mounted display system (HMDS). The HMDS delivers much more information than a fourth-generation HUD can deliver, and it projects that information directly onto the inside of the pilot's visor. This sys-

18. C. A. DeVilbiss, J. C. Antonio, and G. M. Fiedler, "Night Vision Goggle (NVG) Visual Acuity Under Ideal Conditions with Various Adjustment Procedures," *Aviation, Space, and Environmental Medicine*, Vol. 65, No. 8 (August 1994), pp. 705–709, https://www.ncbi.nlm.nih.gov/pubmed/7980329 (accessed January 30, 2019).

tem has a built-in night-vision camera that boasts an advanced bi-ocular, 30-by-40-degree field-of-view image that is also projected onto the visor, eliminating the need for separate night-vision goggles. As if that were not enough, the HMDS can also display the visual image offered by the distributed aperture system (DAS), allowing the pilot to "look through" the body of the aircraft by toggling a switch on the Hands-on Throttle and Stick (HOTAS). Collectively, this system is capable of offering pilots an exceptionally high level of spatial orientation and situational awareness.[19]

Unfortunately, the HMDS has not yet lived up to that potential. The daytime situational awareness and targeting capability that the HMDS offers is a game changer, but almost every pilot interviewed complained that the HMDS has significant issues that unnecessarily complicate otherwise administrative or mundane chores in a night environment.

Many of the tasks associated with employing fighters at night are considered routine—even pedestrian by the standards of the profession. Taking off and landing, flying formation, even air-to-air refueling at night are so well practiced that they are considered the equivalent of a walk in the park for the average fighter pilot. Hundreds of repetitions refine hand-eye coordination to a point where pilots are so comfortable with those tasks that they execute them while sharing their attention with other, often much more complex, issues. During combat ops, for example, many pilots will continue to listen to the active employment (radio) frequency in order to build or maintain their situational awareness on the battlefield while they are on the tanker boom, actively receiving fuel. That ability changes considerably when visual acuity drops in bad weather, or when a critical system fails or begins to perform below standard. Depending on the severity, those situations can test a pilot's every faculty.

The F-35A's HMDS was designed to simplify combat employment at night by blending the inputs from the night vision camera (NVC) and the DAS, along with the data normally projected on the HUD, such as airspeed, flight attitude, and weapons systems displays. Unfortunately, night system interface issues within the HMDS have made many mundane tasks so challenging that, in many cases, they become all consuming. A majority of the experienced pilots interviewed spoke of those problems, with some going so far as to say that they considered air-to-air refueling or "tanking" a near-emergency procedure. An F-16 Weapons Instructor Course (WIC) graduate with several hundred hours in the F-35A said: "Tanking at night gets my full attention and there are times where the visuals get really disorienting. Fixing the HMDS is an urgent operational need." A former A-10 instructor with equal time in the F-35A went on to say: "On several occasions, the double vision the system projected on to my visor was so bad that I had to close one eye to get on the ground [land] safely."

The HMDS has significant issues that unnecessarily complicate otherwise administrative tasks in a night environment, and fixing this system is an urgent operational need.

Simulation

The operational advantages that come with the F-35A's suite of sensors and weapons portfolio have also created challenges for airspace and electronic warfare ranges that were envisioned during the JSF's earliest stages of development. It can detect, sort, target, and engage threats at distances never envisioned during the age of unguided munitions when air-to-air and air-to-surface training ranges were cordoned off. Most overland ranges are now considered too small to allow pilots to fully exploit the jets' capabilities during training. The solution to those challenges and several others was believed to be high-fidelity simulators.[20]

With the fielding of every new fighter comes the promise of game-changing simulators (sims) that, unlike previous generations, can legitimately act as a replacement for flight time. When adding the real advances in computers and processing speeds witnessed over the past two decades, sims appear to hold even more promise.

If the Air Force could trade an hour in the air for an hour in the F-35A sim and give a pilot *more realistic* training in the process, the savings and collateral benefits would make the decision a no-brainer. By flying

19. Collins Aerospace, "F-35 Gen III Helmet Mounted Display System (HMDS)," https://www.rockwellcollins.com/Products-and-Services/Defense/Avionics/Displays-and-Controls/Helmet-Mounted-Displays/F-35-Gen-III-Helmet-Mounted-Display-System.aspx (accessed April 18, 2019).
20. James Drew, "Analysis: Next-Gen Simulation Preps F-35 Units for Battle," Flight Global, February 15, 2016, https://www.flightglobal.com/news/articles/analysis-next-gen-simulation-preps-f-35-units-for-b-421462/ (accessed April 1, 2019).

the jets half as often, the Air Force would save wear and tear on the aircraft, effectively doubling the JSF's years of viable service. The direct savings in operations and maintenance (O&M) costs would be huge over the life of the system, and that does not begin to include the collateral benefits. Flying less would free up high-demand air-to-air and air-to-ground training ranges, reduce fast-moving traffic from the FAA's overcrowded airspace, and even lower the number of noise complaints. All the while, the Air Force would reduce its risk of losing an $80+ million asset by keeping it on the ground. If the sims were as good as flying the jet, what fiscally responsible leader could argue against the trade-off?

The value of sims has always been promising, but fiscal realities drive funding and fielding trade-offs on which systems, or elements of a system, receive priority. That is particularly true when it comes to software. The idea that software in the F-35A runs everything masks the depth of that reality. Software does not merely control how individual switches and screens manipulate specific sensors, or how the sensors are fused together. The F-35A software provides the coding behind the firmware, sensors, and the database threat intelligence libraries from which they feed.

Threat intelligence libraries hold friendly and enemy weapons systems data that allow the F-35A to identify the emissions and signals associated with each. Signals intelligence and other collection methods that feed those libraries are constantly at work gathering data on the spectrum of adversary systems. Getting those updates into the JSF is obviously important.

The library also holds the weapons kinematics and stealth signature attributes of the F-35A itself, a signature that changes with the jet's position and heading relative to a threat. The jet's onboard processor then calculates that system's known detection capabilities and the kinematic attributes (speed and range) of that system's weapons portfolio, and pairs them against the JSF. The F-35A's onboard processing takes those combined data sets and calculates the real-time, dynamic capability of a threat and presents it in "breathing" threat rings to the pilot, which shows the point at which the threat can detect and engage the F-35A. In dense SAM environments and scenarios, such as the one surrounding Kaliningrad Oblast,[21] the margins between being able to kill an adversary system before it is able to fire on an F-35A are thin, which means that having the most up-to-date software and threat libraries is critical.

Both the F-35A and its simulators require regular software and threat library updates in order to stay viable. However, even in the best of budget years, funding is tight and priorities have to be set for when those systems receive software updates. There are few who would rationally prioritize sims ahead of fielding updates in operational fighters, but what may be lost in that thought is just how much time separates the two, as well as the significance of that delay.

The pilots at Hill AFB conveyed genuine confidence in the 3F update that was fielded in the jets at Hill AFB in 2018. That operational software package gave pilots an expanded weapons portfolio, a threat library that allows them to engage the S-400 SAM system,[22] and it fixed many irritants and issues found in previous software updates. While many spoke positively about the simulator's ability to help them train for high-threat scenarios, the 3F software update has not yet reached the sims. Those delays are in line with every other software update that has reached the F-35A to date, and often mean that the simulator is operating on software that is *two* updates behind.[23] Most every pilot complained that threat libraries in the simulators were now so out of date that they often delivered training that would undermine their chances of being effective in combat.[24]

If the history of Air Force simulator programs can be used as a guide, that lagging trend for soft-

21. Kaliningrad Oblast is a Russian exclave between Poland and Lithuania that most refer to simply as "Kaliningrad." The surface-to-air-missile systems Kaliningrad are layered in a way that makes employing fighter aircraft in that area incredibly challenging. The effective range of those systems can put aircraft operating over Sweden, Poland, and much of the Baltic Sea at risk.

