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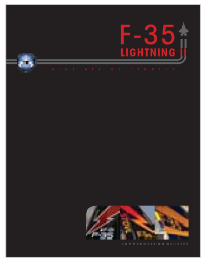
# F-35 LIGHTNING II

## JOINT STRIKE FIGHTER





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# THE FIFTH-GENERATION LEAP FORWARD

**BY J.R. WILSON**

The designation of fighter aircraft by "generations" began with the first subsonic jets toward the end of World War II. While never an official definition, such designations have been widely accepted for more than six decades, with each new generation typically reflecting a major advance in technology or capability.

The first generation (mid-1940s through the mid-1950s) included the Lockheed P-80 Shooting Star (U.S.), de Havilland Vampire (U.K.), Mikoyan-Gurevich MiG-9/-15/-17 (USSR), Shenyang J-2/J-5 (PRC), and Dassault Ouragan (France). Aside from speed, they were not significantly different from the last generation of advanced piston-driven fighters from World War II.

The second generation (mid-'50s through early-'60s) was defined by supersonic speed and missile armament. Jets of that generation included the McDonnell Aircraft F-101 Voodoo (U.S.), English Electric Lightning (U.K.), Sukhoi Su-7/-9/-11 (USSR), Chengdu J-7 (PRC), and Dassault Mirage III/5 (France).

Third-generation fighters (1960s) focused on improved air-to-air missiles and analog avionics, while air combat over Vietnam showed dogfights were still part of the equation. It also saw a proliferation of nations and companies producing jet fighters, with representative aircraft including the McDonnell Douglas F-4 Phantom II and Northrop F-5 (U.S.), BAE Harrier (U.K. – the first VSTOL jet), MiG-21/23/25 (USSR), Mitsubishi F-1 (Japan), IAI Kfir (Israel), and Mirage F1 (France).

The fourth generation was the first to be split into two segments – Gen 4 (1970-mid-'90s) and Gen 4.5 (1995-present).

Fourth-generation aircraft used increasingly sophisticated weapons and avionics in multirole configurations; vastly improved sensors, missile range, and accuracy brought an end to dogfighting – but made air-to-air combat even more deadly. Representative aircraft – most still in service – include the General Dynamics/Lockheed Martin F-16 Fighting Falcon, Grumman F-14 Tomcat, and McDonnell Douglas/Boeing F/A-18 Hornet and F-15 Eagle (U.S.); MiG-27/29/30/31/35 and Su-33/34 (USSR/Russia); Panavia Tornado (U.K./Germany/Italy); Chengdu J-10, Shenyang J-11, and Xian JH-7 (PRC); Mirage 2000/N/D (France); and HAL Tejas (India).

Generation 4.5 (1990s-present) represented both significant upgrades to legacy aircraft as budget cuts and downsizing delayed development of the next generation, as well as the introduction of stealth, advanced digital avionics, Active Electronically Scanned Array (AESA) radar, increased weapons precision, limited super-cruise speed, extensive use of composite materials, and both offensive and defensive components required for the new network-centric battlespace.

Aircraft generally designated as 4.5 (some still in development) include the Boeing F/A-18E/F Super Hornet and F-15E Strike Eagle/F-15SE Silent Eagle and Lockheed Martin F-16 Block 60 (U.S.); Eurofighter Typhoon (U.K./Germany/Italy/Spain); MiG-35 and Su-35BM (Russia); Saab 39 Gripen (Sweden/Italy); Dassault Rafale (France); and Mitsubishi F-2 (Japan/U.S.).

The fifth generation (2005-mid 21st century) marks the blending of all generation 4/4.5 technologies and materiels with the latest cutting-edge advances across the board, which significantly limits the nations/manufacturers capable of producing such aircraft. Generation 5 aircraft are designed from scratch to incorporate advanced radar-absorbent composites, "shaping," and minimal IR signature for enhanced stealth.

Other criteria include integrated communications, navigation, and identification (CNI) avionics; multi-sensor data fusion for situational awareness infrared search and track (SAIRST), which constantly tracks all targets (and friendlies) within range and provides the pilot with an instant 360-degree picture; jam-resistant high-speed data-links; glass cockpit and helmet-mounted displays; integrated electronic warfare components (offensive and defensive); centralized "vehicle health monitoring;" and super-cruise without afterburners – all providing what the Pentagon calls a "first look, first shot, first kill capability."

"There is a clear distinction between fifth generation and earlier models, primarily in lethality and survivability – threat scenarios into which you would never launch a fourth or even 4.5 generation aircraft," noted Tom Burbage, Lockheed Martin Aeronautics executive vice president and F-35 program integration general manager.

"We also have a much more powerful set of multispectral sensors and fuse the information so the pilot no longer manages the sensors – he becomes a mission manager, not a platform manager. That's important because, combined with the element of stealth, you have a tactical advantage you don't have with today's aircraft."

All three variants of the JSF – the F-35A conventional takeoff and landing (CTOL), F-35B short takeoff/vertical landing (STOVL), and F-35C carrier-based aircraft – have essentially identical flight-and-fight characteristics. But for Burbage, while those capabilities are vital, they are only part of the story.

"The transformational characteristics are the ability to hold strategic threats at risk in denied access areas, do ISR (intelligence, surveillance, reconnaissance) and survive and return

An F-35A and F-22A in formation. The F-35 and F-22 are the only two fifth-generation aircraft types in production in the world today.

Lockheed Martin photo by Senior Flight Test Photographer Darin Russell

to the fight in scenarios into which other aircraft could not be launched. In lower threat scenarios, such as Iraq, when the airplane is in both joint and coalition service, you have a common platform, ordnance, logistics tails," he explained. "Even the same type of airplane today may have different blocks of sensors, so the logistics tail supporting them is very large.

"The potential to drive that infrastructure down is one of the advantages of moving toward a joint coalition-based platform. You will have economies of scale and commonality we don't have today. The challenge is how to exploit that. There is no similar system out there today, so we have no legacy model to help us."

Mission and capability targets set out for the Joint Strike Fighter include being:

- four times more effective than legacy fighters in air-to-air combat;
- eight times more effective in missions against fixed and mobile targets;
- three times more effective in non-traditional ISR and Suppression of Enemy Air Defenses and Destruction of Enemy Air Defenses (SEAD/DEAD) missions; and
- comparable in procurement cost, but with significantly less tanker/transport and infrastructure requirements, including a smaller basing footprint.

Only two fifth-generation aircraft currently exist – Lockheed Martin's F-22 Raptor air superiority fighter and F-35 Lightning II Joint Strike Fighter – but others are known to be in some phase of development – the Russian Sukhoi T-50, the Sukhoi/HAL FGFA (Russia/India), the J-20 (PRC), the Medium Combat Aircraft (India), and an as-yet unnamed Japanese aircraft.

Only the F-22 is fully fielded in operational service. The F-35 will be the second fifth-generation aircraft to reach that point, with initial operational capability – with the U.S. Marine Corps – planned for the 2014-2015 time period.

Most experts agree no other nation has the technology nor manufacturing infrastructure to produce a genuine fifth-generation fighter in less than a decade. The most likely, based on existing capabilities, are Russia and China, both of which claim to be close to fielding such aircraft. But according to Richard Aboulafia, vice president of analysis with the Teal Group, a true fifth-generation fighter is more than the sum of its parts.

Three F-35s reflected in the Electro-Optical Targeting System (EOTS) of another. Sensor fusion is one important element of a fifth-generation fighter.

Lockheed Martin photo by Paul Weatherman

"You can bolt on the subsystems to claim fifth-generation status, but that's a long way from a broader architecture. The closer you get to fifth generation, the further you come in realizing the aircraft matters less – it's a broader constellation of ISR, doctrine, air-to-air refueling, etc.," he said.

"One of the biggest attributes of fifth generation is its ability to act as a network node as it evolves. That will take time, of course, but if you just have a very good plane with a bunch of subsystems added on – AESA, for example – that is just a highly evolved fourth-generation aircraft."

Even the most capable contenders – Russia and China – fall short, in his estimation.

"It sounds like a lot of puffery and smoke. There's no question they will build better and more capable jets, but something that is truly integrated and designed to work in harmony with all its onboard and offboard sensors? Probably not," he said. "To a very strong extent, it also involves training and doctrine, which they are not very good at, and making use of all available inputs. You're also talking about two countries with extremely limited air-to-air refueling capabilities."

As might be expected, Russian Prime Minister Vladimir Putin disagreed, claiming the new Sukhoi T-50 will enter service by 2015 and "will be superior to our main competitor, the F-22, in terms of maneuverability, weaponry and range." He pointed to T-50 controls the pilot can operate without taking his hands off the joystick in crucial high-*g* maneuvers as an example.

"I know, I've flown," Putin is quoted as saying on a government website.

The joint Sukhoi/HAL fifth-generation fighter aircraft being developed by Russia and India, based on the T-50, would give India a significant boost, especially if it is serious about developing a separate, indigenous fifth-generation fighter. Planned as a two-seat aircraft, rather than the T-50's single seat, the Sukhoi/Hindustan FGFA is projected to enter service around 2018.

"That aircraft has been in development for a long time," Burbage said of the T-50. "It did make its first flight (in January 2010), but has been on the verge of doing that for several years. It's clear they borrowed some design features from the F-22, but it's doubtful they have anywhere near the level of experience integrating stealth. It's a big airplane with big engines and no doubt maneuvers well in the air, but the current generation of MiGs and Sukhois are very impressive maneuverability aircraft as well.

"When you load them up with sensors, weapons, and fuel tanks, they lose a lot of that envelope. The real question is


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whether they have survivability. We're talking surface-to-air threats, getting into a high-threat environment and holding it at risk. That is the description of an F-35; the adversaries' airplanes are, generally speaking, highly maneuverable, twin-engine, big airplanes with thrust vectoring, but fifth-generation is a lot more."

China has been working for more than a decade on the J-20, which first flew in January 2011, an indication that the People's Liberation Army (PLA) may be making faster progress than most predictions indicate.

"We're anticipating China to have a fifth-generation fighter operational right around 2018," Wayne Ulman, a senior China analyst at the Air Force National Air and Space Intelligence Center, told the U.S.-China Economic and Security Review Commission in May. The commission was chartered by Congress in 2000 to assess and report on the national security implications of the growing economic relationship between the United States and PRC.

"The capabilities of China's air forces, particularly those of the PLAAF (People's Liberation Army Air Force), have improved dramatically over the course of the past decade. From an overly large, technologically inferior force, the PLAAF is emerging as a well-equipped and increasingly well-trained force, with some identifiable shortcomings and weaknesses. All indicators point to the continued improvement of both PLA Air Force and PLA naval aviation over the next decade, to the point where China will have one of the world's foremost air forces by 2020."

However, Russia, China and others talking about building fifth-generation aircraft have a questionable manufacturing base, according to Burbage: "Another factor is whether any of those countries have the industrial capacity to build these airplanes on a routine production. It's one thing to build a prototype, another to open a regular production line."

Entering service and becoming a primary warfighting asset are separated by several years, as demonstrated by both the F-22 and F-35, both of which required roughly 20 years, followed by another five years or so from the start of initial operations to becoming an operational mainstay in the fleet.

The Raptor began initial operations with the U.S. Air Force in 2002, with the last of a significantly reduced buy of 187 aircraft to be delivered in November 2011. The F-35 is midway through an eight-segment low-rate initial production (LRIP) phase, with 554 aircraft, in all three variants, going to the U.S. Marine Corps, Air Force, and Navy and six of the eight other JSF program partners through 2016. While the schedule remains in flux, the first operational F-35s are to be delivered in 2013-15.

Delivery of all three F-35 configurations, from LRIP through full-rate production aircraft (running from 2017 through 2036),

OPPOSITE: Russian Prime Minister Vladimir Putin claims the Sukhoi T-50, shown here, will be superior in some respects to U.S. fifth-generation fighters, but for now it remains a prototype.

LEFT: The F-35's cockpit. A key aspect of fifth-generation fighters is that the pilot becomes a "mission manager" rather than a "platform manager" due to advanced sensor fusion.

Photo courtesy of Lockheed Martin

**"THE F-22 IS FOR AIR SUPERIORITY PRIMARILY; WHILE ALSO VERY GOOD AT DELIVERING WEAPONS TO GROUND, IT DOES NOT HAVE THE ABILITY TO SELF-TARGET. THE F-35 IS DESIGNED FOR MULTI-ROLE AIR-TO-GROUND. SO THE RAPTOR IS KING KONG IN AIR-TO-AIR, THE F-35 IN AIR-TO-GROUND."**

currently is expected to total more than 2,400 to the United States and about 730 to the other eight international partners. Purchases from non-partner nations are expected from Belgium, Finland, Greece, Israel, Japan, South Korea, Spain, and Singapore. With its three variants intended to meet the requirements of any allied military, the intent is to make the F-35 the predominant fighter aircraft of the 21st century for the United States and its allies, significantly increasing interoperability and simplifying maintenance and logistics.

"At the end of the day, the biggest single factor in arms sales is the strategic relationships you form," Aboulafia said. "And as long as the U.S. is pretty much the only one other countries want to have a strategic relationship with, the F-35 is a good value."

Congress banned foreign sales of the F-22, although some allies – such as Japan and Australia – are pushing for a change of policy before the Raptor production line is shut down next year. But with the F-35 available and the high cost of developing and manufacturing a new fifth-generation aircraft for only a limited domestic/foreign market, it is unlikely many other nations will commit already scarce defense funds to building their own.

Russia and China are the obvious exceptions. But even with Putin's claim that the T-50 will begin operations in 2015, it probably would not become fully integrated in enough numbers to matter before 2020. That would be roughly the same schedule as the F-35, but by then the U.S. Air Force (USAF) will have been flying F-22s as a major fleet component for more than a dozen years. And given the significant differences between a true fifth generation and even a generation 4.5 fighter, that kind of pilot experience would be crucial in any future combat.

The bottom line is the United States will have the only operational fifth generation fleet for at least the next decade, possibly longer. Initially, that will be the F-22, with the Air Force operating fewer than one-third the number of Raptors it desired. However, an upgrade program already is under way to incorporate as much newer F-35 technology as possible into the F-22.

While the two share advanced systems and capabilities, Burbage noted, they were designed for different missions.

"The F-22 is for air superiority primarily; while also very good at delivering weapons to ground, it does not have the ability to self-target. The F-35 is designed for multi-role air-to-ground. So the Raptor is King Kong in air-to-air, the F-35 in air-to-ground," he said.

"The F-22 also flies at a higher altitude and airspeed regime just because of its aerodynamics; the F-35 flies in the air regime of the aircraft it replaces (F-16 Falcon, A-10 Thunderbolt II, AV-8B Harrier, F/A-18 Hornet, A-6 Intruder). Both carry weapons internally and so have a full operational envelope, unlike generation 4 and 4.5, which carry weapons and sensors externally, creating drag that changes the operational envelope."

Some argue it is a waste of money to build fifth-generation fighters in a world in which the United States has gone unchallenged in the air for nearly four decades and where no other nation is likely to have a comparable capability for at least one and probably two or more decades. Aboulafia sees that argument as short-sighted, at best.

"They (China and Russia) are going to have enough power to cause casualties in current generation equipment in future decades. And if we don't have a fifth-generation capability in 20 or 30 years, when they will have a very advanced fourth generation, then you will be fighting even in the air and probably be wiped out on the ground and at sea," he warned.

"So just because there isn't anything even in sight today, that doesn't mean there won't be in 20 or 30 years. And you also can't match fourth generation against fourth generation without the outcome being bloody and unpleasant."

If even the limited number of fifth-generation aircraft the United States is planning are fully and properly integrated into a highly networked battle force, he added, being outnumbered diminishes greatly in significance.

"The fifth generation has an advantage – given the integration of onboard and offboard assets, all functioning in harmony, you can obliterate the other guy. If you are talking about an exercise in which offboard assets are not really involved, then you probably would only have a two- or maybe three-to-one advantage (against fourth generation and earlier aircraft)," Aboulafia said, "but not the kind of overwhelming odds if you had the fifth-generation fighter integrated into a larger package, including AWACs (Airborne Warning and Control Systems), satellites, etc. That kind of integration would make short work of the other side."

Burbage agreed, adding the USAF F-35A is a prime example of all the advantages JSF will bring to both its U.S. and international operators, no matter which variant they fly.