22. The S-400 surface-to-air missile system is comprised of four different missiles with ranges from 40 km (24 nautical miles) to 380 km (230 nautical miles). The acquisition and target-tracking radars of each sub-system are networked and provide seamless coverage from the surface to well over 100,000 feet of altitude.

23. Major General Scott Pleus, Director of Plans, Programs and Requirements, Headquarters Air Combat Command; response to query, March 21, 2019.

24. The actual term used was "negative training"—which means training that would undermine their chances of being effective, or of surviving in combat.

ware updates will not likely change over the life of the F-35A. Unfortunately, lagging software was not the only difference between the sim and the jets that the pilots pointed out.

While sim operators will inject failed subsystems and emergency situations to help pilots prepare for those eventualities, there are other "soft" degradations that happen in the air that the sim does not replicate.

Sensor fusion has improved markedly in the aircraft, but there will always be situations when the F-35[25] displays present multiple or duplicate images for a single threat. The foundational systems and geospatial algorithms in satellites, U-2s, and other off-board platforms will feed the JSF coordinates that are slightly different than those plotted by F-35A sensors. The F-35's radar is by far the most accurate and trusted sensor within the JSF's fusion feed options. When it tracks a target, the fusion algorithm correlates its tracks with other F-35 sensors and off-board feeds, and the jet's fusion process eliminates the respective errors, "fusing" whatever multiple tracks there may be for the same target together to what is really there.

When an F-35 turns away from the threat and there are no other F-35s pointed down range, the system's master fusion sensor is no longer able to track those targets. As other systems continue to feed the pilot situational cues on the threats behind him, the opportunity for multiple images to appear for the same target returns. Most every pilot interviewed felt that the process is both accurate and consistently works well in the jet, but that very real anomaly does not happen in the simulator because sensor fusion there works ideally.

That ideal is still at work when multiple pilots are flying a simulator mission together (in up to four linked sims), and the pilots in each of the simulator cockpits near magically see the exact same picture. The same thing is true for the ground-mapping capability of the AESA radar. The sim always presents a crystal-clear picture of the threat array on the ground, something that does not always occur in the jet. This means that pilots flying the sim never suffer or have to mentally sort through the variances and degradations that are a natural part of real-world flying.

That degradation-free ideal, coupled with software funding and fielding decisions, has opened up a gap in realism that will likely grow, if only slightly, over the years. Advocates and those holding out hope that JSF sims will buck historic trends and surpass live training, point out the fact that the budget for simulators is only now beginning to bear fruit. A new simulator building is, after all, under construction at Hill AFB, and if the Air Force gives simulators the same software funding and fielding priority as it does the jets beyond that building's christening, they may very well be right. Unfortunately, if the history of more than 30 years of high-fidelity sims is a guide, that is not likely.

When the JSF was on the drawing board, Air Force leaders rightfully envisioned that its great capabilities would also bring significant training challenges. Limits in range space, range emitters (appropriated-enemy SAM systems or their facsimiles), adversaries, support aircraft, and associated funding put simulators at the top of the list of potential solutions to those challenges.

Distributed Mission Training (DMT) allows pilots to link multiple simulators together to execute a Large Force Employment (LFE) mission together. LFEs are an integral part of operational F-35A employment, and with aircraft and training airspace limitations, the burden for those employment repetitions was designed to fall on multiple sims at different locations being networked together. Unfortunately, DMT has not yet materialized for the F-35A. The first location scheduled to go on line with DMT is Nellis AFB in Nevada in 2019,[26] and as other units go operational, bringing DMT up to speed will likely take precedence over other costly sim improvements.

In their current state, F-35A simulators were not viewed as a viable replacement for time in the air by the vast majority of pilots interviewed for this *Backgrounder*. To partially remedy that issue, software updates for the F-35A simulator should be concurrent with those made to the aircraft, and the number of simulators connected through the DMT must be expanded to incorporate the standard number of aircraft in an LFE package. In an ever-tightening budget environment, assuming that the Air Force or the Joint Program Office will elect to pour more money

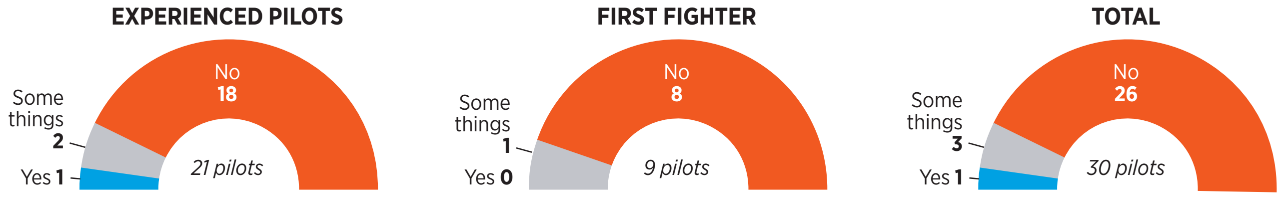
25. While the three variants of the F-35 were designed to operate in different environments, the sensor package, onboard avionics, and central processing units are identical. In this *Backgrounder*, the term JSF (or F-35 without the variant—A, B, or C) applies to all three JSF/F-35 variants.

26. Woodrow Bellamy III, "DMT Will Enable Up to 12 F-35 Pilots to Virtually Fly Together," *Aviation Today*, November 2, 2018, https://www.aviationtoday.com/2018/11/02/dmt-will-enable-12-f-35-pilots-virtually-fly-together/ (accessed April 18, 2019).

CHART 5

Can F–35 Simulation Replace Time in the Jet?

Q: "Do you believe flight time in the simulator is a viable replacement for time in the jet?"



SOURCE: Author's survey of 30 fighter pilots currently flying the F–35A at Hill Air Force Base, Utah. See Appendix for details.

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into the sims instead of adding operational capabilities to the aircraft is a bad bet.

That in no way means that sims are not valuable, as most pilots believed they were an important addition to live training. However, in their current form, simulators are not adequate replacements for the training ranges, emitters, and adversaries they were supposed to replace. Fortunately, a viable solution for training is still up in the air.

Embedded Training

The F-22 Raptor was the first fifth-generation fighter ever fielded, and with it came every training challenge envisioned for the F-35A. The Raptor's capabilities far exceeded the limited number of air-to-air assets available for most day-to-day training sorties, and while two of the jet's first basing locations had massive ranges, they were over water, leaving pilots with very limited access to training opportunities with threat emitters that could replicate today's high-end SAM threats. One approach to solving the challenge of training Raptor pilots was to develop embedded training.

Modern-day fighters have exceptionally fast and capable computer processors that allow them to do much more than handle the computational requirements of basic fighter employment. Over the past 15 years, simulations have been developed and embedded within those processors that allow pilots to activate and engage with fully interactive live, virtual, constructive (LVC) simulations while in flight.[27]

Today, F-22s can very rapidly plan an embedded training mission with reactive, synthetic, air-to-air and surface-to-air threats. The simulation actually calculates the changing stealth signature of an F-22 as it approaches, employs on, or reacts to simulated enemy systems. Those systems can be programmed to "turn on," or Russian SU-35 fighters can be triggered to enter the fight, as the F-22 reaches a certain point in a scenario, causing Raptor pilots to react in real time.[28]

The F-35A has a similar embedded training (ET) capability that allows pilots to build simulated combat scenarios with up to four virtual (synthetic) air-to-air adversaries, and 10 SAM systems on a single mission.[29]

F-35A ET was designed to have several internal modules that handle everything from the mission-planning elements to debrief playback. Adversary air and ground threats are programmed during mission planning and embedded in the jet's computer through data-transfer cartridges, which pilots use to load mission details into the jet.