"The Air Force version is very important from a couple of perspectives. It further modernizes the Air Force and is the platform most of our allies will use; airman-to-airman relationships are extremely important in those coalition ties. So you will see a very high leveraging effect when everyone flies an F-35," he said. "It was amazing to see, within the first couple of flights, the pilots operating without any verbal communications, just system-to-system.

"Historically, information sharing is done verbally. This aircraft has a very high-speed broadband data link, so there is no need to do much talking. The system identifies targets in a priority order and which aircraft is going after which target. The pilots basically are watching and managing the missions as they unfold, transmitting information to other aircraft in the fight without verbal communications. The pilots adapt to that very quickly, doing cooperative maneuvers in real time without having to tell someone 'there is a target at your 6 o'clock,' because everyone can see that."

With the speed at which technology has and will continue to advance, the Pentagon continues to look to what comes next. The Air Force, for example, already has asked industry to offer ideas for a sixth-generation (or perhaps generation 5.5) replacement for the F-22. Considering the Raptor – along with the F-35A – is replacing some 1,200 F-15s, which entered service in 1976 with an expected service life of 50 years, and the average 20-year development time, to have a new fighter available at a similar mid-point in the F-22's operational life would mean development would have to begin soon.

Boeing has proposed a sixth-generation aircraft, primarily carrier-based for the Navy, but Aboulafia doubts it has much traction, for now.

"The answer is, we really don't know. To me, sixth generation is a set of technologies that probably could be applied to existing airframes, along with some incremental airframe improvements. But it's hard to see how they would pay their way compared to just developing bolt-on capabilities for a fifth-generation plane," he concluded.

"It's very tough to tell what is going to happen in the next decade and most predictions about air power in the 20th century were pretty damned wrong. But if you believe in tactical air power at all, then fifth generation looks like a pretty good value in comparison to older equipment."

# THE COMMANDERS' TAKE

## America's Military Aviation Chiefs Discuss the JSF Variants

BY JAN TEGLER




Lockheed Martin photos

The three variants of the F-35 Joint Strike Fighter (JSF) represent the future of manned, fixed-wing tactical aviation for America's armed forces and the air forces of eight nations partnering with the United States in the Joint Strike Fighter program.

Understanding this, it's hard to overstate the importance of the Lockheed Martin F-35 Lightning II. Far into the 21st century, the JSF will be one of the chief components of Western security strategy. The capabilities the aircraft will eventually bring to bear, and its capacity to serve alongside other modern and emerging military platforms, will influence our nation's application of airpower for decades to come.

The F-35 also represents the most expensive military acquisition program in America's history. The total program tab, at nearly $400 billion according to the Pentagon, covers the development and production of 2,443 examples of the JSF through 2036, built in three variants to serve the U.S. Air Force, U.S. Navy, and U.S. Marine Corps. Replacing a variety of legacy tactical aircraft, the F-35 will form the backbone of the nation's combined strike/fighter force.

More than 20 years of development are behind the Joint Strike Fighters now arriving at Eglin. The System Design and Development (SDD) phase of the program, begun in 2001, is still in full swing, and the continuation of development work is critical to the aircraft's success. Thus, the early production examples in the markings of the 33rd Fighter Wing represent a beginning for the Air Force, Navy, and Marines.

In the following interviews, Gen. William M. Fraser III, commander, Air Combat Command; Maj. Gen. Thomas K. Andersen, director of Requirements – Headquarters Air Combat Command; Vice Adm. Allen G. Myers, commander, Naval Air Forces; and Lt. Gen. Terry Robling, deputy commandant of aviation for the Marine Corps, share with us their thoughts about the current status of the F-35 variants.

First, however, a bit of context is in order. Recognizing that the Joint Strike Fighter program is truly a combined effort to produce a near-common platform for America's three primary air arms and that military acquisition does not operate in a vacuum, each of the commanders commenting here must view the endeavor beyond the scope of their own force.

As is well documented, the JSF program has suffered a number of developmental difficulties. Challenges of this type are not new for military aircraft programs, particularly those as complex and advanced as the F-35. But given the seminal role the Lightning II will play in American tactical aviation, the implications of any hiccup have wider impact.

While each of the service aviation chiefs eagerly looks forward to the introduction of the JSF into service and the leap in capability that accompanies it, the delays in IOC announced in the spring (to 2016 for the Air Force and Navy) have forced these leaders to re-examine their aging tactical aircraft fleets and to improvise solutions to extend the life of legacy platforms while acknowledging a "fighter gap" caused by the setback.

Here then are responses from America's aviation force leaders to a set of queries about current development, challenges to be overcome, and the impact of program delays: the commanders' take.

Two F-35As, AF-1 and AF-2, fly together during an aerial refueling evolution. The Air Force's F-35A is perhaps the most straightforward of the variants.

Lockheed Martin photo

# GEN. WILLIAM M. FRASER III
## Commander, Air Combat Command, U.S. Air Force

BY JAN TEGLER

Gen. William M. Fraser III is commander, Air Combat Command, with headquarters at Langley Air Force Base, Va., and Air Component commander for U.S. Joint Forces Command. As the commander, he is responsible for organizing, training, equipping, and maintaining combat-ready forces for rapid deployment and employment while ensuring strategic air defense forces are ready to meet the challenges of peacetime air sovereignty and wartime defense. ACC operates more than 1,000 aircraft, 22 wings, 13 bases, and more than 300 operating locations worldwide with 79,000 active-duty and civilian personnel. When mobilized, the Air National Guard and Air Force Reserve contribute more than 700 aircraft and 49,000 people to ACC. As the combat air forces lead agent, ACC develops strategy, doctrine, concepts, tactics, and procedures for air and space power employment. The command provides conventional and information warfare forces to all unified commands to ensure air, space, and information superiority for warfighters and national decision-makers. ACC can also be called upon to assist national agencies with intelligence, surveillance, and crisis response capabilities.


F-35A Lightning II, airframe AF-6, flies over Edwards Air Force Base in May 2011.

Lockheed Martin photo by Paul Weatherman

Fraser entered the Air Force in 1974 as a distinguished graduate of the Texas A&M University ROTC program. His operational assignments include duty as a T-37, B-52, B-1, and B-2 instructor pilot and evaluator. Fraser has commanded an operations group and two bomb wings. His staff duties include tours on the Air Staff, Joint Staff, and Joint Strategic Target Planning Staff at Offutt AFB, Neb. He has also served as chief of the Nuclear Requirements Cell at Supreme Headquarters Allied Powers Europe, chief of staff for U.S. Strategic Command, and as the assistant to the chairman of the Joint Chiefs of Staff.

Fraser has extensive wartime, contingency, and humanitarian relief operational experience. During Operation Enduring Freedom, he led an intelligence fusion organization that provided direct support to the warfighter. Prior to assuming his current position, Fraser served as the Air Force vice chief of staff.

As commander of Air Combat Command, Fraser was in a unique position to answer some questions about the development of the F-35A, the fighter's current status, and challenges going forward.

**Jan Tegler: The Air Force's specifications for the F-35A call for a stealthy, multi-role aircraft, primarily to be used for air-to-ground strike missions, replacing the F-16 and A-10, and capable of complementing the F-22. How have requirements evolved over the course of the development program (SDD) so far?**

**Gen. William M. Fraser III:** Requirements for the F-35A have remained relatively stable, with the exception of design changes driven by the F-35B weight reduction effort. However, two factors have focused our efforts to ensure the proper blend of combat capability. First, the early termination of the F-22 program has enforced our resolve to procure a platform capable of complementary or stand-alone capability in an anti-access environment. Second, irregular warfare operations have grounded our vision to today's fight, ensuring we field a viable platform with existing legacy capabilities.

**Please summarize the current status of the F-35A program as regards the USAF.**

Conservatively, production is six months behind schedule and development and testing of mission systems are one year behind. System Development and Demonstration (SDD) has been extended twice, once in 2008, (...) and the second time in 2010 (...). These extensions relieve some program test concurrency, and allow us to retain essential capabilities supporting Initial Operational Capability (IOC).

**What impact has parallel development of the B/C variants had on F-35A?**

Since the CTOL and STOVL (short takeoff/vertical landing) variants are a nearly identical airframe, the F-35B variant has had major impact on development of the F-35A. During the F-35B weight reduction efforts, STOVL design changes directly impacted the F-35A. This was a good news/bad news story. Where sacrifices were made on redundancy, the F-35A made concessions. Where efficiencies were realized, the F-35A gained growth capacity.

**What work has been done on a concept of operations for USAF F-35As to date? Have evolving worldwide military, political, and economic developments had effects on plans for the aircraft's operational employment?**

The services and the JSF Program Office are currently working on development of concepts of operation (CONOPS) and concepts of employment (CONEMPS). Nearly all of our simulation events directly impact CONOPS and CONEMP development. Our people are defining how this weapon system will integrate and enhance the overall battle space. Ongoing military efforts in Iraq and Afghanistan have affirmed our emphasis on "non-traditional" ISR (Intelligence, Surveillance, and Reconnaissance) and irregular warfare (IW) missions. The F-35 brings unprecedented sensors, connectivity, and situational awareness to the fight without sacrificing legacy tactical fighter capabilities.

**What contributions/changes to the A-model variant has the USAF made over the last nine years and what factors have driven alterations?**

USAF requirements have remained consistent throughout development. Changes to aircraft design dramatically impact program cost, therefore we do everything we can to keep the design stable. The F-35B weight reduction effort drove deletion of the speed brake, movement of the Integrated Power Pack (IPP) exhaust from top to bottom, and a forward tilting canopy. Since that time, we have constrained any requirement growth to software content, sensor enhancements, and weapons integration priorities.

**What weapons systems will the F-35A enter operational service with and which systems may be added as development advances and subsequent Block versions appear?**

F-35A will have the ability to conduct all counter-air and counter-land missions at USAF IOC. F-35A will have full weapons carriage and release for AIM 120C, GBU-31, GBU-12, GBU-39 (SDB – Small Diameter Bomb Increment I), an internal 25 mm cannon, and external AIM-9X Block I. Growth items following SDD include SDB Increment II, AIM-9X Block II, and a 500-pound PGM (precision-guided munition) weapon to be determined by the partnership. Further, we will expand our mixed weapon load external carriage pallet, enhancing mission flexibility. As subsequent Block versions appear, capability is backward compatible to all existing F-35s, ensuring a homogenous fleet.

**How will delays in the JSF program affect the USAF? What are the implications of delays for the training of units planned to transition to the F-35A and for the Air Force's existing fleet of tactical aircraft?**

Essentially, program delays have slowed the F-35A bed-down plan, which in turn slows retirement of some legacy aircraft. We are constantly examining our TacAir force structure to identify if and when legacy aircraft will need additional modernization and sustainment efforts to bridge the transition.

**To date, what has been the most challenging aspect of CTOL variant development? Looking ahead, what is the most critical/challenging aspect of F-35A development between now and IOC?**

Our biggest challenge has been in preserving combat capability under the scrutiny of program slips, cost overruns, and production delays. Looking ahead, the most challenging aspect is a timely completion of developmental test followed by a very thorough initial operational test and evaluation period for the most complex aircraft ever built.

**When does the Air Force expect to achieve IOC for F-35A and how is the service collaborating with Lockheed Martin to ensure development continues expeditiously?**

The IOC date for the Air Force is currently estimated to be in 2016. The Air Force IOC date is intricately associated with full Block 3 capability and completion of initial operational test and evaluation. The USAF is working closely with Lockheed Martin Aero and the JSF Program Office to fine-tune the developmental test schedule to realize efficiencies and reduce risk.

**How many SDD examples of F-35A will be built/tested?**

There are four flying F-35A SDD jets, each having a specific role in developmental test: flutter and flying qualities, loads, mission systems, and flight sciences. Further, there are two ground test articles to examine static and durability testing.

# MAJ. GEN. THOMAS K. ANDERSEN

## Director of Requirements, Headquarters Air Combat Command, U.S. Air Force

BY JAN TEGLER

Maj. Gen. Thomas K. Andersen was kind enough to speak with us about the F-35A. His comments build on those of Fraser, adding perspective on the Air Force's current outlook on its second fifth-generation fighter, the challenges that lay ahead, and plans for its introduction to service.

**Jan Tegler: Gen. Fraser mentioned the design changes to the F-35A airframe necessitated by F-35B weight reduction efforts. How did those changes affect F-35A?**

**Maj. Gen. Thomas K. Andersen:** The three major changes for us as a result of the weight reduction were the deletion of the speed brake, the movement of the Integrated Power Pack to the bottom (the IPP combines the auxiliary and emergency power units and environmental control system to save weight, and it is required to start the engine and power the aircraft), and the change to a forward-hinged canopy. We had to change our way of doing business given the weight reduction effort, so for instance, instead of the canopy blowing before the ejection seat comes up the rails, the pilot will go through the canopy. It hasn't been difficult to balance combat capability even with the stricter weight and design limitations. We've just adapted to what is available.

**Is the Air Force confident that its four SDD aircraft can generate test sorties at a pace that allows the current schedule to be maintained? What crossover is there for F-35A in terms of the SDD testing being carried out for F-35B and F-35C? In other words, can F-35A SDD make use of test points being flown by F-35B SDD aircraft?**

From an Air Force point of view, SDD is progressing pretty well. The CV and the CTOL variants are a lot closer to each other than the CTOL is to the STOVL. I would expect that wherever the (F-35) Program Office and the operational test community can, they would try to leverage testing across the variants. When you get to mission systems testing where you're looking at the radar, electro-optical system, and the helmet, etc., then I think the testing will be applicable across all three platforms. We have dedicated production aircraft to SDD so that we accelerate and maintain a robust SDD process to have early discovery of any issues and iron out problems before they become catastrophic. As a note, the flying out at Edwards (AFB) has been going very well. The Program Office has a goal for X-number of sorties that they want to generate and they're either on or just above that curve. We've invested a lot of money in modeling and simulation, in excess of $2 billion. The test community is encouraged because the predictions based on the simulation have been verified in actual flight testing. We'll see if that investment can really pay dividends.

**Gen. Fraser mentioned that F-35B SDD had a major impact on F-35A development and that compromises had to be made. Please expand on the efficiencies gained in the process and growth capacity garnered for F-35A.**

The whole issue with the weight of the STOVL variant added time and money to the program and we were kind of along for the ride. Again, we have a different canopy. We moved the IPP and we removed the speed brake but we're (the F-35A) going to be able to carry more fuel because that space the B requires for the lift-fan engine is not needed for our variant so we'll make that up with extra fuel capacity.

**Lt. Gen. George J. Trautman III, USMC-Ret., (former deputy commandant of aviation) mentioned that there has been complementary work between the services on CONOPS/CONEMPS. He also alluded to the large amount of innovative work that has already been carried out in the very low observable (VLO) realm by the F-22 community. Can F-35A benefit from work already done in the F-22 community on a concept of operations?**

I'd break it down into the operational aspects of using stealth and some of the benefits it gives you. We're working not only with the F-22 community but the B-2 community, because those are platforms we expect to be operating in an anti-access environment and they need to be able to talk to each other. We've met with the Marines and the Navy and the high levels of the Air Force and OSD (Office, Secretary of Defense) to make sure we're developing that connectivity and that we'll not only be able to communicate in an anti-access environment but also outside of it to carrier strike groups and expeditionary task forces and to other Air Force platforms.

On the logistics and maintenance side we've had stealth for a long time in the Air Force. Our real introduction to that was the F-117. We've also had the B-2 and F-22. We've learned a lot of lessons. Where those are applicable to the Marines and Navy, we're going to make sure we transfer them. More importantly, the lessons we've learned from operating those airplanes were rolled into the development of F-35. We anticipate that the F-35 will be a much easier platform to maintain than its predecessors. That should be a big plus for us. We've all worked on making sure that the avionics suite is good across all of the platforms. The Air Force, Navy, and Marine communities all have different desires, so we're trying to ensure we have the flexibility in the avionics displays in the cockpit to satisfy the different requirements.