That ET simulation was envisioned to be robust and all inclusive, taking the jet's radar-warning systems, fire control radar, missiles, chaff, and maneuvering into the live/virtual simulation, and to realistically assess hostile capabilities, as well as F-35A

27. "USAF Integrates F-16 and F-22 Fighter Jets During LVC Exercise," Air Force Technology, August 8, 2016, https://www.airforce-technology.com/uncategorised/newsusaf-integrates-f-16-and-f-22-fighter-jets-during-lvc-exercise-4973955/ (accessed April 1, 2019).

28. October 29, 2018, interview with a former F-22 pilot, now flying the F-35.

29. North Atlantic Treaty Organization, "F-35 Embedded Training," October 2009, https://apps.dtic.mil/dtic/tr/fulltext/u2/a567738.pdf (accessed April 10, 2019).

weapons effectiveness down to hit calculation and probability of kill—assessments that currently have to be done on the fly in simulators. As envisioned, the interactive playback tool generates a synchronized representation of the cockpit displays, aircraft flight tracks, and shot/event lists.[30]

Unfortunately, as the F-35A program began to suffer cost overruns, funding for ET was diverted to other parts of the JSF, and while it is still available to use, it does not quite measure up to the lofty goals once envisioned. Like the F-22's training program, the F-35A's ET allows multi-ship formations of F-35As to train together and to replay every aspect of the tactical portion of the mission in all three dimensions.

However, the F-35A does not employ the click-and-drop mission planning capability of the F-22, and the F-35A ET mission-planning software is both non-intuitive and labor intensive. Using the program requires special training, and even the pilots that have been through it find it so cumbersome that most forgo the opportunity.[31]

A second challenge involves the fidelity of the visual displays offered in this embedded training simulation. One of the primary roles that the F-35A will play in a high-end, force-on-force conflict is to take down an adversary's integrated air-defense system. The layered defenses of a Russian S-400 SAM system are complex, and its sub-components (batteries) consist of networked mobile acquisition and targeting radars and missile transporter erector launchers (TELs) that are geographically dispersed. The F-35A's exceptional sensors and geolocation capability allow the jet's AESA radar to build a vivid picture of each targetable element. With that picture, a flight of four or more F-35As can sort, target, and engage the system as a team.

Unfortunately, the ET air-to-surface threat array presentations are too generic to allow pilots to sort and target individual elements within a SAM system. It provides pilots with a simulated threat—but not a target array that can be attacked.

A third limitation is that the detection ranges and engagement capabilities of the threats are set or contrived by the mission-planning team who builds each scenario. Operational F-35As have the most up-to-date threat library in the world, and yet this system does not draw from it in any way. Nor does the ET program take the jet's changing azimuth and associated radar cross section into consideration in any facet of the simulation.

The F-35A's embedded training system needs user-friendly software with a selection of both canned (pre-programmed) and tailorable SAM batteries that allows mission planners to quickly design and capture mission scenarios. Those threats should be tied to the jet's threat library and include dynamic and correlated F-35A stealth signatures into its calculations—just like the jet does against real-world threats.

Whether working these changes through the two Dutch companies who own the intellectual property (IP) for the current F-35A embedded training software (Dutch Space and NLR[32]), or starting over with Lockheed Martin using the F-22 ET as a baseline, funding and an iterative approach will be required to develop the aircraft coding and the mission-planning software pilots will need for threat scenario design and mission planning. Once the ET has come up to speed, little maintenance and funding should be required to keep it going, since warfighting software and threat library updates that are made to the jet will keep the LVC completely up to speed. The potential for exceptional training and cost savings is pretty big with this approach to ET.

The F-35A system is so precise and refined that it will only identify real-word systems as threats. When it does, the JSF's system will display *"breathing"* threat rings around enemy acquisition radars, SAMs, or fighters that expand and contract to let the pilot know when those threats can target his jet. Those threat rings give pilots incredible levels of situational awareness in combat—and when flying on an electronic warfare (EW) range in peacetime. Unfortunately, the vast majority of EW range "threats" are emitters designed to replicate real-world systems—not the systems themselves. The JSF will not tie breathing threat rings to emitters it knows are not threats, which really limits the training pilots get on those ranges.

Still, those emitters are accompanied by mock missile sites that contain structures that resemble

30. NLR, "The LVC Enable for Fighter Aircraft," https://www.nlr.nl//downloads/f261-nlr-dutchspace.pdf (accessed April 19, 2019).

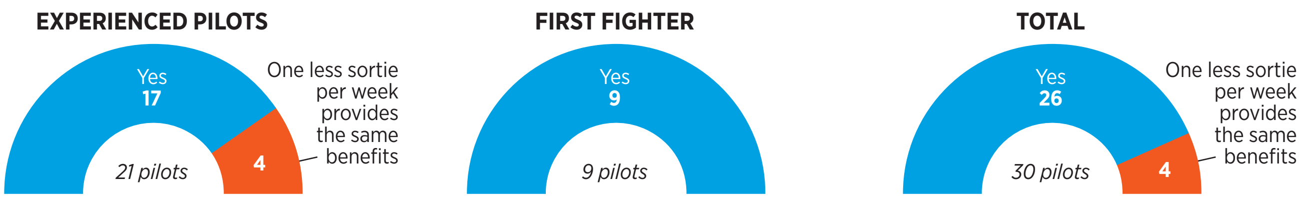
31. Oral statements by several F-35A pilots interviewed between October 29, 2018, and November 1, 2018, at Hill AFB, UT.

32. "Lockheed Receives F-35 Embedded Training System," Air Force Technology, July 15, 2012, https://www.airforce-technology.com/news/newslockheed-e-cats-dutch-space/ (accessed April 1, 2019).

CHART 6

How Many Sorties per Week Should Pilots Fly?

Q: "Do you agree with this statement regarding proficiency and sorties per week? If I fly two sorties or less a week, my skills in the jet diminish, flying three per week maintains and sustains my skills, and when I fly four times or more a week, my skills in the jet improve across the board."



SOURCE: Author's survey of 30 fighter pilots currently flying the F-35A at Hill Air Force Base, Utah. See Appendix for details.

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an enemy system—its acquisition and tracking radars, missile TELs, and associated vehicles. The emitter signal allows the jet to find and fix the site, and the ground mapping function of the AESA radars "paint" the targets that flights of F-35As use to sort and target that system. Dummy missile sites are not that expensive to build, but they are rarely moved or reconfigured, and once a pilot has seen it the first time, the training value it offers decreases substantially with every pass he makes on the same site.

If the Joint System Planning Office elects to invest in ET to bring it to its full potential, it can simultaneously reduce requirements to place and man range emitters, or construct new SAM sites, which will save money. And, U.S. and partner-nation pilots can plan and execute unique, demanding, and realistic sorties where nominal system degradations, real weather, and the influence of Gs are unavoidable—challenges that will never be available in the simulator.

The F-35A embedded training system should be redesigned to include user-friendly mission-planning software to include a selection of canned and tailorable SAM systems. Threats should be pulled from the jet's library and paired against the jet's real stealth signature for all employment calculations.

Pushing for concurrent software in JSF simulators and investing in embedded training can give the Combat Air Forces (CAF) a huge advantage in generating the number of experienced pilots that will be required to fill the rapid growth in the number of operational F-35A squadrons on the horizon.

F-35A Operations

In order to be combat ready, operational fighter squadrons must not just develop the skill sets of the wingmen, flight leads, instructors, and mission commanders currently qualified for those roles in their units. They must also train replacement pilots as they arrive, and grow the generation of flight leads, instructors, and mission commanders required to replace the generation that departs for other assignments. Balancing those demands is hard enough in well-established squadrons, but doing it in units transitioning to a new weapons system like the F-35A presents unique challenges. In order to more fully grasp this issue, one must understand how the Air Force grows and matures pilots, and what it takes to be considered "experienced."