I think the one thing this platform is going to give all of the services is unprecedented situational awareness (SA). The pilots flying the simulators and the folks just starting to fly the avionics test bed are probably realizing this in spades. The amount of SA F-35 offers will be unlike any platform the services have had. Coming to grips with the best way to share that information, not only with your flight but to push it out of the anti-access environment and share it with the Intel community or the C2 (command and control) community is going to be a challenge and be very exciting. We've focused a lot of effort on sending our guys to Fort Worth (Lockheed Martin facility) to do mission decomposition. We're trying to anticipate that SA workload that we haven't dealt with until now or been able to share. Again, I've reminded everyone that we need the F-35 to be able to talk to the F-22 and B-2 and then outside the anti-access environment to anyone in any of the services that needs the information.

**Apparently the Navy and Marine Corps are urging Lockheed Martin to aid them in making F-35 more expeditionary. Specifically they'd like to drive down the weight associated with the airplane's automated logistics infrastructure (peculiar support equipment, predictive maintenance, etc.) and requirements for connectivity in places where data pipes are not readily available. Is this something the Air Force would like to address as well?**

We took our lessons learned from the F-117, the B-2, and F-22, and Lockheed Martin's now doing the job of rolling those lessons learned into the design of the F-35 so that it can be by nature more expeditionary. We're right in lockstep with the Navy and Marines when it comes to the need to have a deployable ALIS (automated logistics information system). That footprint has to be smaller. We're not always going to be at a fixed base where you can have a big computer system running.

We need a small palletized system that is durable and can be operated at austere airfields and is easy to carry forward. I submit that we're just as expeditionary in the last 10 years as any of our sister services. This capability is just as important to us as it is to the Navy and Marines. The squadron-based ALIS is too big to be deployable currently and all of the services have made it clear that we need a deployable system that can be scalable, put on a couple pallets, and moved out of town quickly.

**Is the Air Force looking ahead to the next-generation jammer and the possibilities of using the capabilities inherent in the F-35A's active electronically scanned array (AESA) radar for airborne electronic attack (AEA)?**

We're really happy with the progress of the APG-81, the radar for the JSF. As of now we're not excited about a jamming pod that would be hung on an F-35. We want to keep the platform as clean as possible. I think what we'd do first is explore the opportunities and advantages of having some EW capability resident in the APG-81 because it does have a lot of growth potential and capabilities that we haven't established a formal requirement for but which we're looking at real hard. We're not interested in the next-generation jammer as it relates to a pod on an F-35. The Air Force is making a lot of investments in electronic warfare right now that should pay some dividends. There is a system of systems and the (EA-6B) Prowlers and (EA-18G) Growlers play a key role, but it's not manned-electronic warfare platforms that you can get into an anti-access environment.

**Gen. Fraser mentioned that program delays will likely lead to prolonged service life for some legacy Air Force TacAir platforms. Are plans being formulated for retention/modernization of F-15/F-16/A-10 fleets beyond those already in place?**


F-35A aircraft AF-1 and AF-2 over Edwards Air Force Base.

Lockheed Martin photo

We're pretty well situated. Our F-15E fleet still has sufficient quantity and capability to see us through well past 2025. We have about 177 Eagles, F-15Cs/Ds that we're putting a new AESA radar on and they'll be capable into the 2020s. With our newer Block-40/50 F-16s, we extend their service life with structural enhancements and avionics improvements. We have money that we've advocated for in our Air Force POM (program objective memorandum) to look at service life issues to make sure we're ready. As the buying and delivery of the F-35 accelerates or slows, we can be pretty flexible now with the three primary platforms (F-15, F-16, F-35). The A-10 will be viable until the late 2020s.

We're hedging our bets and our reaction will be scalable depending on how fast we can get F-35s into the system. In our 2010 POM, we've already removed just over 200 older Block-30 F-16s from the Air Force. We've taken the low-hanging fruit there and been proactive. We're prepared to be flexible as the delivery schedules for F-35 become clear. I should add that the F-22 is going to be around until the early 2030s and we're still taking delivery of F-22s every couple weeks. That production is winding down but it's not over yet.

**What will a Block-3 F-35A be? What will it mean for pilots? What will its operational capability be?**

Our definition of IOC is a platform whose capability is C-D'ed (concept defined). It has maintenance manuals and crews in place. It has sufficient spares to begin operations. We won't declare IOC until operational testing of Block-3 is complete. Our Block-3 aircraft will carry AIM-120s, AIM-9s, and the ability to drop precision weapons, the JDAM and a laser (guided) weapon and its internal gun. Block-3 operational test ends in late 2015. That lines up with the end of SDD and the milestones that OSD has set out. That's why we've declared spring 2016 as our objective IOC date. It isn't until IOC that you get the full operating envelope either. We're looking at basic capability of weapons systems but full capability of the platform.

# F-35B

# LT. GEN. TERRY ROBLING

## USMC Deputy Commandant of Aviation

BY J.R. WILSON

U.S. Marine Corps aviators have been an integral part of naval aviation from the beginning, dating their own centennial (May 2012) only one year after the Navy's. They have been recognized for their innovation, skill, courage, and overall contributions to U.S. military campaigns from the start of World War I to current operations in Afghanistan.

It is the element of innovation that has been both a Corps hallmark and a constant source of controversy and battle, both with the Navy and the Pentagon. Getting congressional approval for the first Marine air bases – and the personnel, aircraft, and other equipment needed for them – was a near thing after World War I, as has been sustaining a Marine aviation component in light of an unending history of opponents claiming it was an unnecessary duplication of Navy, Air Force, and even Army capabilities. The Marine Corps also has engendered controversy in its selection of aircraft, especially those that have been Corps-specific, such as the AV-8A Harrier and AV-8B Harrier II jump-jets,

Lockheed Martin Photo by Andy Wolfe


F-35B aircraft BF-2 and BF-3 in flight. The F-35B gives the Marine Corps a stealthy, first-day-of-the-war supersonic strike fighter, a quantum leap in capability.

the MV-22 Osprey tiltrotor, and the F-35B short takeoff/vertical landing (STOVL) variant of the Joint Strike Fighter. After considerable effort, the Marines proved the Harrier and Osprey to be relable, critical components of Marine aviation.

The battle now centers on the F-35B. In January 2011, Defense Secretary Robert M. Gates, citing technical, cost, and flight test issues, placed the F-35B on a two-year probation, with a threat to cancel it entirely if those problems were not resolved. That came on the heels of a U.K. decision not to buy the F-35B; they were to have been the second largest operator after the Marines. The impact of that decision on production rates and costs is still being calculated. In April 2011, Lt. Gen. Terry G. Robling, the Marine Corps assistant commandant for Aviation, gave his assessment of the F-35B program to Faircount Media Group Senior Writer J.R. Wilson.

**J.R. Wilson: What were the initial Marine Corps requirements for a STOVL JSF variant to replace the service's AV-8Bs and F/A-18A/C/Ds?**

**Lt. Gen. Terry Robling:** Marine aviation is an integral part of the Marine Air-Ground Task Force (MAGTF) and must be capable of expeditionary basing ashore and/or deployment at sea. The Marine Corps' requirement is for one type of aircraft, capable of multiple missions, providing the MAGTF with flexible expeditionary basing and superior technology to dominate the fight. STOVL supports the rapidly changing nature of expeditionary operations by providing flexible basing options that allow tactical aircraft to improve responsiveness and increase sortie generation rates, as recently demonstrated in combat operations in Afghanistan and Iraq. The Marine Corps' need to field the STOVL JSF is driven not just by the requirement to replace an aging fleet of AV-8Bs, F/A-18A/C/Ds, and EA-6Bs (Prowler electronic warfare aircraft), but also by the need to replace them with a more survivable, flexible, and capable aircraft to meet the operational requirements of future combat environments. Technology advancements will allow the STOVL JSF to survive in the 2012 and beyond threat environment that has the potential to exceed our legacy aircraft capabilities.

**How have Corps requirements evolved through the course of the F-35 System Development and Demonstration program so far?**

As the Joint Strike Fighter matured through development it has become obvious the technological improvements designed to meet our requirements are enabling greater capabilities than expected. We have held firm on our requirements, neither increasing nor diminishing the critical elements we must have – very low observable (VLO) signature, enhanced self-protection, superior targeting, integrated networking, and highly flexible and agile basing capabilities. Our challenge is understanding the full potential of the aircraft and ensuring we take timely advantage of the improvements through a logical integration strategy across the MAGTF.

**"WITH THE F-35B, WE CAN FLEX ACROSS THE RANGE OF MILITARY OPERATIONS AND EITHER ASSUME, RELIEVE, OR AUGMENT OUR SISTER SERVICES' TACAIR RESOURCES IN THE EXECUTION OF THEIR ASSIGNED MISSIONS. THERE ARE NO VIABLE ALTERNATIVES TO THE F-35B THAT SUPPORT THE FULL RANGE OF CRISIS RESPONSE OBLIGATIONS OF THE UNITED STATES MARINE CORPS."**

**What role has the Corps played in F-35B design and requirements changes in the past decade – and what were the most important/significant of those?**

The Marine Corps has had a very active role in all aspects of the program since inception, to include test pilots, acquisition professionals, program managers, systems engineers, and logisticians. The single key initiative that will enable success, for not only the F-35B but also the remaining two variants, was STOVL weight reduction. We shaved thousands of pounds out of the aircraft design that ensured we would meet our critical performance requirements for range, weapons payloads, and vertical lift requirements. Second was the steadfastness of our operational requirements, which has precluded the "requirements creep" syndrome that occurs as programs grow in complexity and capability, while also refusing to relax requirements as offsets to schedule pressures.

**How important is the F-35B to the future of Marine Corps aviation?**

The Marine Corps gains a significant advantage in overall joint warfighting capability by having a TacAir platform that allows us to work detachments aboard L Class (amphibious warfare) ships concurrently with operations at main base facilities, from austere forward deployed sites and aboard conventional aircraft carriers. This capability enables us to conduct economy-of-force operations from sea or land bases with minimal disruption to the main effort. With the F-35B, we can flex across the range of military operations and either assume, relieve, or augment our sister services' TacAir resources in the execution of their assigned missions. There are no viable alternatives to the F-35B that support the full range of crisis response obligations of the United States Marine Corps.


WE CONGRATULATE TEAM F-35
ON MAKING VISION A REALITY

**"AS A FIFTH-GENERATION WEAPON SYSTEM, THE JSF WILL ENHANCE PRECISION STRIKE CAPABILITY WITH UNPRECEDENTED STEALTH, RANGE, SENSOR FUSION, IMPROVED RADAR PERFORMANCE, COMBAT IDENTIFICATION, AND ELECTRONIC ATTACK CAPABILITIES COMPARED TO LEGACY PLATFORMS."**


**What impact will the United Kingdom's decision not to buy the F-35B have on the Corps?**

The U.K.'s commitment to the capabilities the F-35 will provide remains steadfast. The Marine Corps and the U.K. have a long enduring relationship of Joint Strike Fighter program cooperation and collaboration that remains intact. The impacts have been minor in terms of the overall program and the F-35B.

**What is the Corps' view of the problems that led Defense Secretary Robert M. Gates to put the F-35B on a two-year "probation" in January 2011?**

Slowing down the production rate of our airplane to allow for responsible fixes to be designed and incorporated into the B-version early on was prudent in light of the progress the Joint Strike Fighter program had made through 2010, and provides the program time to develop and implement solutions for the technical challenges discovered in developmental test. Though none are insurmountable or beyond tangible engineering solutions, it is prudent to optimize the production rate to facilitate incorporation into as many of the early lot aircraft as possible. This is the most efficient process for incorporation and will deliver a higher quality of aircraft in the shortest amount of time.

**How does the change in that schedule affect Corps aviation force structure and capabilities, both near- and long-term?**

The slower rate of production slows down our rate of transition. Currently, we are successfully managing our strike fighter aircraft inventory to meet our operational commitments. We are confident we will be able to continue to manage our legacy aircraft appropriately with a variety of service life management initiatives until the F-35B is fielded.

**What are the improvements Gen. James F. Amos cited to the Senate Armed Services Committee on March 8, 2011, leading him to believe the probation could be lifted in less than two years?**

F-35B flight test has recovered calendar year 2010 loss and is ahead of schedule for CY 2011, and all STOVL technical challenges have mitigation and recovery plans. The first operational training aircraft procured are scheduled to arrive at Eglin AFB in the Fall of 2011 and LHD ship trials and Developmental Test #1 (are) on track

F-35B aircraft BF-2 makes its first vertical landing.

Lockheed Martin photo by senior flight test photographer Phaedra Loftis

for October-November 2011 at sea. In addition, training at Eglin AFB is on track for spring 2012 and the first operational aircraft arrival at MCAS Yuma is scheduled during August 2012.

**What impact has parallel development of the three variants had on the F-35B?**

Parallel development of the three variants has had no (negative) impact on the F-35B. The Joint Strike Fighter is unique in that the program is centered on the concurrent development of a family of highly common aircraft variants. Synergies are evident in software development, flight-testing, and, most importantly, sustainment. Though each service has distinctive operational requirements, a communal approach toward supporting all aspects of the program exists and is enjoined by all the partners. Success and failure is a shared common dependency and, from a joint perspective, the JSF is a major leap toward collaborative implementation and operational fielding.

**How have evolving worldwide military, political, and economic developments affected the F-35B and Corps plans for its operational deployment?**

The recent developments in Libya – and particularly the rescue of the downed F-15 aircrew – clearly demonstrated the need and benefits of deploying STOVL-capable aircraft with our Marine Expeditionary Units on our large deck amphibious ships. Clearly, as world dynamics shift from nation-state level conflicts toward concentrated asymmetrical tensions, the ability for strategic flexibility and operational agility becomes a necessary capability our nation requires.

**What work has been done on a Marine Corps concept of operations for the F-35B to date?**

Our concept of operations continues to evolve as the requirements we laid down for the F-35B come closer to fruition. I would define it more as a refinement of techniques and procedures that takes advantage of the superior capabilities of the aircraft, with the most important aspect being the acquisition, access, sharing, and collaboration of data and information we gain from the integrated sensor suite of the Joint Strike Fighter.

**What weapons systems does the Corps plan for an operational F-35B fleet up front – and what systems may be added as technology evolves and subsequent block versions are implemented?**

The F-35B Block 2B is far superior to current aircraft in the USMC inventory. With VLO survivability, a powerful integrated sensor suite, fused information displays, interoperable joint connectivity, a precision weapon capability, and self-protect anti-air weapons, it is a total package of capabilities that will revolutionize our expeditionary Marine air-ground combat power in all threat environments. Initially, we plan to have a complement of laser-guided munitions, GPS-guided munitions, and air-to-air missiles on the jet. But we have a plan for a flexible weapons suite, with future growth projected to counter the threat. We intend to upgrade our software right alongside our Navy and Air Force partners as they move into Block 3, the Operational Requirement-compliant configuration of the F-35.

**What aspects of Gen-5 technology and capability in the F-35B are most important to the Corps – and why?**

As a fifth-generation weapon system, the JSF will enhance precision strike capability with unprecedented stealth, range, sensor fusion, improved radar performance, combat identification, and electronic attack capabilities compared to legacy platforms. Upgrading our legacy aircraft to obtain the same capabilities requires costly improvements and redesign that will have limited return on investment due to the aging of the airframe structures and increasing support costs necessary to sustain the readiness and availability required to meet our operational demands. The fifth-generation JSF fills our tactical aviation requirements for the next 40 years, which cannot be met by our current inventory.

**Does the Marine Corps decision not to buy the EA-18G (Growler EW replacement for the Prowler) mean you have plans to develop an electronic warfare capability for the F-35B?**

An integral part of the Marine Corps' tactical aviation "neck-down" strategy is expansion and assimilation across all Marine aviation electronic warfare capabilities, to include manned and unmanned aircraft. No longer will we have only a single platform to conduct this vital mission; we will expand our EW capabilities and distribute them among our

F-35s and unmanned aircraft systems. The F-35B by itself is a robust electronic warfare platform and we will enhance this with the Next Generation Jammer to provide a superior capability to the EA-6B aircraft without the procurement of a specialized EW aircraft. The F-35B is inherently capable of meeting our electronic warfare requirements to control the electromagnetic spectrum.

**How has that been affected by program delays and restructuring?**

Our EA-6B aircraft have a robust capability today and have kept pace with our electronic warfare requirements. The program delays and restructuring have had minimal effect in maintaining this capability until the F-35B is delivered in the quantity required to replace the Prowlers. An important note is that, with the STOVL variant, we will obtain a responsive and collocated electronic warfare capability with our Marine Expeditionary Units that we have never had before.