Individual pilot skillsets are grown through the number of sorties and hours each pilot flies, and the depth or intensity level associated with each mission. Both sorties and hours are important, and as such, they are carefully tracked; but there is an important distinction between the two. When a pilot flies multiple sorties on back-to-back days, the repetitions allow him to develop habit patterns, muscle memory, and the hand-eye coordination so critical to making flying the jet second nature. With regular repetitions, employing a fighter becomes subconscious, allowing those pilots to focus on exploiting the tactical situation at hand. In that state, pilots do not have to think about flipping switches or remembering how to call up specific displays. Pilots who are able to fly aircraft at the "subconscious" level are ready to execute the squadron's mission in combat.

The Air Force places a distinct value on the number of sorties that pilots receive, and it further tracks the individual training events that pilots accomplish over the preceding 30-day, 60-day, and 90-day periods. But there are unwritten guidelines on the rate at which pilots fly, which have been around for decades, and which are, perhaps, even more important.

When a pilot flies two sorties or fewer a week, his competence and confidence continually wane. Conscious and subconscious faculties falter, and most end up having to think their way through even administrative tasks in the cockpit. Pilots flying three times a week can generally maintain the skills they entered the week with, but those that fly four times or more in a week get better at (seemingly) everything. Here, flipping switches, calling up displays, and complex tasks like air-to-air refueling are so well practiced they can be executed almost without thinking, allowing their focus to remain on dominating the fight.

Competencies at any level are perishable, and if those same pilots fall back to a rate of flying two sorties or fewer a week for several weeks in a row, most will lose that subconscious processing capacity and the employment confidence that comes with it.[33] Like the generations that have preceded them, every inexperienced pilot and the vast majority of the experienced fighter pilots interviewed by this author over the past three years have reaffirmed those guidelines.[34]

Hours are also important. Time in the air opens pilots up to the school of hard knocks where bad weather, low fuel states, and sub-system failures challenge their faculties in a way that builds pilot confidence. Unlike in a simulator, every situation in the air has to be taken to a logical conclusion in real time with a pilot's flesh-and-blood body on the line. Simulators offer great training for those moments, but their value pales in comparison because pilots can pause the simulator and talk through how they could successfully recover the jet while on the ground. Simulators are excellent for procedural training, but the successful handling of an emergency in the sim does not offer the surge in confidence that pilots get after safely recovering an aircraft.

Unlike other volatile skill sets, the air sense (airmanship) and confidence that come through repeatedly handling high-pressure situations in the air actually accumulate and generally stayswith pilots throughout their careers.

Over decades and decades of developing aviators, the Air Force determined that it takes recent flight school graduates 500 hours in a specific fighter to gain enough confidence to be considered experienced. Those who have crossed that experience threshold in one type of jet need 300 hours to be considered experienced in another fighter.[35] The designation is important, since, once a pilot is labeled *experienced* in a weapons system, he is ready for supervisory positions, such as flight lead, instructor, or mission commander—positions that are important not just to that individual's growth, but for growing the generations of pilots required to fill unit-wide and Air Force–wide demands for mission-ready pilots.

Sorties and hours are important, but the details are equally so. For example, a single six-hour mission with the pilot flying from one airfield to another is not nearly as valuable as flying four 1.5-hour sorties due to the former's lack of complete sortie repetitions.

Gaining hours and sustaining robust pilot sortie rates are important, but how does the actual quality of sorties fit into the picture, and how is that quality measured?

The potential growth of any mission is determined by the combined value of four individual sortie elements—mission planning, briefing, execution, and the debrief. The subtle variables and all-important nuances within each element are hard to grade, and there is no accepted fighter standard for the quality

33. John Venable, "Independent Capability Assessment of U.S. Air Force Reveals Readiness Level Below Carter Administration Hollow Force," Heritage Foundation *Backgrounder* No. 3208, April 17, 2017, https://www.heritage.org/defense/report/independent-capability-assessment-us-air-force-reveals-readiness-level-below-carter.

34. The author interviewed 76 USAF fighter pilots over the past three years, asking the same battery of questions regarding aircraft performance, simulator capabilities, and individual requirements for flight time. Sixty-one of those pilots, along with their backgrounds, are detailed in Appendix Table 1 of this *Backgrounder*. In addition to those, the author interviewed 15 operational F-16 pilots at Spangdahlem Air Base in Germany in March 2017.

35. Albert A. Robbert, "Reducing Air Force Fighter Pilot Shortages," RAND Corporation, 2015, p. 8, https://www.rand.org/content/dam/rand/pubs/research_reports/RR1100/RR1113/RAND_RR1113.pdf (accessed April 19, 2019).

of any one area. Left to their own devices, the inclination common in operational units, however, is to strive for the "ideal" in each of the four areas. In that regard, fighter pilots follow the lead of their Weapons Instructor Course graduates—pilots who continually push for more demanding standards like the ones they fed on when they were students at Weapons School.

The Weapons School Standard

The best instructor pilots, executing the most up-to-date tactics in the world, are at the United States Air Force Weapons School at Nellis AFB.[36] Those selected to attend the school are highly experienced instructors from operational and training units with proven track records. Once there, those students enter an otherwise meat grinding, six-month-long curriculum designed to take a deep dive into every aspect of planning, briefing, flying, and debriefing. Every sortie is flown with and graded by the best instructor pilots in the world. The course is so intense, and the expectations so high, that the students have no duties other than training. All chores associated with a flying unit are absorbed by the staff.

Planning for the most complex missions for the Weapons School curriculum takes the students a full day. The actual briefing and flight generally consume less than five hours, but the debriefing often takes another eight, adding up to two days to execute one sortie.

That pace allows upgrading pilots to squeeze every ounce of learning from every mission. Course graduates leave with the confidence to not just lead employment packages from the point, but also to technically dissect and explain any aspect of a flight to the best pilots in their home units.

The Weapons School can afford two days to execute every sortie because students are programmed to fly just 35 sorties in the six-month syllabus.[37] Time is much scarcer in an operational unit. There, fighter pilots need to fly many more sorties every six months to hone their skills, while also executing additional duties required to keep the squadron running, preparing for and deploying overseas, and participating in regional exercises.

And, time becomes even scarcer when flying combat missions. There, long sortie durations, or the requirement to fly multiple combat turns in a single day, all but eliminate the ability of mission pilots to plan their own missions or enjoy anything more than a cursory debrief. Pilots are handed mission materials developed by planning teams, and every combat pilot has to have the ability and the mindset to rapidly scan, digest, and successfully execute those missions.

Without question, growing the depth of experience or skills for individual pilots is important, but operational squadrons must also grow the actual number of people who meet the definition of an "experienced" pilot. Growing that experience requires increasing the sortie tempo rates that allow pilots to literally fly more sorties and hours. Missions that take two days to plan and execute may be ideal for depth of learning, but they limit the number of repetitions that individual pilots can fly on any given week, and repetitions are important to growing a squadron's breadth of experienced pilots in a unit.

The leadership at Hill AFB has executed the F-35A transition exceptionally well. Operations has taken full advantage of the hand-picked, highly select manning of this first operational wing to explore this new jet with an unrivaled suite of sensors and capabilities. As the wing's maintenance team was gaining its F-35A footing, the associated low sortie rate preserved the operators' drive for mission complexity and depth. There is little question that the F-35A will be employed in LFE packages during the opening days of a conflict with a near-peer competitor. Furthermore, the desire to sustain a pace that allows regular two-day LFE sorties was stated unequivocally by every pilot interviewed at Hill AFB.

But now the maintenance team at Hill AFB can produce more lines (sorties) than the wing's pilots currently fly,[38] and the Air Force must consider striking a balance between two-day LFEs and increasing sortie tempo rates. Accelerating sortie rates will increase the breadth of operational and maintenance experience levels and help offset the F-35A manning and fielding challenges that are on the horizon.