**Given all that has happened in the past year or so, what do you consider to have been the most challenging aspect of developing the STOVL variant?**

The most challenging aspect of the STOVL variant over the last two years is achieving a steady state of flight test performance to enable confidence in the design and capabilities of the aircraft. Since January, we have not only surpassed flight test expectations but fully recovered the 2010 test shortfall. The STOVL variant was the first of the three variants to enter flight test and, as such, was the first to incur the normal and expected discoveries associated with establishing a test routine – uncovering design nuances and providing adequate support capabilities. So the STOVL aircraft broke trail for the other two variants; the lessons learned were invaluable and the result is flight test is now experiencing steady and predictable progress.

**And in light of those changes, what do you believe will be the most critical/challenging aspects of F-35B development between now and IOC?**

We have two challenges ahead of us: sustaining our flight test to provide the performance capabilities required of the aircraft and establishing the support infrastructure required to sustain fleet operations. Our F-35B Transition Task Force started three years ago, putting into place the entire infrastructure required to bed down the aircraft at our Marine Corps air stations. We start implementing those plans this year, commencing with Eglin AFB in preparation for our first training aircraft arrival this fall and then quickly shifting the focus toward MCAS Yuma for our first operational aircraft the following year.

**You recently said the Corps, in implementing Gen. Amos' new change to a mixed buy of F-35Bs and -Cs, will acquire 340 STOVL and 80 carrier-based variants; while you also said you hope the F-35B eventually will operate from Navy carriers, how would those aircraft be divided among Marine Corps amphibious ship basing and ground bases in the interim?**

We are buying five squadrons of F-35Cs, plus spares and attrition, mainly to fulfill our part of the bargain on Tactical Air Integration with the Navy. In the early TacAir integration agreements, we were looking at 10 squadrons of Marine aircraft integrating aboard carriers. We looked at what is realistic and required by the Navy for Marine aircraft and came to the conclusion five squadrons would be about right. Those will not always be aboard carriers; some will be back in training. So while the carrier variant does not allow for STOVL operations, the systems and aircraft will still be the same (due to program-mandated commonality, to the extent possible, across the three variants). The Marine Corps has procured 32 STOVL Joint Strike Fighters during FY08 through FY11. The first 15 aircraft will be delivered to Eglin AFB starting in the fall of 2011 and be used to conduct initial training for both aircrew and maintenance personnel. The degree of training complexity will be reliant on the progress of the program, specifically flight test and software development. Four of these aircraft will transfer to Edwards AFB in 2013 for Operational Test and Evaluation. The remaining aircraft will be delivered to MCAS Yuma, starting in late 2012, to the first operational squadron. Our first F-35C aircraft will be delivered in FY14 and we stand up our first operational CV (Navy carrier-based) squadron in 2016. The procurement of the F-35C allows the Marine Corps to simultaneously meet its enduring commitment to carrier Tactical Aircraft Integration while we continue our measured transition to a fifth- generation F-35B expeditionary capability. The remaining F-35 aircraft, once procured, will populate our remaining squadrons throughout the Marine Corps and will source MEU, OPLAN (Operations Plan), and UDP (Unit Deployment Plan) requirements in the future.

**"THE F-35B BLOCK 2B IS FAR SUPERIOR TO CURRENT AIRCRAFT IN THE USMC INVENTORY. WITH VLO SURVIVABILITY, A POWERFUL INTEGRATED SENSOR SUITE, FUSED INFORMATION DISPLAYS, INTEROPERABLE JOINT CONNECTIVITY, A PRECISION WEAPON CAPABILITY, AND SELF-PROTECT ANTI-AIR WEAPONS, IT IS A TOTAL PACKAGE OF CAPABILITIES THAT WILL REVOLUTIONIZE OUR EXPEDITIONARY MARINE AIR-GROUND COMBAT POWER IN ALL THREAT ENVIRONMENTS."**

# F-35C

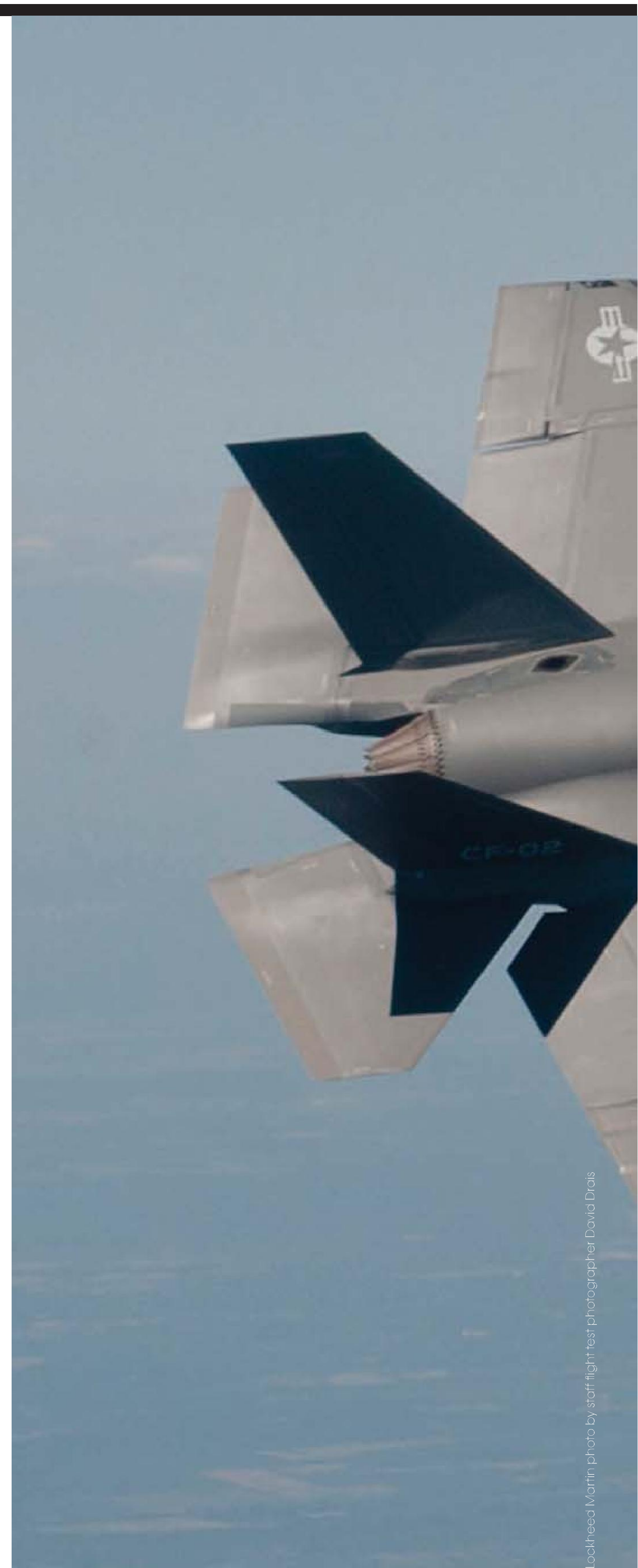
## VICE ADM. ALLEN G. MYERS

### Commander, Naval Air Forces

BY JAN TEGLER

Vice Adm. Allen G. Myers, commander of Naval Air Forces, is a 1978 graduate of the U.S. Air Force Academy and a northern Virginia native. He recently completed two tours in Washington, as director, Warfare Integration/Senior National Representative (OPNAV N8F), and director, Air Warfare Division (OPNAV N88). Prior to that he served as commander, Carrier Strike Group 8, where he commanded Expeditionary Strike Force 5th Fleet, Combined Task Force 50, Combined Task Force 152, and the Eisenhower Carrier Strike Group during an extended deployment in support of Operations Iraqi Freedom and Enduring Freedom 2006/2007. Before that assignment, Myers served in flag tours as the senior military assistant to the secretary of the Navy and deputy director for Requirements, Assessments Division (OPNAV N81D).

In August 2001, Myers completed command of USS *Kitty Hawk* (CV 63), permanently forward deployed to Yokosuka, Japan, and deployed to the Western Pacific. He previously commanded USS *Sacramento* (AOE 1). *Sacramento* deployed to the Western Pacific and Persian Gulf with the




Lockheed Martin photo by staff flight test photographer David Drais

F-35C airframe CF-2 on its third flight. The F-35C provides the carrier strike group commander with a "day-one" stealthy strike aircraft.

Constellation Battle Group and was awarded the Battle "E" and CNO Safety "S" under Myers' command. In December 1994, he completed command of Fighter Squadron VF-32, flying F-14 Tomcats aboard USS *Dwight D. Eisenhower* (CVN 69). VF-32 deployed to Bosnia and the Persian Gulf and was awarded the Battle "E," the Clifton Award, and the Fleet Fighter Adversary Readiness Program Trophy under his command.

Prior squadron and sea tours include VF-143, VF-14, VF-101, and VF-103. Tours ashore have also included: executive assistant to commander, U.S. Fleet Forces; Organizational Policy Branch chief in the Strategic Plans and Policy Directorate, J-5, Joint Staff; deputy executive assistant to the chief of naval operations; chief staff officer, Fighter Wings Atlantic; and deputy special assistant to the chief of naval personnel for flag officer matters.

Myers is a 1988 graduate of the Naval Command and Staff College, and holds master's degrees in national security affairs from the Naval War College and Salve Regina University. He has accumulated more than 3,600 flight hours and more than 900 arrested landings. Decorations include: Defense Superior Service Medal; Legion of Merit (eight awards); Meritorious Service Medal (two awards); Air Medal; Joint Service Commendation Medal; Navy Commendation Medal (two awards); and Navy Achievement Medal (two awards), in addition to various campaign and unit awards.

Myers provided insight on F-35C design developments, requirements changes, production delays, concept of operations and challenges ahead when he answered questions for Faircount Media Group writer Jan Tegler.

**Jan Tegler: The Navy's specifications for the F-35C call for a "first day of war" aircraft, a survivable strike fighter aircraft to complement the F/A-18E/F. How have requirements evolved over the course of the development program (SDD) so far?**

**Vice Adm. Allen G. Myers:** The Navy requirement for the F-35C carrier variant (CV) is enduring: to optimize the complementary capabilities of the F/A-18E/F Block II and EA-18G in providing survivable, long-range strike capability and persistence in an access-denied environment with the versatility to sustain operations across the full spectrum of modern warfare. The F-35C provides the Carrier Strike Group Commander with a survivable, "day-one" strike platform that operates with impunity, possessing tactical agility and strategic flexibility to counter a broad spectrum of threats and win in operational scenarios that cannot be addressed by current legacy aircraft.

**What impact has parallel development of the A/B variants had on F-35C?**

Parallel development of multiple variants of the JSF capitalizes on the benefits of air vehicle and mission system commonality as well as providing unparalleled supplier stability.

As a result, the F-35 program is structured to capture and control total ownership cost of operating Navy and Marine Corps tactical aircraft, plus allow enhanced interoperability with the Air Force and the eight partner nations. All variants of the F-35 aircraft will provide combatant commanders greater flexibility across the range of military operations. A true fifth-generation aircraft, the JSF will enhance precision strike capability through unprecedented stealth, range, sensor and data fusion, radar performance, combat identification, and electronic attack capabilities as compared to legacy platforms.

**What work has been done on a concept of operations for Navy F-35Cs to date? Have evolving worldwide military, political, and economic developments had effects on plans for the aircraft's operational employment?**

The F-35C is the fifth-generation answer to the threat spectrum, from irregular warfare in an asymmetric environment to a near-peer anti-access conflict. The Navy, along with the Marine Corps and the Air Force, has begun F-35A-C CONOPS development using lessons learned by other U.S. fifth-generation aircraft.

Subject matter experts from each of the services, weapons school staffs, and service requirements action officers have been developing CONOPS and tactics, training, and


CF-2 is the second F-35C Lightning II flight test jet, shown here in May 2011.

Lockheed Martin photo by David Drais

procedures (TTP) to cover all mission areas over the last several years by utilizing 'man in the loop' simulators as well as various modeling software. Multiple modeling simulations have proved JSF mission effectiveness against fully-vetted U.S. Navy analytical scenarios across the spectrum of warfare.

**What contributions/changes to the C-model variant has the Navy made over the last nine years, and what factors have driven alterations?**

The F-35C has been a relatively stable platform with consistent requirements; design and configuration changes have been a result of modeling refinement and design maturity.

The Navy requirement for carrier operations has driven some unique characteristics into the F-35C design. For example, to enable Category 1 flying qualities at approach speeds, the F-35C horizontal stabilators and wing control surfaces are noticeably larger to increase the planform area. This improves the handling characteristics at slow speeds and enables a slower approach speed to facilitate carrier arrestments.

Additionally, on the F-35C, the integrated power pack exhaust (IPP) is vented up, rather than down, as on the F-35A/B. The re-routing of the IPP was done specifically to improve compatibility with the shipboard environment by reducing the risk to personnel operating on a constrained flight deck as well as reducing the risk of heat damage to the carrier flight deck non-skid surface and underlying structure.

With continued maturation during system development and demonstration, the capabilities of the F-35C will be tested and assessed to ensure compatibility with the unique requirements of naval aviation.

**What weapon systems will the F-35C enter operational service with, and which systems may be added as development advances and subsequent block versions appear?**

The F-35C has a defined set of weapons to be integrated during SDD. When the Block III F-35C enters operational service, it will have the ability to employ GBU 31/32/12, AGM-154, AIM-120, AIM-9X, and a 20 mm gun pod. Subsequently, post-SDD efforts will add JSOW C and SDB II. Weapons integration efforts will continue beyond the SDD effort and will continue to increase the warfighting capability of the F-35C.

**How will delays in the JSF program affect the Navy? What are the implications of delays for the training of units planned to transition to the F-35C and for the USN's existing fleet of tactical aircraft?**

The actions taken by the Secretary of Defense in restructuring the JSF program include procuring an additional F-35C aircraft to be used for developmental flight testing, loaning three early production aircraft to developmental test, and directing the addition of another software integration line to the program. These three steps, taken together, establish a viable program supporting the Navy IOC (initial operating capability) date.

The current program of record procurement ramp enables the standup of squadrons in the most efficient manner possible while not exceeding the manufacturing capacity of Lockheed Martin and allowing testing to inform needed modifications to early lot production aircraft. The Navy still plans to begin transition and training of its first F-35C Fleet Squadron starting in 2014 and to deploy the first 10-aircraft squadron with combat capability in 2016. The restructured program procurement ramp supports the Navy's 2016 IOC date.

Near term (through 2015) strike fighter inventory shortfall reduction can be achieved by continued investment in high flight hour inspections of our F/A-18A-D aircraft to achieve a baseline service-life goal of 8,600 flight hours and implementation of inventory management "actions." These management actions or "levers" help to reduce the near-term inventory challenges and allow the Navy time to refine the long-term legacy aircraft service-life management strategy. There is risk in our assumptions and the mitigation options we are considering, and our projections will continue to evolve as investigations and analyses are updated.


The increased wing and tail planform area of the F-35C is shown to advantage in this photo.

Lockheed Martin photo by David Drais

**To date, what has been the most challenging aspect of CV variant development? Looking ahead, what is the most critical/challenging aspect of F-35C development between now and IOC?**

Development of the F-35C has been highly successful. The only major structural issue to date, the CV keel modification, was discovered very early, which allowed retrofit corrections of three SDD aircraft and in-line manufacturing corrections to the third and all subsequent F-35C aircraft.

The most stressing Navy IOC capability requirement is destruction of enemy air defenses (DEAD), which requires a highly integrated mission systems suite and stand-off weapons. This capability will be realized with the delivery of our first Block 3 aircraft in LRIP (low rate initial production) 5.

Delay in delivery of required capabilities is the most significant risk to the Navy IOC, with any further delays exacerbating the overall strike fighter shortfall. Moreover, the Navy requires a sufficient ramp to stand up a training squadron and a fleet squadron prior to declaring IOC. The Navy's intent is to stand up squadrons as aircraft become available and declare IOC when sufficient capability is tested and delivered.

**When does the Navy expect to achieve IOC for F-35C and how is the service collaborating with Lockheed Martin to ensure development continues expeditiously?**

The IOC for the F-35C is in 2016. The Navy IOC date is based on three items: sufficient aircraft quantities; desired capability to conduct all ORD missions, to include, but not limited to, AI, OCA, DCA, CAS, SEAD/DEAD, and CSAR in a denied, near-peer environment better than legacy aircraft; and completion of operational test of delivered capability.