Squadrons require experienced flight leads and instructors who can train and supervise the growth of pilots at every skill level. To date, Hill AFB has

36. Nellis Air Force Base, "United States Air Force Weapons School," https://www.nellis.af.mil/About/Fact-Sheets/Display/Article/284156/united-states-air-force-weapons-school/ (accessed April 19, 2019).

37. Paul Kennedy and Guy Aceto, photographers, "Weapons School" (photos), *Air Force Magazine*, June 1996 http://airforcemag.com/MagazineArchive/Magazine%20Documents/1996/June%201996/0696weapons.pdf (accessed April 19, 2019).

38. Interviews with two squadron commanders and multiple squadron schedulers, Hill AFB, UT, November 6, 2018.

been stacked with highly experienced fighter pilots who have transitioned from other units. Accessions of first-assignment fighter pilots (those right out of flight school) that began just over a year ago will grow, and in very short order, every squadron will need to spend more time and resources (re)building the pyramid of mission-qualified wingmen, flight leads, and instructors.

As additional weight, the quality of those first-assignment pilots will also change. To date, the system has "hand-picked" flight-school graduates for the F-35A. As the CAF-wide F-35A fleet expands, the ability for the system to continue that practice will wane. As the number of new arrivals grows and their overall quality fades, leaders will be forced back into an age-old challenge: to balance the depth of learning with the additional repetitions those incoming pilots will need to employ in combat.

Mastering the individual elements executed within an LFE is done through repetitions that the literal size of those sorties often precludes. In the past, fighter squadrons have broken LFE elements up into building-block sorties where pilots were given the opportunity to master those individual elements. In fourth-generation aircraft, those elements were separated into sorties that focused on the missions and mission elements of Defensive Counter Air (DCA), Offensive Counter Air (OCA), Suppression of Enemy Air Defenses (SEAD), Low Altitude Tactics (LOWAT), Air Combat Maneuvering (ACM), and Basic Fighter Maneuvering (BFM)—sorties that can be flown with relatively little planning.

While the benefits of breaking up mission elements into separate sorties may not be innately obvious, looking at a single mission area may be helpful in understanding why they are needed, and how they add up.

BFM is best visualized by classic dogfighting common during World War I and World War II. Many believe that the odds of a fifth-generation F-35A being forced into a dogfight are low, but with the small number of air superiority F-22s and that jet's historically low mission-capable rate, it is very likely the F-35A will be tasked with air-to-air roles in the next major war. Those missions inevitably degenerate into opportunities where out-fighting an adversary in dynamic, high-G engagement means the difference between life and death.

The Pratt & Whitney F135 engine is the most powerful motor ever mounted in a U.S. fighter, and had the weight of the F-35A stayed true to the original design, the thrust-to-weight ratio would have taken much of the challenge of energy management out of a JSF pilot's crosscheck. Unfortunately, the jet grew much heavier than planned, considerably lowering the jet's thrust-to-weight ratio. That fact, coupled with a pilot's ability to pull energy-depleting nine-G turns at any given point in the sortie can set pilots up for failure. High G-loadings placed on aircraft without equally high thrust-to-weight ratios can bleed energy quickly, resulting in a pilot being so low on airspeed that he is vulnerable to otherwise innocuous threats.

Learning to master the energy state of any fighter takes regular BFM repetitions. However, with the focus on LFE sorties, F-35A pilots are only averaging one BFM sortie every 20 missions. That equates to one BFM sortie every two months—or six a year, a number that is nowhere near what it takes to learn, much less master, that skill set in this new jet. The same thing can be said for other mission elements where developing a pilot's hands are more important than his faculties as a sensor operator.

As long as the building-block sorties are in place, flying one LFE mission a week is a healthy rate. And if the community adjusted the expectations for flight-member presence in mission planning and cut debriefs to truly essential elements, it would free up room for more elemental blocking-and-tackling sorties that would help pilots master LFEs, no matter their flight school ranking.

The move will certainly open up the organization's leadership to challenges and potential counter accusations of choosing quantity over quality, but the F-35A weapons system is about to grow very rapidly. By 2024, the Air Force will accept the delivery of at least 60 F-35As every 12 months, equating to two-and-a-half new squadrons every year. Growing the CAF-wide operational experience that is required to man those cockpits is a huge challenge. Transitioning an active-duty squadron from a fourth-generation fighter to a mission-ready state in the F-35A takes up to a year and a half.[39] If organizations that are already mission-ready with the F-35A accelerate the pace at which they grow experience, they can help shorten the time it takes for follow-on Wings and the expanding F-35A operational fleet to become mission-ready.

39. Interview with General David Goldfein, Chief of Staff, USAF, on February 12, 2019.

A pilot arriving from the flight school pipeline will have just over 100 hours in the F-35A when he is finished with unit mission qualification training. While the math is not pure, that generally means that the pilot will need 400 more hours of flight time before he will be considered for flight lead. In 2018, the average F-35A pilot received just over 130 hours of flight time.[40] At that rate it will take a new arrival three-and-half more years to reach the experienced milestone. Increasing a pilot's hours per year to 200 drops the time it takes to become experienced down to one assignment in the F-35A. Increasing it to 300 hours a year grows an experienced pilot in a year and a few months—which would allow that pilot to begin growing the generation that follows him.

While that sortie rate seems far-fetched, it is anything but. When the F-16C first arrived at Torrejon, Spain, in 1987, new pilots frequently averaged more than 300 hours a year.[41] Line fighter pilot wingmen, flight leads, and instructors should average a minimum of three sorties in the aircraft a week to grow or sustain their skillsets, as well as grow the F-35A experience level with the CAF. Doing that in the F-35A would accelerate the maturity of the unit and allow the CAF to begin moving more experienced flight leads and instructor pilots (IPs) to other transitioning units—all with the goal of accelerating the mission-ready status of the next transitioning Wing. Recent squadron revitalization in the Air Force could actually make accelerating the pace much easier than it was in years past.

Blue Force Program Paying Off

Many of the tasks associated with a functional fighter squadron do not require a pilot's skill set to execute. Two years ago, Chief of Staff of the Air Force (CSAF) General Dave Goldfein started an initiative to revitalize the squadron by adding support personnel to units to handle those tasks.[42] The program is called Blue Force, and every pilot interviewed spoke glowingly about how much time those additional support personnel saved him, and how important it was to sustain that program.

Growing experience as quickly as possible needs to be a priority across the F-35A community, and the CSAF's initiative has made possible the ability to do just that. Ultimately, this will mean flying more sorties, and, while it may seem counterintuitive, those additional sorties will actually help the F-35A maintenance team to grow experience.

Maintenance. The F-35As at Hill AFB are flying incredibly well. The rework and subcomponent redesigns of issue-laden parts fielded in early production F-35A aircraft have paid big dividends. In November 2018, the wing's fleet of 46 jets sustained a 92 percent Code 1 rate. That means that 92 percent of the time, every F-35A landed without any issues or discrepancies whatsoever. While aircraft coming off mature production lines are expected to fly well in their first years of operational life, the 92 percent Code 1 rate at Hill AFB surpasses virtually any other fourth-generation or fifth-generation aircraft at any stage of operational life.

A Code 2 aircraft is one where the pilot discovers minor discrepancies during the flight, but assesses that the jet is still fully mission capable. Aircraft designated as Code 3 have discrepancies, failures, or issues in mission-essential equipment that require repair or replacement before the jet can be scheduled to fill an operational line.

When maintenance is tasked to repair one of those discrepancies, the F-35A's airframe and skin-coating design have allowed the jet to be much more sustainable and maintainable than previous stealth platforms. Access to critical, and frequently serviced, avionics bays that hold pop-in, pop-out line-replaceable-units (LRUs)[43] were designed so that 86 percent of all avionics reside behind doors and panels with non-low

40. Headquarters U.S. Air Force, Deputy Chief of Staff for Operations, written response to Heritage Foundation request for information on Air Force flying hours and manning levels, April 9, 2019.
41. Author's personal experience as a fighter pilot in the 613th Fighter Squadron, 401st Tactical Fighter Wing, Torrejon Air Base, Spain, August 1987–August 1990.
42. Stephen Losey, "Goldfein: Air Force Must 'Redefine Our 21st Century Squadron,'" *Air Force Times*, September 20, 2016, https://www.airforcetimes.com/news/your-air-force/2016/09/20/goldfein-air-force-must-redefine-our-21st-century-squadron/ (accessed April 1, 2016).
43. A line-replaceable-unit is a specially designed box or container filled with electronics that slides into, and can be latched securely within, a specific bay or compartment in the fuselage of an aircraft. The simple design incorporates wiring connectors that make it easy for a technician to open a panel, pull the failed component out, and replace it with a new or refurbished one right on the flight line.

observable (LO) seals.[44] This means that the most frequently accessed panels require no special handling—no stealth recoating or cure time. Many Code 3 failures can be repaired in a few hours, if not a single maintenance shift, if the parts and technical data are available.

The panels that allow access to the remaining 14 percent of LRUs require varying degrees of low observable (LO) repair and cure times that run between a couple of hours and a couple of days,[45] but the stealth treatments are exponentially easier to maintain, sustain, and restore than those on the F-22.[46]

Still, there are shortfalls, anomalies, and failures that caused six of Hill AFB's 46 F-35As to suffer Code 3 issues last November that took them off the flight line for extended periods of time. That would have left the wing with 40 jets (86 percent of the fleet) to build the daily schedules, had there been no other production challenges.[47] Before discussing those other challenges, it is important to understand how critical the F-35A's Autonomic Logistics Information System (ALIS) is to every aspect of F-35A maintenance, supply, and operations.[48]

Autonomic Logistics Information System (ALIS). Every aspect of the F-35A's maintenance, supply, and operations are managed through the F-35A operating system, commonly referred to as ALIS. Much like an Apple iPhone Operating System (IOS), ALIS is a computer operating system that holds a conglomeration of 65 applications, sub-programs, or modules. Some were built exclusively for the F-35A, others are commercial-off-the-shelf (COTS) programs, and each module is accessed through a drop-down menu, just like one might find Microsoft Word or EXCEL on any modern-day computer.

ALIS uses interactive 3D technology to streamline operations, maintenance, prognostics, supply chain, and customer support services data.[49] It holds a massive digital data warehouse of information that is continually updated, and it provides that data to every module within the operating system.

ALIS Applications for Maintenance. The four modules that maintenance units routinely use are the Anomaly and Failure Resolution System (AFRS), the Computerized Maintenance Management System (CMMS), the Joint Technical Data (JTD), and the Squadron Health Management (SHM). These programs are designed to give maintenance technicians—with the click of a mouse—immediate access to an aircraft's maintenance history, the specific fault tree associated with a recently flagged malfunction, a step-by-step guide on accomplishing F-35A repairs, as well as interactive, 3D diagrams throughout the repair process.[50]

The AFRS is a solid module that assists technicians in troubleshooting the faults with step-by-step checklists. The JTD module is a bell-ringer and, while there are still shortfalls within this program that are discussed below, there is not a maintainer on an F-35A flight line who would want to lose the incredible capability he now has at his fingertips.[51]

The SHM module provides maintenance with prognostic health reporting codes and post-flight status of every F-35A after it lands. If a code either predicts or reports a sub-system failure, it will automatically create work orders for repair, and order the spare parts that maintainers will need to get the jet back on the flight line. This program, and the chain of events it triggers, is where several of the largest ALIS challenges remain.

44. Stealth platforms have low observable airframe and skin designs that mask the presence of that aircraft to radar. The panels that allow technicians access to LRUs must preserve the low observable (LO) design of the stealth platform. The location of each panel determines which (if any) additional precautions must be taken to preserve the LO characteristics of the jet. Eighty-six percent of the F-35A's avionics can be accessed through panels that require "no additional" precautions—meaning that no additional LO treatment is required following the opening and closing of those panels.

45. Interview with Colonel Michael T. Miles, 388th Maintenance Group Commander, November 1, 2018.

46. John A. Tirpak, "The F-35 and F-22 Teach Each Other New Tricks," *Air Force Magazine*, February 2018, http://www.airforcemag.com/MagazineArchive/Pages/2018/February%202018/The-F-35-and-F-22-Teach-Teach-Other-New-Tricks.aspx (accessed April 19, 2019).

47. Ibid.

48. Lockheed, "ALIS: Keeping the F-35 Mission Ready," three-minute video tutorial on the Autonomic Logistics Information System, May 31, 2017, https://youtu.be/yqShP6R5P6g (accessed April 19, 2019).

49. Phillip Tracy, "Case Study: Lockheed Martin Uses Big Data for F-35 Maintenance," RCE Wireless News, September 2, 2016, https://www.rcrwireless.com/20160902/internet-of-things/case-study-lockheed-martin-uses-big-data-f-35-maintenance (accessed April 19, 2019).

50. Interview with Colonel Michael T. Miles, 388th Maintenance Group Commander, November 1, 2018.

51. Ibid.

As a new system, post-flight data after an F-35A sortie must be downloaded and analyzed before that F-35A can fly again. Occasionally, internal conflicts within ALIS sub-programs have stymied that process due to conflicts created when digital inputs from the jet or other sub-programs meet analog inputs or processing from another. Those conflicts have kept data from a jet that landed with no discrepancies (Code 1) at the end of one day from being downloaded in time for the jet to fly the next morning. Several pilots complained bitterly about an entire first "go" (all the jets in a morning launch) being cancelled for this very reason.

While infrequent, these conflicts are incredibly frustrating for maintainers and operators alike. In the words of an affected pilot: "Failures in ALIS's data collection have kept us from flying perfectly good jets."

The previously mentioned 92 percent Code 1 rate is impressive as a stand-alone statistic, but there are other factors that drive the fleet's mission-capable (MC) rate. Many jets suffering minor (Code 2) and more significant (Code 3) failures can be repaired relatively quickly. That expectation is only reasonable if there is a technical order that details how the repair must be accomplished and the parts required to make the repair are on hand. These two issues are primarily responsible for constraining the readiness rates for the F-35A.

While those issues may sound unsatisfactory for a brand-new weapons system, they are common to complex systems fielded from new, clean-sheet designs. Routine maintenance repair procedures and the supporting JTDs in mature systems have been developed and refined over years, if not decades. However, the clean-sheet designs of the F-14, F-15, F-16, F-18, and F-22 all suffered growing pains in their first years of operation. JTDs have to be devised and written from scratch for every new design, and, while engineers do their best to predict component failures, some parts that were designed to endure several years of operational use suffer unexpected failures.

As an aircraft moves from its initial operating capability to full operational capability (FOC), the number of flight hours the system accumulates increases significantly, which floods the supporting infrastructure with the experience and data it needs to develop and refine maintenance practices and spare-parts inventories.

The concurrent fielding of the F-35A while it was still being developed *helped* the program validate the JTDs/maintenance practices in the field.[52] Unfortunately, there are still aircraft issues and system failures that do not have supporting JTDs. When an F-35A suffers one of those breaks, the jet is grounded while an Action Request (AR) is sent to a joint government/Lockheed Martin team, requesting tailored instructions to fix the discrepancy.

The average response to an AR is currently five and a half days, which, in and of itself, is a significant amount of time for a jet to be off the flight line.[53] The sheer number of these requests is high, and the complexity of some of the associated failures significantly extends their resolution time. Some ARs are so challenging or complex that Lockheed Martin has to fly a team out to the field to troubleshoot the system. The time it takes for the iterative information exchanges between the field and Lockheed Martin to bring that visit about often exceeds 30 days.[54]

When a jet has been down for more than 30 days, it is designated as a "Hanger Queen," a disparaging status that levies special management and maintenance challenges on units already struggling to gain momentum. In November 2018, six of Hill AFB's 46 F-35As (18 percent of the fleet) were Hanger Queens, a percentage that was a near constant in 2018. In order for Hill AFB to overcome that starting position, the Air Force must increase the number of personnel it has dedicated to resolving ARs, as well as the number of teams it makes available to deploy for on-site troubleshooting.