# EGLIN'S 33RD FIGHTER WING

## Three Squadrons, Three Services, Three Variants

BY ROBERT F. DORR

An extraordinary military outfit, the 33rd Fighter Wing (FW) at Eglin Air Force Base (AFB) near Valparaiso, Fla., will soon mark a defining moment for the Lockheed Martin F-35 Joint Strike Fighter (JSF) – the single-engine, stealthy, dual-role combat aircraft on which the United States is basing its tactical air warfare future. Eglin is where future maintainers, pilots, and leaders in the F-35 world will learn their craft. They'll receive instruction as members of an Air Force fighter wing that isn't officially rated as "joint" yet epitomizes the jointness that is so much a part of American warfighting doctrine today.

"We couldn't function more jointly if we tried," said Lt. Col. Arthur "Turbo" Tomassetti, vice commander of Eglin's 33rd Fighter Wing in a telephone interview.

In another telephone interview, 33rd Fighter Wing Commander Col. Andrew J. "Drifter" Toth said that duty in the wing doesn't officially count as "joint" but that the wing is "fully integrated." That is certainly the case: Toth is an Air Force officer while deputy Tomassetti is a Marine. The wing has had a recent leadership change and Toth said Tomassetti is "the continuity that keeps us going."

As to the jointness of a wing that isn't officially joint, Toth said, "The way we're structured, a glance at an organizational chart can be very deceiving, but as you study it you find that we have our sister services integrated into what is essentially an Air Force structure. We also have a Marine Corps squadron and a Navy squadron that are collocated."

The wing has an Air Force-style operations group (ops group), but it's currently commanded by a naval officer, Capt. Michael "Trigger" Saunders. The wing also has a maintenance group (again, an Air Force unit, but with a Marine Corps commander), and an academic center (currently headed by a Navy captain). Under the operations group are three flying squadrons – one each for the Air Force F-35A, Marine Corps F-35B, and Navy F-35C. Some Marines will also train on and fly the carrier-capable F-35C.

"Our maintenance group has a Marine commander and looks a lot like an Air Force maintenance organization with Marine details," said Toth. "The 33rd Fighter Wing is also allocated an Army ground liaison detachment consisting of one officer and one enlisted." Added Tomassetti: "If we were any more joint we'd all be wearing the same clothes."

The F-35 will, of course, be flown by the Air Force, with its F-35A conventional takeoff and landing (CTOL) version; the Marine Corps with the F-35B short takeoff/vertical landing (STOVL) model capable of operating from land or from the decks of amphibious assault ships; and the Navy, with the F-35C aboard aircraft carriers. Nine partner nations are signed up for the F-35 effort, which will become one of the largest defense programs in history, and two or three more countries are often mentioned as likely future partners. All will eventually send representatives to Eglin and all will train maintainers there, starting with Great Britain.

### Instructing the Instructors

Before the 33rd Fighter Wing can train an operational pilot or maintainer it must first forge a cadre of instructors who will teach the new aircraft – a task experts say is eased by the simplicity of the F-35 and by the fact that the three versions are similar.

How similar? "When you get inside the airplane and sit in the seat all (three versions are) the same except for the 'STOVL/tailhook' switch," said Tomassetti, adding that the switch is labeled the same in all three cockpits but just performs a different function depending on the variant. "As far as tactical employment goes, the airplanes are very similar. The F-35B has a slightly smaller weapons bay, but the mechanics of deploying the weapon are the same."

For its initial flying activities, the 33rd Fighter Wing will operate the F-35 alongside F-16C/D Fighting Falcon "companion" aircraft to provide flying time for instructors, enhance efficiency by escorting F-35 flights, and keep pilots and maintainers busy as the unit ramps up. The arrangement is like that of the Air Force's four F-22 Raptor stealth fighter wings, which operate T-38A Talon "companion" aircraft. This isn't the long-term plan but is seen as a short-term measure to make it easier for the wing to build its strength and proficiency.

The "Nomads" were gearing up for operations for a full 17 months before Jan. 13, 2011, when the initial batch of four F-16C/D Block 25 Fighting Falcons arrived on loan from Luke Air Force Base, Ariz. "Everybody who operates on this base will benefit from an airplane taxiing out of here," said Col. James Ravella, then-33rd Operations Group commander, "and outside the base, from (nearby) Tyndall AFB to Pensacola Naval Air Station and other divert bases will get used to us coming over there."

"You are driving down risk by the type of aircraft, the type of flying we are going to be doing, and just establishing a battle rhythm at the 33rd FW with the integration of Team Eglin," said Saunders, who was then the 33rd Operations Group deputy commander and stepped up to replace Ravella on March 31.

Officials elected to bring the F-16 to the wing because of its similarity to its descendant, the F-35. Its flying characteristics are similar to the F-35 so the training and mindset pilots are going to have in a single-engine fighter transitions from the F-16 into the F-35. The plan originated at Air Education and Training Command (AETC), which is responsible for the 33rd Fighter Wing. Gen. Edward A. Rice, Jr., is commander of AETC.

The F-16 has many characteristics in common with the F-35. In a world where most jet fighters have two engines, both are


F-35 Lightning II jet AF-7 on its ferry flight to Edwards Air Force Base, Calif. This tailcode will soon be seen daily in the skies over Eglin AFB.

Photo by Senior Flight Test Photographer Darin Russell

single-engine craft. Both use a sidestick controller instead of a conventional stick between the pilot's knees. Toth said the F-16s will remain at Eglin until December 2011, flying a two-ship mission every morning and afternoon. "We will have 14 pilots current in the F-16 at all times," said Toth, himself an F-15 Eagle pilot who was scheduled to undergo F-16 transition training in May 2011 (and to check out in the F-35 in early 2012). "Their presence will make the transition to the F-35 more seamless."

Toth said that Air Force, Marine, and Navy pilots in the initial cadre of instructors are maintaining flight currency in their already-assigned aircraft by traveling to other locations and logging flight hours. Even though the 33rd Fighter Wing has four F-16s from Luke AFB, there is not enough capacity to keep all pilots current at Eglin.

Other pilots assigned to the 33rd Fighter Wing are required to travel to other host units to maintain their flight currency. One pilot rated in the F-16 is maintaining currency by flying with a test squadron located separately at Eglin. Other instructors keeping up on their currency with trips to other locations include two in the F/A-18C/D Hornet at Marine Corps Air Station (MCAS) Beaufort, S.C.; two in the AV-8B Harrier II at MCAS Cherry Point, N.C.; two in the T-45C Goshawk at Naval Air Station Pensacola, Fla.; two in the F-15E Strike Eagle at Seymour Johnson Air Force Base, N.C.; one in the F-16 at Dannelly Field in Montgomery, Ala.; one in the F-16 at Carswell Joint Reserve Base, Texas; one in the F-15C Eagle at Jacksonville, Fla.; and one in the T-38C Talon at Randolph AFB, Texas.

## Flying Squadron

The arrival and integration of the F-35 will be gradual, but the Eglin ramp will eventually be buzzing and the 33rd Fighter Wing will boast a mix of flying squadrons like none that has ever been seen in any flying unit in any service branch. In anticipation of a busier


Marines of Marine Fighter Attack Training Squadron 501 salute the colors during the redesignation ceremony of Marine Fighter Attack Squadron 451 to VMFAT-501, "Warlords," at Eglin Air Force Base, Fla. VMFAT-501 is the first Marine Corps training squadron for the new Joint Strike Fighter.

U.S. Marine Corps photo by Pfc. Samantha H. Arrington

ramp and of full-fledged F-35 training duties, the "Nomads" have been extremely busy developing training plans and honing the skills of the wing's initial personnel – plank owners, in Navy parlance.

The history of the wing is, of course, all Air Force: Its predecessor 33rd Fighter Group fought in North Africa and in the China-Burma-India theater. It later helped defend North American skies in its postwar identity as the 33rd Fighter-Interceptor Group. Still later, in the Cold War and Vietnam eras, the 33rd Fighter Wing flew F-4 Phantom IIs. Its service included a combat deployment to Southeast Asia in 1972. The wing converted to the F-15 Eagle in 1979.

In Operation Desert Storm in 1991, the Eagle-equipped Nomads scored the war's first air-to-air victory and finished with more kills (16) than any other unit. The 33rd boasted the most combat sorties and hours for any F-15 squadron (1,182 and 7,000), the greatest number of pilots in one squadron with a kill (12), the most pilots from one squadron with multiple kills (four), and the most MiG-29s destroyed in the air by any unit (five).

The 33rd Fighter Wing's history also includes the tragic loss of 12 airmen (among a total of 19 Americans and one Saudi killed) in the terrorist bombing at Khobar Towers in Saudi Arabia in 1996.

Now, the wing will be responsible for initial F-35 pilot and maintainer training for the Air Force, Marine Corps, and Navy and, in the future, overseas users. Never before has an Air Force wing consisted of members of three service branches, representing distinct methods, traditions, and cultures. Under Toth is the 33rd Operations Group, commanded by Saunders. The wing's key components also include the 33rd Maintenance Group led by Marine Col. Laura Sampsel; her deputy is an Air Force officer, Col. Mark E. Fluker. The director of the wing's Academic Training Center is Navy Capt. Steven James; his deputy is Air Force Reserve Col. Greg Jones. The director of the wing staff is Air Force Col. Don Finley.

The ops group will oversee the activities of three flying squadrons with three similar, yet different, aircraft:

The Air Force's 58th Fighter Squadron, "Mighty Gorillas," commanded by Lt. Col. John "Pimp" Wilbourne, stood up on Oct. 1, 2009, and will operate 24 of the F-35A CTOL models, probably beginning with the airframe AF-8, which is the eighth F-35A off the flight line and soon to be followed by AF-9, both in summer 2011.

The squadron's achievements began when it flew P-40 Warhawks in the invasion of North Africa in November 1942. According to the squadron's website, during subsequent combat in the Mediterranean theater, the 58th earned the "Gorillas" appellation for the guerrilla warfare-like techniques it utilized. In different theaters in World War II, the group flew the P-40, P-47 Thunderbolt, and P-38 Lightning.

During the Cold War, the Gorillas operated both the F-84F Thunderstreak and F-94C Starfire. In 1972, equipped with the F-4E Phantom II, the Gorillas deployed to Udorn, Thailand, under what was known as the "Summer Help Program." During this period,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the 58th became the first temporary-duty unit to down an enemy aircraft. On June 2, 1972, pilot Maj. (later Col.) Philip W. Handley and weapons systems officer 1st Lt. John J. Smallwood shot down a North Vietnamese MiG-19 fighter with a 300-round burst from their 20 mm M61A Gatling rotary cannon – believed to be the only supersonic "gun kill" in history.

"I held down the trigger," said Handley in a telephone interview in 2006, "and for just a fleeting moment the (gun) wound up to its 100 round per second (firing) rate. I had the dread feeling that I was too close and would collide with the MiG." But the MiG suddenly had "fire, smoke, fluids, and pieces ... streaming from its right wing root." The MiG-19 crashed into a meadow and exploded, Handley said. Sadly, Smallwood was killed in Cambodia on June 16, 1973 – one of the last American fatalities in Southeast Asia.

When Operation Desert Storm began, the Air Force at first credited a different F-15C Eagle unit with the first MiG kill of the 1991 war. Once the records were examined, it became clear that the war's first aerial victory was a MiG-29 shot down by the Gorillas' Capt. Jon K. Kelk on the night of Jan. 17, 1991, using an AIM-7 Sparrow radar missile. In an era when a Marine Corps uniform was an unusual sight in an Air Force squadron, Capt. Charles J. "Sly" Magill, a leatherneck exchange officer with the Gorillas, also used a Sparrow to shoot down a MiG-29 on Sept. 17. The Gorillas proudly flew the F-15C Eagle until 2008, when the Air Force began planning on today's new job for the squadron.

In their new assignment, the Gorillas are expected to find the F-35A to be the easiest of the three JSF versions to fly. The F-35A has the same dimensions as the F-35B (wingspan 35 feet, length just over 51.4 feet, and wing area of 460 square feet), but its fuel load of 18,250 pounds is almost 50 percent more than the F-35B and slightly less than the F-35C. The F-35A has a dorsal receptacle for the "flying boom" air refueling system, unlike the F-35B and F-35C, which rely on the probe and drogue method. The F-35A's planned 25 mm, four-barrel Gatling gun is located near the left wing root, unlike the F-35B, which can carry a gun only on an external centerline pod and surrenders its stealth capability when it does so.

With a weapons payload listed as 18,000 pounds, the F-35A shares with other versions its role as what the manufacturer calls "a multi-role, supersonic, stealth fighter that has extraordinary acceleration and 9 *g* maneuverability and agility." Pilots will eventually learn about more than the sidestick controller, throttle, rudder pedals, and weapons release. The Air Force emphasizes that the F-35A is meant to be "both an information gatherer and transmitter in a vast network. Its processing power, open architecture, powerful sensors, information fusion, and flexible communications links will make the F-35A an indispensable tool in future operations."

The Marine Corps Squadron VMFAT-501 "Warlords," commanded by Marine Lt. Col. James "Baja" Wellons, was stood up on April 2, 2010, and will operate 20 of the F-35B STOVL versions.

U.S. Air Force photo by Airman 1st Class Anthony Jennings


U.S. Air Force photo by Samuel King Jr.

OPPOSITE: Navy Capt. Michael "Trigger" Saunders tries on the new F-35 Lightning II Joint Strike Fighter helmet after being measured for the new flight suit Feb. 25, 2010, at Eglin Air Force Base, Fla. Saunders is the 33rd Operations Group commander.

LEFT: Airmen get a close-up look at the F-35 Lightning II Joint Strike Fighter test aircraft AA-1 as it sits on the ramp at Eglin Air Force Base, Fla. The aircraft's first arrival at the base was to provide a showcase to base members and the local community.

VMFAT-501 carries the flag and the lineage of a proud Marine squadron that previously used the number "451" and was reactivated as VMFAT-451 on April 1, 2010, after 13 years in retirement – and was quickly given its new number.

The historical predecessor of today's Warlords was activated in 1966 and flew the F4U-1D Corsair aboard USS *Bunker Hill* (CV 17), continuing a long Marine tradition of fighting from ships' decks. The squadron was among the first carrier-based units to conduct air strikes against the Japanese mainland. Bunker Hill was hit and seriously damaged by kamikaze attack but VMF-451 intercepted and shot down many more of the Japanese suicide aircraft, sparing the fleet further damage.

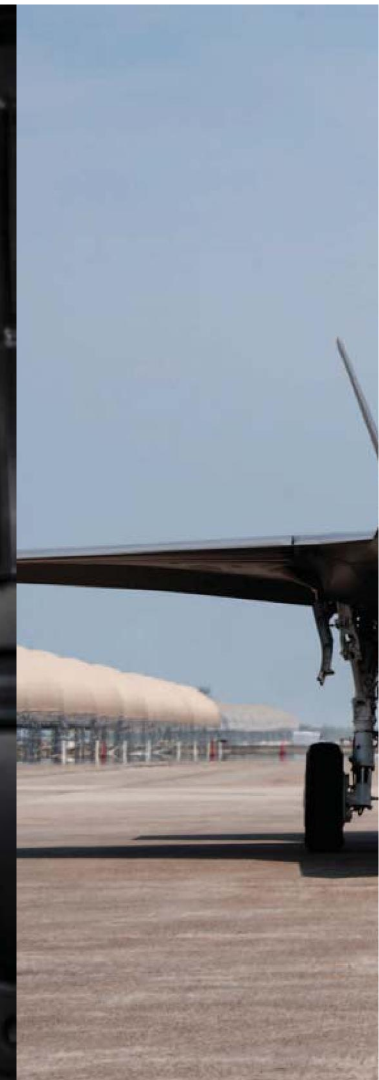
The squadron operated early jets, transitioned to the FJ-4 Fury, and was on alert on Formosa (Taiwan) during the crisis there in 1958. They later flew F-8 Crusaders and deployed to South Vietnam in the F-4 Phantom. The Warlords were an F/A-18A/B Hornet unit when they were deactivated in 1997. In their newly revived role as a fleet replacement squadron (FRS) to train pilots and maintainers, the F-35B-equipped Warlords will fall operationally under Eglin's 33rd Fighter Wing and administratively under Marine Aircraft Group 31.