Supply Issues. One of the many impressive facets of an F-35A operation is the depth to which maintenance leadership maps out aircraft production and repair details. Making it all work seamlessly requires incredibly detailed scheduling that pairs qualified personnel with repair parts as they move from wherever they are stored to the flight line. Ideally, the num-

52. Office of the Director, Operational Test and Evaluation, *FY 2017 Annual Report*, "FY 17 DOD Programs: F-35 Joint Strike Fighter (JSF)," January 2018, p. 35, http://www.dote.osd.mil/pub/reports/fy2017/pdf/dod/2017f35jsf.pdf (accessed April 19, 2019).

53. Interview with Colonel Michael T. Miles, 388th Maintenance Group Commander, November 1, 2018.

54. Ibid.

ber and location of those parts would be based on user operational tempos and predicted component failure rates[55]. In the 1980s, the number of aircraft parts that were stored in base warehouses "owned" by individual fighter wings could readily sustain that wing's normal operations. That changed with the advent of Federal Express (FedEx)[56] and the realization of global supply chain management. With it came the demand for efficiencies, which brought big changes to the way parts are stored and handled.

The vast majority of critical F-35A components are stored in centralized Lockheed Martin warehouses strategically located around the world.[57] Lockheed Martin has not done a great job providing transparency on its global parts supply system for the F-35A,[58] and parts or components that fail are replaced on a "just in time" basis that begins with a requisition initiated through ALIS when the failure is identified. ALIS is also used to schedule qualified maintenance personnel to install those components, based on the date and time that that same system states the part will arrive at the base.

The collective F-35A component availability has suffered regular shortages. That, coupled with consistently unreliable delivery schedules for those parts, has made the system unreliable. There is no in-transit visibility, and all too often there are shortfalls on parts, such as wiring harnesses, that ground jets for extended periods of time. When ALIS shows the parts are available, they do not arrive on time, and the professionals that were pulled from one part of the flight line to make the repair are lost to both maintenance opportunities. An April 2019 Government Accountability Office report on F-35 aircraft sustainment[59] accurately details the challenges within the F-35 parts supply system, but gaining clear visibility on the logistical flow of parts was repeatedly cited by the maintenance leadership at Hill AFB as the issue that could help mitigate other maintenance challenges within operational units.[60] Parts availability, supply visibility, scheduling, and the joint technical data available to maintenance personnel within ALIS should be brought up to the specifications established for each as fast as possible.

Changes Are on the Way

Failure rates based on data that are already available should give rise to more robust component production, better centralized storage, and delivery timelines that live up to the FedEx standard. The latest software version or "service pack" for ALIS was released in October 2018, and while every iteration has brought big improvements, the belief (and hope) among senior maintenance leaders is that the service pack delivered in 2019 will bring dramatic improvements for JTDs, module interface, and component-delivery schedules.

The maintenance team at Hill AFB is chomping at the bit for these improvements. Even with JTD and parts-availability challenges—and a daily average starting position of just 82 percent of the total fleet available for the flying schedule—the wing managed a total MC rate of 72 percent for all possessed aircraft in November. While not quite up to the 80 percent MC-rate threshold that then-Secretary of Defense Jim Mattis set for the services by the end of 2019, they are getting close. Once the JTD, supply issues, and ALIS delivery timelines are fixed, the F-35A will exceed the MC rates for fourth-generation aircraft when those jets were flying at their very best.

Strategic Planning for F-35A Bed-Down.[61] Hill AFB is the first operational (combat) wing in the U.S. Air Force, but the bed-down plan will see many more

55. Referred to as a "Base Spares Package." Diana Maurer et al., "F-35 Aircraft Sustainment: DOD Needs to Address Substantial Supply Chain Challenges," Government Accountability Office *Report* No. GAO-19-321, April 26, 2019, p. 9, https://www.gao.gov/products/GAO-19-321 (accessed April 29, 2019).
56. FedEx, "Shipping Solutions for Aerospace & Aviation," http://www.fedex.com/fr_english/aerospace/ (accessed April 21, 2019).
57. Referred to as a "Global Spares Package." Maurer et al., "F-35 Aircraft Sustainment: DOD Needs to Address Substantial Supply Chain Challenges," p. 9.
58. Ibid.
59. Maurer et al., "F-35 Aircraft Sustainment: DOD Needs to Address Substantial Supply Chain Challenges," p. 39.
60. Interview with Colonel Michael T. Miles, 388th Maintenance Group Commander, November 1, 2018.
61. Bed-down is a military term for moving aircraft to a base or operating location and then training the entire flying operation and its associated personnel to operate, maintain, and employ those aircraft.

active-duty, National Guard, and Reserve locations transition to the F-35A. The planning for those transitions is very involved, and the Air Force is well on its way to streamlining that effort.

The maintenance group of the 388th Fighter Wing has done quite a bit to give the next unit a leg up for its transition to the F-35A. Hill AFB has absorbed and trained 30 percent more maintenance personnel at all three qualification levels (3, 5, and 7) than Hill AFB manning documents call for. That additional manning will allow this maintenance team to provide a trained cadre of start-up maintenance professions for the F-35A bed-down at Eielson AFB in Alaska, which is slated to begin in 2019. That said, there are several factors working against the effort.

Currently, 44 percent of maintenance personnel at Hill AFB for levels 3, 5, and 7 are fully qualified at their respective skill levels. To reach the wing goal of at least 50 percent, those in training must have hands-on, supervised experience repairing their level-specific portfolios of component and system failures. While a 92 percent Code 1 rate is good news on most every other front, the lack of failures means lack of training opportunities for a maintenance team hungry to master the job. Maintenance can already produce more sorties than operations is currently flying, and unless the Code 1 rate goes down, or operations increases its flying tempo, the wing will struggle to reach its 50 percent goal.

Carrying those extra personnel adds additional weight to F-35A operating costs, and artificially inflates the personnel portion of O&M costs by 30 percent. That penalty carries over to the F-35A weapons system as a whole, a penalty no one outside the industry even attempts to factor out.

The Air Force should segregate the costs associated with overloading unit maintenance manning for the sake of expediting the bed-down and the pace at which future F-35A locations become mission-ready, and it should exclude those costs from F-35A O&M cost calculations.

The maintenance leadership at Hill AFB has done an extraordinary job of building a robust team of maintainers who are ready for war. And the strides that Hill AFB has taken to grow the initial cadre for the next F-35A bed-down location at Eielson AFB is a step that will accelerate the CAF's fielding of this extraordinary system.

Recommendations

The U.S. Congress should fund and authorize the Air Force to purchase 72 F-35As in the National Defense Authorization Act for 2020, and 360 over the Five-Year Defense Plan (FYDP).

The Department of Defense should approve full-rate production of the F-35A, and move to field the F-35A as rapidly as possible. The DOD should forego the acquisition of fourth-generation F-15EX fighters, and acquire 72 F-35As in 2020, while also funding the associated spare parts accounts.

The F-35 Joint Program Office should:

- **Repair the visual challenges and conflicts within the HMDS** as an urgent operational requirement.
- **Elevate the requirement for and adequately fund a robust embedded training suite of capabilities within the F-35.** That suite should include user-friendly software that has a selection of both canned (pre-programmed) and tailorable mission scenarios, and a level of fidelity that allows multi-ship F-35A packages to find, fix, sort, and target layered SAM systems that are pulled from the jet's threat library.
- **Install concurrent software updates for the F-35A simulator** in line with those made to the aircraft.
- **More rapidly improve F-35A Distributed Mission Training** to increase the number of simulators connected through the Distributed Mission Training System to the standard number of aircraft in an LFE package.
- **Improve user transparency of its global parts supply system for the F-35A,** accelerate the delivery of those parts, provide users with visibility of those parts as they are in transit, and bring delivery schedules for those parts up to modern-day global-supply-chain-management standards.
- **Increase the number of personnel dedicated to resolving maintenance action requests (ARs)** and the number of teams it makes available for on-site troubleshooting.