The future of the F-35B has been the subject of much discussion since Great Britain, in an economy move, dropped its plans to operate the aircraft. The Marine Corps once planned to operate F-35Bs only, but will now employ a mix of the STOVL B model and the carrier-capable C model. Gen. James F. "Tamer" Amos, the commandant of the Marine Corps and the first aviator to serve as the nation's top leatherneck, argued that the F-35B is essential to the Marine Corps' *raison d'etre*, which is ship-to-shore amphibious operations.

"We … held out on buying another attack aircraft for 11 years," said Maj. Shawn M. Basco, VMFAT-501's executive officer in a Marine Corps news release. "We have been waiting for the F-35B to come along and provide us with an all-STOVL force. We will have the capabilities of a Harrier, some organics (of the) Prowler and some effects and capabilities of a Hornet in one aircraft." The EA-6B Prowler has long been the Marines' standard electronic warfare aircraft.

Almost identical in appearance to the F-35A, the F-35B incorporates a counter-rotating, shaft-driven LiftFan located behind the cockpit. The LiftFan is turned by a drive shaft from the F-35B's engine, which features a swiveling rear exhaust nozzle that vectors thrust downward during vertical flight. The LiftFan, engine, and stabilizing roll ducts beneath the F-35B's wings combine to produce 40,000 pounds of lifting force. Making the transition from STOVL to conventional flight and vice versa requires only the pilot's push on the sole button on the console that differs from other variants. Otherwise, the system operates automatically.

The F-35B has the same wingspan, length, and wing area as the F-35A, but one-third less fuel at 13,888 pounds. It will have significantly higher wing loading than the Navy F-35C because the latter has a wider and broader wing. The probe and drogue refueling probe will be on the right, or starboard, forward fuselage just ahead of

U.S. Air Force photo by Samuel King Jr.

U.S. Air Force photo by Ashley M. Wright

the pilot. The LiftFan (weighing 2,700 pounds), roll posts, and three-bearing swivel nozzle (together weighing 1,350 pounds) are unique to the F-35B's STOVL mandate. The F-35B is slightly larger and heavier than an AV-8B Harrier II and has about a 30 percent greater spot factor, meaning that it occupies more space on a ship's deck.

"We're absolutely convinced that this aircraft is going to only further enhance what is a tremendous asymmetric advantage that we hold in terms of controlling the air, taking advantage of intelligence, surveillance and reconnaissance capabilities, multi-sensor capabilities, and the ability, if need be, to drop a bomb in a precision strike," said the Marine Corps' last commandant, Gen. James T. Conway. Amos is similarly enthusiastic. The Marine Corps had once planned to declare F-35 initial operational capability (IOC) in December 2012 but following a restructuring of the program now expects to achieve this goal in 2015, still slightly ahead of the Air Force and Navy. The Marines need 10 F-35Bs equipped with Block IIB software, six aircraft capable of austere and/or ship-based operations and a flight envelope of 7 *g* and 50-degree angle of attack to declare IOC.

U.S. Navy squadron VFA-101 "Grim Reapers" will eventually be equipped with 15 carrier-capable F-35C fighters. When this article was written, VFA-101 had not yet been formed and a commander had not yet been named.

The original Grim Reapers squadron began duty in 1942, flew F4F Wildcats and F6F Hellcats in the Pacific in combat, and was disestablished in 1945. Designated VF-101, it was revived to fly FG-1D Corsairs in the Korean War. The Grim Reapers began their role as a replacement air group (RAG), a term later changed to fleet replacement squadron in 1958, training pilots of the F4D-1 Skyray and F3H-2 Demon. The Grim Reapers later served as the East Coast RAG for the F4H-1 (F-4B) Phantom I and subsequent Phantom variants.

Capt. Gerald "Jerry" O'Rourke, the squadron commander in 1963 and a veteran of night fighters operations in Korea, was instrumental in setting up a Grim Reapers detachment at Key West, Fla., to train back-seat radar intercept officers. O'Rourke also gave an F-4B orientation flight to a unique back-seater, Sen. Barry Goldwater R-Ariz. "In the early days, our bosses didn't reckon up to the fact that the Phantom's mission as an interceptor depended on the guy in the back seat," said O'Rourke in a 1979 interview. "Only long after I set up the first RAG, we replaced the term radar operator with the term RIO (radar intercept officer). A few years later, we created the term NFO (naval flight officer) to cover all air crew officers who were not pilots." The detachment at Key West

FAR LEFT: Maj. Eric Smith, 58th Fighter Squadron assistant operations director, flies the 33rd Fighter Wing mission rehearsal trainer for the F-35. The trainer will use state-of-the-art technology to further familiarize students with the Joint Strike Fighter.

LEFT: F-35 Crew Chief Tech. Sgt. Brian West from the 33rd Fighter Wing guides a Lockheed Martin F-35 Lightning II to its final parking position at Eglin Air Force Base, Fla. The aircraft, known as AF-9, is the first production F-35 to be delivered to the wing. AF-9 arrived at 1:18 p.m. July 14, 2011, after its more than 90-minute ferry flight from Fort Worth, Texas.

BELOW: Aerial view of the Joint Strike Fighter Training Center construction site at Eglin AFB, Fla.

Photo courtesy of the U.S. Air Force

did not last, but the emphasis on RIO training persisted after 1980, when the squadron became the RAG for the F-14 Tomcat.

As the only F-14 training squadron just before being disestablished in 2005, VF-101 owned as many as 130 F-14A, F-14A+, and F-14D Tomcats, plus a handful of T-34C Turbo Mentors for currency training and range safety.

The F-35C is the largest version of the Joint Strike Fighter, with a wingspan of 43 feet and a wing area of 668 square feet. Horizontal tail area is also larger. It carries the most internal fuel – 19,750 pounds. With the same refueling probe as the F-35B, it has strengthened landing gear and, of course, a tailhook for carrier landings. (The F-35A carries a tailhook for arrested landings on runways). The F-35C is smaller than an F/A-18E Super Hornet and has a smaller deck "spot factor," or footprint.

## A New Culture

In his Air Force fighter wing filled with members who don't belong to the Air Force, Toth said all kinds of cross-cultural developments are taking place. "The Marines do a combat fitness test that's different from the way the Air Force does physical training," Toth said. "AETC gave us money to go buy a track so our Marines could do their fitness test." Airmen in the 33rd Fighter Wing follow the current practice of wearing dress uniforms on Mondays and work utilities the rest of the week. Referring to the fierce pride leathernecks feel in their own service branch, Toth said, "In our environment, the loyalty that Marines show to Marines they also show to the mission we all share."

It's a unique organization, the 33rd Fighter Wing. Said one observer: "I'll bet they have interesting conversations in the O Club on Friday nights."

Toth arrived to command the 33rd Fighter Wing midway through its preparations for the F-35. "The bottom line is, when I first came into this organization my focus was not to change the things we were doing but to keep on with the great folks we have in the 33rd FW," said Toth. "Our focus is not to worry about the aircraft program or with delays that we can't control but to get ready for the first aircraft when it arrives."

Said Toth: "This will be the first ever fifth-generation fighter DoD (Department of Defense) fighter training center. When they leave here they will have completed their basic training in the system they're going to fly. They will move from the 33rd Fighter Wing to a combat wing. There, they'll get a checkout and will immediately be mission ready."


Image courtesy of Lockheed Martin

Lockheed Martin's STOVL Strike Fighter (SSF) concept, developed under a DARPA program, was one of several separate initiatives merged into the Joint Advanced Strike Technology (JAST) program, which later became the Joint Strike Fighter program.


# THE DEVELOPMENT OF THE JOINT STRIKE FIGHTER

## History, Concept, and Design

BY SCOTT R. GOURLEY

In his March 11, 2010, testimony before the Senate Armed Services Committee, Dr. Ashton B. Carter, under secretary of defense for Acquisition, Technology & Logistics, observed, "The Joint Strike Fighter is the Department of Defense's largest acquisition program, and its importance to our national security is immense.

"As Secretary (Robert M.) Gates has said publicly, 'We cannot afford, as a nation, not to have this airplane,'" he continued. "The JSF will form the backbone of U.S. air combat superiority for the next generation. It will replace the legacy tactical fighter fleets of the Air Force, Navy, and Marine Corps with a dominant, multi-role, fifth-generation aircraft, capable of projecting U.S. power and deterring potential adversaries. Furthermore, the JSF will have the capability to effectively perform missions across the full spectrum of combat operations. For our international partners who are participating in the program, the JSF will become a linchpin for future coalition operations and will help to close a crucial capability gap that will enhance the strength of our security alliances. ..."

As identified in government program descriptions, the F-35 JSF program is a joint, multinational acquisition to develop and field an affordable, highly common family of stealthy, next-generation strike fighter aircraft for the United States Air Force, Marine Corps, and Navy as well as international partners. The JSF is a single-seat, single-engine aircraft incorporating low-observable (stealth) technologies, defensive avionics, advanced sensor fusion, internal and external weapons stations, and advanced prognostic maintenance capability. There are three variants. The conventional takeoff and landing (CTOL) variant will primarily be an air-to-ground replacement for the Air Force's F-16 Falcon and A-10 "Warthog" aircraft, and will complement the F-22A Raptor. The short takeoff/vertical landing (STOVL) variant will be a multi-role strike fighter to replace the Marine

Corps' F/A-18C/D Hornet and AV-8B Harrier aircraft. The carrier-suitable variant (CV) will provide the Navy a multi-role, stealthy strike aircraft to complement the F/A-18E/F Super Hornet.

While some point to an aircraft history beginning in November 1996 with a five-year competition between Lockheed Martin and Boeing to determine the most capable and affordable preliminary aircraft design, closer analysis traces JSF origins to several programs from the 1980s and early 1990s.

Early predecessor systems included the Advanced Short Take-Off/Vertical Landing (ASTOVL) (1983); the STOVL Strike Fighter (SSF) (1987-1994) and Common Affordable Lightweight Fighter (CALF) (1993-1994); Multi-Role Fighter (MRF) (1990-1993); Advanced Tactical Aircraft (ATA) (1983-1991); Naval Advanced Tactical Fighter (NATF) (1990-1991); and Advanced-Attack/Advanced/Fighter-Attack (A-X/A/F-X) (1992-1993).

ASTOVL activities, for example, emerged from a Defense Advanced Research Projects Agency (DARPA) program to begin looking at the technologies available to design and manufacture a follow-on supersonic replacement for the AV-8 Harrier. Eventually becoming a joint U.S.-U.K. collaborative effort, the initial results of ASTOVL reportedly indicated that the technologies available were not yet advanced enough to generate a satisfactory Harrier replacement.

However, DARPA histories reflect that the agency approached the Lockheed Skunk Works to develop an ASTOVL-type aircraft. Lockheed reportedly responded with some ideas requiring maturation, a process that eventually led to DARPA's continuation of ASTOVL "Phase II" as a cover for the covert work being done at the Skunk Works.

A NASA engineer mounts a model of one of the iterations of the McDonnell Douglas Model 279, a supersonic lift-cruise vectored thrust aircraft with a close-coupled canard/tailless delta layout, in a wind tunnel at NASA's Ames Research Center. The Model 279 was one of many STOVL designs analyzed over the years for programs that eventually died out or merged into the JSF program.

NASA photo

SSF activities in the late 1980s involved another classified program between Lockheed Skunk Works and NASA Ames to explore the possibilities of designing a stealthy supersonic STOVL fighter.

According to official summaries, the cooperative program utilized the assets of NASA (wind tunnels, personnel, supercomputers, etc.) along with the expertise of the Lockheed Skunk Works in designing stealthy air vehicles, with the results indicating that such a fighter could be successfully flown.

"Management at the Lockheed Skunk Works was convinced that the SSF design could be sold to both the U.S. Air Force and the U.S. Navy (the U.S. Navy's NAVAIR is the procuring office for Marine Corps aircraft)," adds one DoD summary. "The Skunk Works proposed a teaming between the USAF and the USN. The services agreed, a Memorandum of Understanding (MOU) was signed between the services and the SSF program began to come out of the black."

The early 1990s also saw the CALF, which DoD historians frequently characterize as "a re-christening" of the ASTOVL and SSF programs as they expanded into multi-service/multiple-variant concepts.

"The management of the CALF program was handled by DARPA due to the experimental nature of the concept," program descriptions explain. "DARPA was also managing the ASTOVL program, which was used by the SSF program as their unclassified, white-world cover story. The CALF program's aim was to develop the technologies and concepts to support the ASTOVL aircraft for the USMC and Royal Navy (RN) and a highly-common conventional flight variant for the U.S. Air Force. Although the CALF program was organized upon a suggestion from Lockheed, the government still wanted multiple contractors involved in the program. Initially, the only two contractors involved were Lockheed and McDonnell Douglas. Boeing later approached DARPA and offered to meet DARPA's financial contribution if they were allowed onto the program."

The CALF program was also known as the Joint Attack Fighter (JAF).

The MRF was an Air Force program started in 1991 as a possible replacement for the F-16. MRF was envisioned as "a relatively low-cost" single-seat/single-engine fighter similar in size to the F-16.

The MRF program was managed by the Aeronautical Systems Center (ASC) at Wright-Patterson Air Force Base, Ohio, which hosted a planning meeting with industry in October 1991 and issued a subsequent Request For Information (RFI) with responses due in January 1992.

Noting, "The major U.S. aircraft manufacturers began to conduct concept and design studies for the MRF at their own expense," DoD program summaries add, "A formal program start was expected around 1994. The MRF was expected to replace a large number of F-16s reaching the end of service life. The MRF might also have replaced Air Force A-10s and Navy F/A-18C/Ds. Therefore, providing large numbers of aircraft affordably was a higher priority for the MRF program than any specific capability enhancements. However, the post-Cold War defense drawdown made the F-16 service life situation considerably less critical. A reduction in the total number of U.S. Air Force fighter wings meant that the existing aircraft would not be replaced one-for-one. Furthermore, F-16 aircraft flying hours were reduced, allowing F-16s to remain in service longer than originally projected. In August 1992, the MRF program was effectively put on hold. Due to budget pressures and the Air Force's commitment to the F-22 program, sufficient funding for a new program start did not appear likely until around 2000. Until then, it was expected that MRF activity would proceed at a low level. Meanwhile, the Air Force intended to continue production of Block 50 F-16s. By early 1993, however, the MRF's projected IOC had slipped to 2015 …"

The program was canceled shortly thereafter.

Another JSF predecessor, the ATA, began in 1983 as a proposed long-range, very low observable, high-payload, medium-attack


The U.S. Air Force's SHARC (Subsonic, High-Alpha Research Configuration) was one of the studies undertaken while the Air Force was pursuing a Multi-Role Fighter (MRF) program. MRF was one of the several programs that eventually became the JSF program. The faceted stealth shaping of the day is readily apparent in the wind-tunnel model.

Photo courtesy of NASA

aircraft to replace the Grumman A-6 in the carrier-based, medium-attack role. Designated as the A-12 "Avenger II," the replacement aircraft would incorporate stealth technology and could be deployed from an aircraft carrier.

In January 1988, the McDonnell Douglas and General Dynamics team was selected over a Northrop team to develop the ATA. The unique flying wing design was to be a long-range, subsonic aircraft with a large internal weapons load, including air-to-surface and air-to-air weapons.

However, the program was canceled in early January 1991 following what service histories describe as "the disclosure of severe cost and schedule overruns and technical problems."

The early 1990s also witnessed congressional guidance under which the Navy agreed to evaluate a "navalized" version of the U.S. Air Force's Advanced Tactical Fighter (ATF) – now the F-22 – as a possible replacement for their F-14s. The exploration program was identified as the Naval Advanced Tactical Fighter (NATF).

As described in GAO reports at the time, "The ATF and the Navy variant are to be twin-engine, all-weather aircraft capable of day or night operations over land or sea. Both are expected to have many new or expanded capabilities, such as maintenance of supersonic speeds over long distances and lower detectability through the use of stealth technologies. Two airframe contractor teams and two engine contractors are involved in the


Photo courtesy of JSF Joint Program Office

demonstration and validation of the ATF and the Navy variant. Each airframe contractor team is building two prototype ATF aircraft, a ground-based avionics prototype, and an avionics test bed to be flown in a commercial-type aircraft. The engines are to be demonstrated in each of the airframe contractors' prototype aircraft … In March 1986 the Secretaries of the Air Force and the Navy agreed to evaluate the potential use of each service's advanced aircraft to meet their future aircraft requirements. This led to the Navy's participation in the ATF program. Similarly, the Navy is developing the Advanced Tactical Aircraft to replace its A-6 surface attack aircraft, and the Air Force is evaluating a variant of that aircraft to replace its F-111 surface attack aircraft …"

An NATF program office was set up at Wright-Patterson Air Force Base in late 1988 and the existing ATF Dem/Val (Demonstration/Validation) contracts were modified to include the development of preliminary Navy specifications and designs suitable for carrier operations.

Examples of the challenges that needed to be addressed between an ATF designed to operate from fixed land bases and an NATF variant operating from pitching and rolling aircraft carrier decks included the Navy's need for a stronger landing gear, an arresting tailhook, and a stronger and heavier structure to withstand the stress of carrier catapult takeoffs and arrested landings. Yet any Navy variant would also be bound by the size and weight limits imposed by a carrier's elevator, catapult, and arresting equipment. Other complications included the need for the NATF to be configured and aerodynamically designed to provide the pilot with adequate visibility and the aircraft with unusually good low-speed flying qualities to make a safe carrier approach and landing.

The net result of the Dem/Val contract modifications meant that, while the Air Force planned to begin full-scale development in July 1991, at that time the Navy would have only had a preliminary aircraft design supported by plans to continue its demonstration and validation effort.

Then, following a Major Aircraft Review that reduced peak production rates of both the ATF and NATF, Navy leadership expressed the belief that the substantially increased program costs resulting from lower production could not fit into any affordable plan for naval aviation. In early 1991, before the final contractor for the ATF was selected, Navy consideration of the NATF was dropped.

Along with the continuation of vital aircraft technology developments, programs like ATF/NATF helped provide joint service aviation development "lessons learned" that have been exploited and optimized in today's JSF.

Meanwhile, the cancellation of ATA and NATF led to the emergence of the Advanced-Attack/Advanced/Fighter-Attack

OPPOSITE: The final McDonnell Douglas JAST (Joint Advanced Strike Technology) design, developed with Northrop Grumman and BAE Systems, lost out to the Boeing and Lockheed Martin contenders.

LEFT: The Boeing Company's X-32 demonstrator shown during a flight test in the Concept Demonstration phase of the program. Boeing's design was determined in large part by the need to place the engine over the aircraft's center of gravity due to the needs of the STOVL variant.

Photo courtesy of JSF Joint Program Office

**PROGRAM PARTICIPANTS SAY THE JAST GOAL WAS "NOT TO HAVE DEVELOPED A NEW AIRCRAFT, BUT INSTEAD IT WAS TO MATURE THE TECHNOLOGIES THAT A NEW SERIES OF TACTICAL AIRCRAFT COULD USE." AS SUCH, JAST WAS CHARTERED "TO MATURE TECHNOLOGIES, DEVELOP REQUIREMENTS, AND DEMONSTRATE CONCEPTS FOR AFFORDABLE NEXT-GENERATION JOINT STRIKE WARFARE."**

(A-X/A/F-X) in early 1991, when the secretary of the Navy directed that planning commence for a new A-6 replacement program. This new A-X concept was described as "an advanced, 'high-end,' carrier-based multi-mission aircraft with day/night/all-weather capability, low observables, long range, two engines, two crew, and advanced, integrated avionics and countermeasures."

The Air Force also participated in the new program, since it was still seeking a replacement for the F-111 and, in the longer term, the F-15E and F-117A.

Contracts were awarded to five industry teams in late December 1991 (prime contractor listed first): Grumman/Lockheed/Boeing; Lockheed/Boeing/General Dynamics; McDonnell Douglas/Vought; Rockwell/Lockheed; and General Dynamics/McDonnell Douglas/Northrop.

Following early A-X/A/F-X concept work completed in September 1992, a solicitation for (Dem/Val) proposals was expected in late 1992, which would have led to a Dem/Val start in 1994 and EMD (Engineering and Manufacturing Development) in 1996. Under the Navy's original plan, the short Dem/Val phase would consist of design refinements and other risk reduction activities, but would not include flying prototypes. However, in late 1992 Congress directed that the A-X Dem/Val phase also include


Lockheed Martin's Joint Strike Fighter concept demonstrator, the X-35, was chosen to proceed to the System Development and Demonstration phase.

competitive prototyping, a directive credited with increasing projected duration of the Dem/Val phase from two to five years.

One DoD historical summary adds, "Concurrently, as a result of the termination of the NATF in 1991, increased air-to-air requirements were added to the A-X, prompting a change in the name of the Program from Advanced Attack (A-X) to Advanced Attack/Fighter (A/F-X)."

When the existing A-X contracts were extended to reflect the revised Dem/Val strategy that now included flying prototypes, the expected Initial Operational Capability (IOC) date of the A/F-X slipped from 2006 to 2008.

"A Defense Acquisition Board (DAB) Milestone I Review of the A/F-X Program was expected in Spring 1993," the summary continues. "(H)owever, the BUR (Bottom Up Review of U.S. Naval Aviation) placed the A/F-X program on hold pending the outcome of the report. (A) Milestone I DAB for the A/F-X never took place.

"On 1 September 1993, the release of the BUR announced the cancellation of the A/F-X as well as the MRF (Multi Role Fighter)," the history notes. "As a result of the BUR, A/F-X efforts during the latter half of 1993 were directed toward closing out the program and transitioning applicable experience and results to the upcoming JAST (Joint Advanced Strike Technology) Program. A core of A/F-X personnel performed a large portion of the working-level planning and definition of the emerging JAST Program. The A/F-X CE/D contracts were extended a second time, through 17 December 1993, to allow the contractors sufficient time to bring their activities to a logical conclusion. All A/F-X program operations ended on 31 December 1993."

That JAST program provided the heart of the JSF.

Program participants say the JAST goal was "not to have developed a new aircraft, but instead it was to mature the technologies that a new series of tactical aircraft could use." As such, JAST was chartered "to mature technologies, develop requirements, and demonstrate concepts for affordable next-generation joint strike warfare."

As JAST program plans evolved, however, it became apparent that JAST would be funding one or more concept demonstrator aircraft starting in 1996 – about the time the ASTOVL program planned to enter its Phase III (full-scale flight demonstrators). One result of this apparent schedule overlap was FY 95 budget legislation passed in October 1994 by the U.S. Congress, which directed that ASTOVL be merged into JAST.

In early 1997, Lockheed Martin (the company was formed in 1995 by the merger between Lockheed and Martin Marietta) and Boeing were selected to conduct the JAST concept demonstration phase. McDonnell Douglas was eliminated, and their team was dissolved. Subsequent additions to the Lockheed Martin team included Northrop Grumman and British Aerospace (in November 1999 British Aerospace and Marconi Electronic Systems merged to become BAE Systems).

Significantly, the Concept Definition Phase of the program saw the name changed to Joint Strike Fighter, with a mandate to develop flying demonstrators for possible production.

Boeing's X-32A CTOL demonstrator lifted off on its first flight on Sept. 18, 2000. DoD histories point to that flight as representing the X-32A's "entry into a five-month flight-test program at Edwards Air Force

Lockheed Martin photo by Tom Reynolds

Base that consisted of approximately 50 test flights totaling about 100 hours to validate the X-32's flying qualities and performance for conventional and aircraft carrier operations."

Those tests were successfully concluded on Dec. 2, 2000.

Boeing's STOVL X-32B took to the air for the first time on March 29, 2001. Following several STOVL flight tests, the aircraft was subsequently flown to Patuxent River Naval Air Station (NAS), Md., making six refueling stops en route. Subsequent flight testing ranged from focus on transition from fully wingborne (conventional) to jetborne (STOVL) flight/hovering mode to a series of supersonic dashes at 30,000 feet, achieving a maximum speed of Mach 1.05.

Lockheed's X-35A CTOL demonstrator successfully completed its first flight on Oct. 24, 2000, completing the flight test program on Nov. 22, 2000. The aircraft was then converted to the X-35B STOVL variant, which made its first flight on June 23, 2001.

The inaugural flight of the Lockheed Martin X-35C (CV) occurred on Dec. 16, 2000. The "C" model differed from the "A" model in having larger wing and control surfaces, the addition of ailerons, and a special structure to absorb high-impact landings.

On Oct. 26, 2001, Under Secretary of Defense for Acquisition, Technology and Logistics Edward C. "Pete" Aldridge Jr. announced the decision to proceed with the Joint Strike Fighter program, with the Lockheed Martin team selected to move forward into the follow-on System Development and Demonstration (SDD) phase.

In 2004, the DoD extended the program schedule to address airframe weight problems discovered during systems integration and design review, a "re-baselining" process that extended development, added resources, and delayed deliveries. In addition, the decision caused a breach of the significant cost growth threshold, commonly referred to as a Nunn-McCurdy breach.

In ceremonies at Fort Worth, Texas, in July 2006, the F-35 (A, B, and C) Joint Strike Fighter was officially named "Lightning II," a name both echoing and honoring two formidable fighters from the past: the World War II-era Lockheed P-38 Lightning and the mid-1950s Lightning supersonic jet, built by English Electric (later to become BAE Systems).

Current acquisition estimates reflect a U.S. DoD purchase of a total of 2,443 JSFs, with U.S. allies expected to procure a minimum of 730 additional CTOL and STOVL aircraft.

# FROM THEORY TO REALITY

## JSF International Partners See Hardware and Hard Costs

BY ERIC TEGLER

From an international perspective, there was no better place to see the promise of the Joint Strike Fighter in the spring of 2010 than on the hangar floor at Lockheed Martin's integrated test facility at Naval Air Station (NAS) Patuxent River, Md.

There, aircraft sat side by side like queen bees attended by crowds of servants. The worker bees included civilian and military representatives from the U.K. and Italy, all getting significant hands-on experience with the first fifth-generation fighter their governments will buy.

"When you actually have real hardware – planes on the ramp, going through the assembly line, being delivered – it ratchets up the excitement level," JSF Deputy Program Executive Officer Maj. Gen. C.D. Moore (USAF) enthused. "I recently met with some senior Italian officers who came from Eglin AFB where they were looking at the training center being readied for operations, and they're fired up about what they're seeing."

This reality is what JSF international partners signed up for as far back as 2001. Great Britain was first to sign a Memorandum of Understanding (MoU) to participate in the Systems Design and Demonstration (SDD) phase in 2001. Over the next year, the U.K. was joined by Italy, the Netherlands, Turkey, Australia, Canada, Denmark, and Norway. Collectively, the international JSF partners have invested more than $4 billion in the F-35.

All remain formally committed to the JSF despite stiff economic headwinds in Europe. Denmark has been rumored to be exiting the program but no formal decisions have been made. The Netherlands, in the midst of electing a new government, debated a delay in its F-35 purchases but ultimately continued its participation.

The first instrumented F-35B prototype (BF-4) arrived at Patuxent River in May 2010, as the financial climate for the partnership became more potentially complicated with the fallout from Greece's credit crisis and subsequent EU bailout. Headline-grabbing though the crisis was, Moore felt it would have limited, largely currency-based effects on the JSF program.

"That does have implications for (the partners') production investments and it all depends on whether you're buying or selling," Moore observed. "If you're buying the product, that's one thing. If you're a best-value provider from overseas then it cuts a different direction. But it's not causing any major changes in the program. In fact, I've probed at the issue of Greece and the pressure on the Euro. The reaction I'm getting from the partners is, 'not that big a deal.' They don't see it as having any sort of significant impact on their relationship in this program."

Though Europe's macroeconomics would likely affect the program's partners to differing degrees, Moore remained

**PHYSICAL MANIFESTATION OF THE DEVELOPMENTAL CONTRIBUTIONS OF THE U.K. AND THE NETHERLANDS WILL SHORTLY BE SEEABLE AND TOUCHABLE WHEN THE FIRST INITIAL OPERATIONAL TEST & EVALUATION (IOT&E) AIRCRAFT FOR EACH COUNTRY ARE DELIVERED IN 2012.**




The Chief of the Canadian Air Staff, Lt. Gen. André Deschamps, speaks during a government of Canada announcement that the Canadian Forces will receive 65 fifth-generation Joint Strike Fighter F-35 aircraft, beginning in 2016, as replacements for their current fleet of CF-18s.

Lockheed Martin photo

confident that decisions taken in one partner country wouldn't unduly sway decision-making in another.

"Each one of these countries has their own internal pressures and constraints and each one of those is playing out independently. I'm not seeing a lot of influence from one country on another in these deliberations. For example, with the Dutch and their government changeover, it just forces a delayed decision. The Danes, looking at their own F-16 fleet, made the determination that they can delay their buy decision for a couple years. I don't think that was due to any sort of influence associated with the rest of the partners. The partners are all still committed to the program, they're just determining when they need to start buying aircraft."

Of course cost, along with lethality, has been central to the Joint Strike Fighter since day one, a theme highlighted in 2001 by U.K. Minister for Defense Procurement Baroness Symons, who said upon its MoU signature that Britain "considered the JSF with all its stealth technology, its multi-role capability, as the most cost-effective means to meet our requirements."

As costs go, "reality will get a vote," Moore asserted. Moore pointed out the projected cost per aircraft looks

**"THERE WILL BE A CONVERGENCE BETWEEN FORECASTING AND REALITY AT SOME POINT. THERE ARE SOME MORE PESSIMISTIC AND CONSERVATIVE FORECASTS FROM A NUMBER OF PARTIES, BUT AS WE NEGOTIATE CONTRACT COSTS, THE INTERNATIONAL PARTNERS WILL SEE HOW AFFORDABLE THE FIGHTER IS."**

OPPOSITE: International JSF officials pose for a group photo. JSF international partners have collectively contributed more than $4 billion to the program.

LEFT: Royal Air Force Squadron Leader Steve Long takes off from Naval Air Station Patuxent River, Md., in an F-35B Lightning II stealth fighter, Jan. 26, 2010. The flight marked the first time an active-duty service pilot from the United Kingdom had flown an F-35.

Lockheed Martin photo by Senior Flight Test Photographer Andy Wolfe

different if viewed in the base-year 2002 dollars upon which the program was based.

"That's how we've always benchmarked the program and I still believe that we're going to come in relatively close to that if you project it to 'then-year' dollars. I believe that for the Dutch aircraft we'll still be in the low $70 million (range). Lockheed will tell you it will be in the high $60 millions from then-year dollars. If you trace (the cost) back to the base-year 2002 dollars, which this program was predicated on, that's where I estimate the figure of $50 million. At one point in time we thought the airplane was going to be in the $30 million range. There are inflation pressures on the aircraft but we still think it's an affordable fighter."

And its affordability, Moore said, will be favorably affected by a reduction in production costs as increasing numbers of F-35s roll off Lockheed Martin's Fort Worth assembly line.

"There's a forecast, then there's the reality. We certainly understand forecasting, it's kind of like a weather forecast. I tell our international partners the reality of what we're paying for aircraft and what we anticipate paying for aircraft is based on contract negotiations. We've almost cut in half the cost of airplanes from our LRIP 1 buy through our projection to LRIP 4. We're expecting to continue bringing that cost down just based on the normal learning curve that we would expect to see in the production of any type of aircraft.

"This is the third aircraft production line I've run, and I'm expecting to see the same type of learning curve I've seen previously. There will be a convergence between forecasting and reality at some point. There are some more pessimistic and conservative forecasts from a number of parties, but as we negotiate contract costs, the international partners will see how affordable the fighter is."

In fact, Moore maintained, JSF international partners are "in an ideal situation right now."