- **Increase parts availability and maintenance visibility into parts sourcing**, improve scheduling, and rapidly increase the joint technical data available to maintenance personnel.

The Air Force should:

- **Increase the average number of sorties for line fighter pilot wingmen, flight leads, and instructors to a minimum of three flights in the aircraft a week** to grow or sustain their skill sets, as well as grow the F-35A experience level with the CAF. In order to accomplish that, it should institute aggressive flying-hour contracts in all wings operating at or above IOC to grow the breadth of fighter and maintenance experience as rapidly as possible.

- **Segregate the costs associated with overloading unit maintenance manning** for the sake of expediting the spin-up of future F-35A bed-down locations, and exclude those costs from F-35A O&M cost calculations.

Conclusion

The Joint Strike Fighter program has endured its share of growing pains, but the F-35A is now fully operational, and those flying the jet have complete confidence in its ability to operate in and around the most intense threat environments in the world. While it will take several more years before the jet, its simulators, maintenance, and logistical support fully realize their potential, the technical issues that limited the early operational employment of the JSF have been overcome, and there is no doubt in the minds of those flying the F-35A at Hill AFB that, even now, this is the most dominant and lethal multi-role weapons system in the world. It is time to field this game-changing weapons system as rapidly as possible.

*—**John Venable,** a graduate of the USAF Fighter Weapons Instructor Course with more than 3,300 hours in the F-16C, is Senior Research Fellow 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

2016 INTERVIEWS

	LEVEL OF PROFICIENCY					AVG. FLIGHT TIME (HOURS)	
	Experienced	**IP**	**IP Plus**	**WIC/TPS**	**Total**	**Previous Fighter**	**F-35**
F-16	0	3	11	6	20	1,441	199
F-15E	0	1	1	2	4	1,850	161
A-10	0	2	2	1	5	1,420	146
F-15C	0	0	1	1	2	1,085	110
F-22	0	0	0	0	0	0	0
All aircraft	0	6	15	10	31	1,467	180

2018 INTERVIEWS

	LEVEL OF PROFICIENCY					AVG. FLIGHT TIME (HOURS)	
	Experienced	**IP**	**IP Plus**	**WIC/TPS**	**Total**	**Previous Fighter**	**F-35**
F-16	2	3	5	5	15	1,601	338
F-15E	0	1	2	0	3	1,667	437
A-10	1	0	1	0	2	717	267
F-15C	0	0	0	0	0	0	0
F-22	0	0	1	0	1	450	200
All aircraft	3	4	9	5	21	1,505	351
F-35 (first fighter)					9		188

NOTE: Levels of proficiency:
- Experienced—Pilot with 500 hours in a specific fighter; pilot who is experienced in a previous fighter needs 300 hours to be deemed experienced in the F-35
- IP—Instructor Pilot
- IP Plus—Instructor Pilot Plus (instructors with higher level certifications, such as Package/Strike Commander and Sandie)
- WIC/TPS—USAF Weapons Instructor Course graduate, or Test Pilot School graduate

SOURCE: Author's interviews with a total of 61 F-35 pilots.

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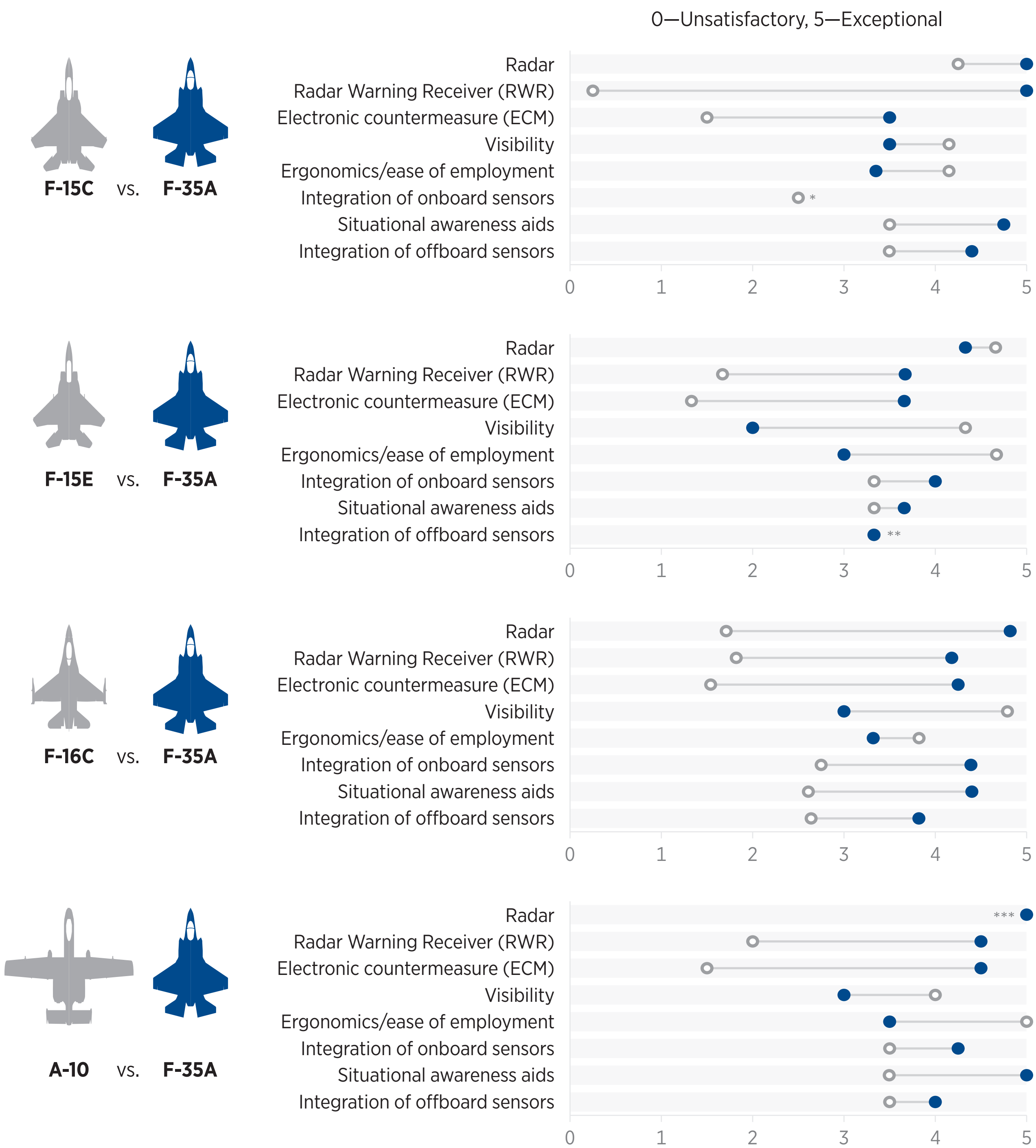
APPENDIX CHART 1

How Pilots Rate Fighter Jet Avionics and Sensors



* F-15C pilots not surveyed ** Identical score for both aircraft *** A-10 pilot responses n/a

SOURCE: Author's survey of 51 former fourth-generation and single fifth-generation pilot currently flying the F–35A. The F-22A pilot rated the F-35A as a five in every area except visibility (3), and rated the F-22A all fives except integration of offboard sensors (4). See Appendix for details on those pilots. See footnotes 13 and 14 for details on the fighter aircraft configuration for this comparison.

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