"We have 730 aircraft currently planned by the partnership during their anticipated buy profile. Since the next buys aren't anticipated until 2012, they're in an optimum position because they're going to be able to watch what price I negotiate on the current lot (4) and they're going to see what I negotiate with the fifth lot. Although they have independent cost estimates, they're going to have the reality of what we've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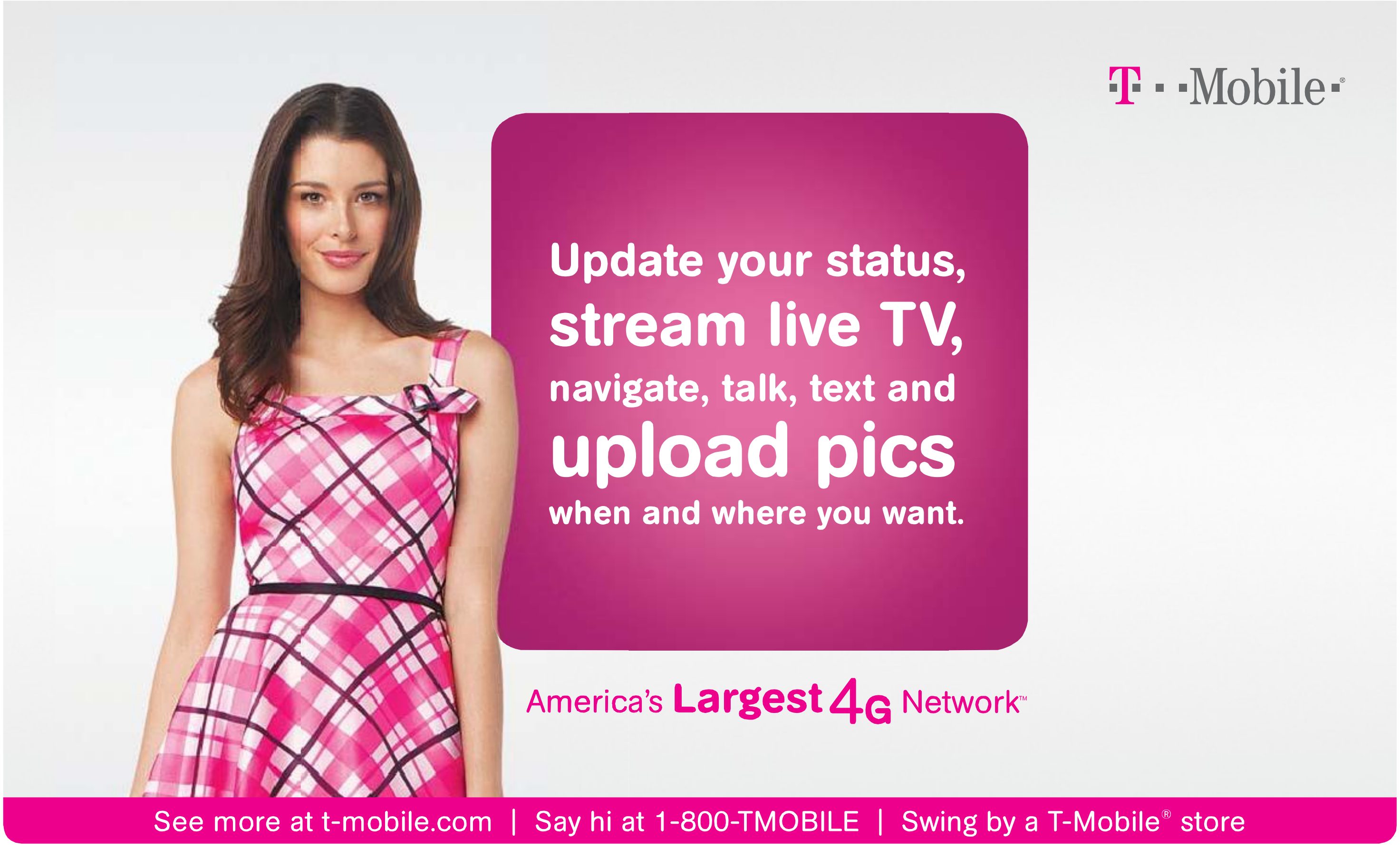
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negotiated and what's on contract. In 2012, the Australians are going to be looking at what the real cost of those CTOL (conventional takeoff and landing) aircraft is and how it's come down. They're in a great position to determine whether they slip (their purchase) or they hold the line. I think they're going to hold the line."

The decline in production costs cited by Moore would indeed put the international partners in an enviable position. Should it hold, not only will they be able to enter into firm purchase agreements when unit costs hit levels each finds acceptable, they will not have had to bear the unanticipated increase in the overall development cost of the program.

"This additional cost associated with the extension of the program is being borne by the U.S. government," the general confirmed. "The international partners have contributed to the development of the weapon system over the past eight years, and they are also planning to make contributions for future development as new capability is added to the weapon system. Their shared costs of development, production tooling, and sustainment (are) mutually beneficial to all of the participants."

Physical manifestation of the developmental contributions of the U.K. and the Netherlands will shortly be seeable and touchable when the first Initial Operational Test & Evaluation (IOT&E) aircraft for each country are delivered in 2012.

Early days though these are, Great Britain and the Netherlands are already seeing favorable production cost trends, according to Moore.

"Actually, they're seeing the same cost decreases lot-over-lot that we are. In fact, I bought two aircraft in the last lot, one British and one Dutch, and they saw the same decrease from Lot 2 to Lot 3 that the U.S. government did. We're buying a British and a Dutch aircraft in LRIP 4 and they're seeing the same decrease there. All the other partners are watching that and when I negotiate LRIP 5 … they'll see that same decrease and they'll use it to make the determination of when to jump in and buy their aircraft."

International partners will be making their own determinations regarding life-cycle support for the F-35 as well. One of the most salient aspects of the JSF program is its Performance Based Logistics (PBL) scheme, which drops the traditional offset arrangements that have been a feature of all previous joint tactical aircraft programs. JSF partners have the opportunity to bid for production and sustainment work based on best value. This competitive approach is expected to yield lower cost and leverage international technology in a way other international programs have not.

Currently, the focus is on expanding production capacity, "a rich environment for companies to bid for work in," Moore noted. "I'd say at this stage, (PBL) has been very effective if you look at the work that has been earned (by suppliers) country by country based on best value. It's very exciting when you see what these countries are bringing to bear for this weapons system in terms of development and production."

As production ramps up, the focus will shift to sustainment, the cornerstone of which for the JSF program is a regional network of facilities in the United States, Europe, and Australasia, an approach to which the Joint Program Office and the partnership are committed, Moore emphasized.

"We're in the early stages of implementing our common global logistics sustainment strategy so we're still working through many of the details, but we see tremendous benefits in parts pooling and the regionalization of sustainment functions."

Regional sustainment is also a departure from past joint programs, which tended to include sustainment facilities in each participating country. The concept has logical legs, but its execution, as with any new approach, will be a challenge. The absence of firm decisions about the location of regional sustainment facilities is to be expected at this early developmental and production stage of the program, but various partners are already jockeying for advantage.

In April 2010, the Italian government announced a halt to plans for its F-35 final assembly and checkout (FACO) facility at Cameri Air Base in Northern Italy. Undersecretary of Defense Guido Crosetto told Italian lawmakers that the return on investment from


From the beginning, representative F-35 development aircraft have sported the flags of partner countries on their intakes.

Lockheed Martin photo

the facility is inadequate. The move and pronouncement were clearly intended to pressure Lockheed Martin into allocating sustainment work to the Cameri FACO. However, the issues were resolved and ground was broken for the facility in November 2010. The plant is expected to be up and producing the first Italian assembled aircraft in 2014, and, subsequently, Dutch aircraft.

Moore said he expects the plant to begin producing aircraft as scheduled, but as for sustainment activity, no decisions have been made. Lobbying by Italy or other partners will have to be set against the most cost and logistically effective strategy for supporting the F-35.

"That's what we're studying across the globe – what would be the appropriate locations for regional MRO (maintenance, repair, overhaul) use? It's premature at this stage to make a determination on what and where. First of all, you need to understand how the weapons system operates, how reliable it is, and what kind of support it needs. Based on that, you make a decision on where that regionalization needs to occur to be most effective for the partnership. Those decisions don't need to be made today nor should they be. Whether or not (FACO) is going to be one of those is what we're trying to determine."

The details will require joint analysis, and the conclusions should be aimed at benefiting the partnership as a whole, not just individual members, Moore stressed.

"Part of the (decision-making) process is going to be, where do you need to do aircraft MRO? Where do you need to have engines and engine MROs? Where do you need spares warehouses? You don't need a spares warehouse in every country, so you need to decide what's in the best interest of the partnership to be able to do it as cost-efficiently as possible. We're looking at those requirements across the globe to come up with the best mix of regionalization as we go forward."

Efficiency aside, the Joint Program Office recognizes that individual partners will argue for the location of sustainment facilities within their borders for economic, political, or sovereign purposes.

"Countries are going to express their desires to meet those needs, and what we have to do is make a determination of what the right balance is," Moore said. "We don't want duplication of capability across the globe, and if someone is insisting for operational sovereignty purposes they have to have that capability, we go into a 'pay to be different' way of operating. That country may have to pay the partnership additional funds to have a duplicative capability. We'd rather not go there. We'd first need to determine the right mix (of capabilities) before someone makes the determination they want to pay to be different."

Once the regional sustainment strategy is finalized, Moore said he suspects at least one partner will still insist on its own MRO facilities and that the financial impact of that decision on the rest of the partnership will be made transparent.

"Those types of discussions will occur. There will be an understanding of the cost implications to the partnership as a whole and that will be factored in to the determination of whatever country decides they want to do something differently. It's the old 'excess capacity.' That affects everybody."

Transparency is the cornerstone of the international partnership, the JSF PEO reiterated, whether the subject is development, production, or sustainment. The Program Office routinely goes into excruciating detail on these issues with JSF partners to ensure that there is clarity and mutual understanding.

"We try to put all of that in the context of the independent cost estimates because they're concerned when they see the higher numbers, and rightfully so. It's our responsibility to help them understand the risks associated with those cost projections and to mitigate that risk by looking at what we're delivering year after year with real costs. We're seeing that with the PBL implementation and we're seeing that in production and in development."

Technology transfer has been an issue that the JSF program has had to work through since its inception and one on which remarkable progress has been made. Not surprisingly, it remains a point of discussion for the partners as they seek to maximize operational sovereignty and the effectiveness and technological benefits of the F-35. Italy expressed some dissatisfaction with technology transfer arrangements in April, but its under secretary of defense expressed confidence that it could be overcome.

"Some of the longer term technology transfer issues that may arise depending on future system development will be dealt with using the technology transfer process that we have in this country just as other countries do," Moore explained. "We've already started some of that associated with follow-on development to ensure that we work with it early enough that it doesn't become an issue for future capabilities so that we can keep this platform as common as possible."

Getting ahead of potential issues both in the program as a whole and as regards the international partnership is a lesson Moore brings from his previous experience as a test pilot, F-16 program director, and as commander of the 478th Aeronautical Systems Wing, responsible for design, production, deployment, modernization, and sustainment of the F-22 aircraft.

**TECHNOLOGY TRANSFER HAS BEEN AN ISSUE THAT THE JSF PROGRAM HAS HAD TO WORK THROUGH SINCE ITS INCEPTION, AND ONE ON WHICH REMARKABLE PROGRESS HAS BEEN MADE.**

"When I first joined the (F-35) program, I immediately dove into some of the areas that were troublesome for me in running the F-22 program to make sure what we learned on the F-22 truly carried over to this weapons system. We had some structural issues early on with the F-22 so I wanted to make sure we had a robust structural design program before we started test flying (F-35). Our static and dynamic load testing on the ground has been very thorough, so I'm resting easier there.

"I was in a meeting this morning with many of my Lockheed counterparts and I kidded that it felt like an F-22 reunion because some of the best and the brightest from the F-22 team have migrated over (to) the F-35 program. We're harvesting the best talent both from industry and government to ensure that we're carrying over all those lessons learned."

Though not directly involved with JSF prior to arriving at the Program Office in June 2009, Moore's previous assignments, including a term as deputy director of the Global Power Directorate in the Office of the Assistant Secretary of the Air Force for Acquisition, have allowed him to feel the pulse of the F-35 program for years. He said that enthusiasm for the aircraft and for the success of the international partnership remain as high as ever.

"For the year I've been on this program – and I've been on the periphery for a number of years – I haven't seen any marked change in the excitement of those involved and their excitement about the weapons system. It's no longer theory. It's now reality."

# A GLOBAL SUPPLY CHAIN

## The F-35 Contractor Community Operates Across America and the World

BY J.R. WILSON

The F-35 Lightning II Joint Strike Fighter (JSF) is perhaps the most international major military program in history – certainly among top-of-the-line fighter aircraft.

Designed in three variants to satisfy the aviation force projection needs of the U.S. Air Force, Navy, and Marine Corps, along with those of major allies, the F-35 is a joint design and production effort by nine international partners (the United States, the U.K., Italy, the Netherlands, Canada, Turkey, Australia, Norway, and Denmark), with a global supply chain comprising dozens of Tier I, II, and III contractors and subcontractors, along with numerous small parts suppliers, supporting the planned production of 3,000-plus aircraft.

It is the largest military contract – in many cases, the largest contract of any type – for a significant percentage of those manufacturers. In part, that massive multinational effort was designed to bring in the best talent and components possible, regardless of origin. Equally important: Growing a U.S.-friendly global high-tech manufacturing infrastructure and providing greater incentive to those companies' host nations to support – even buy – the F-35.

"We're working with a global supply chain because part of the partnership agreement included industrial participation, so industry was competing from all parts of the world and winning competitively, with guarantees. That's quite a different kind of supply chain, a lot different from offset," noted Tom Burbage, Lockheed Martin Aeronautics' executive vice president and F-35 Program Integration general manager.

"We weren't tracking it as an objective, but were surprised to find, on the first airplane, we had parts from all nine partners. That involvement of the international supply chain did not occur when the contract was signed, at which time we only had one partner: the U.K. As the others joined in the next few months, we had to integrate their parts into the supply chin, which was quite a problem. In a way, we are recapitalizing the industrial chain as much as we are the air forces."

The F-35 faced many of the same problems encountered by other multinational programs such as the International Space Station – different work cultures, slight variations in measurement systems, translation concerns (especially with respect to terminology), etc. Perhaps most important, however, was the considerable difference in how a manufacturer would – or could – respond to changes in delivery dates, production numbers, etc. That became a major concern during the program's effort to address size and weight issues well into the research, development, test, and evaluation (RDT&E) cycle.

"Our challenges really started when we went through the SWAT (STOVL weight attack team) redesign to take weight out of the airplane. We were successful at that, but we had to stop and then restart our supply chain. When you get down to the second and third tier, there were some real challenges for that group," Burbage explained. "There were contracts and batches halted pending redesign and, in some cases, part numbers changed. The actual design of the wing changed substantially and some contractors were told to wait for new orders – only to find their parts were no longer in the airplane – so that caused considerable problems.

"We tried to be sensitive to produceability, but there was some unitization of parts and some parts sizing that were stretched. The whole industry supporting advanced technology fighters has shrunk in the last 20 years around the F/A-18 and F-22. We had to restart the supply chain from scratch, and in doing that, we got into problems with late release of engineering and later delivery of parts, out of sequence. But, to their credit, the supply chain worked through all those challenges."

Both prime contractor Lockheed Martin and the Department of Defense (DoD) Joint Program Office (JPO) expressed high praise for the widespread contractor community, from those who were there at the beginning of the JSF concept to those just being tapped for their first deliveries as low rate initial production (LRIP) moved from lots contracted under LRIP-4 to those in LRIP-5 (a total of eight LRIP lots, currently planned to total 554 aircraft overall, are scheduled through 2016, although both the numbers and dates are subject to change).

"They've certainly had slips with flight test milestones, but if LRIP-4 comes in on budget, on time, they will look stellar, especially compared to all the other aerospace programs out there in the world," noted Teal Group's Richard Aboulafia, vice president of analysis.

Tier I contractors on JSF are prime contractor Lockheed Martin Aeronautics and its two principal partners – Northrop Grumman Aerospace Systems in San Diego, Calif., and BAE Systems in the U.K. Each of the three also has Tier II and III contracts across its various components.

"That (team) has come together well, despite challenges for all of us going through the redesign. But we have a pretty tightly knit team that has always put the team and the project first. That team will stay together for the logistics phase, which we will run through Team JSF as a shared relationship between those three as the leaders," Burbage said. "We are definitely establishing new models in terms of how you run supply chain management. We stood up a global team that worries about all the things that can bring a program like this to its knees."

In addition to being the F-35 chief integrator, Lockheed Martin Aeronautics has oversight responsibility for the entire global supply chain. In the beginning, it sent a team to each of the other eight principal partner nations to assess which of their manufacturers were best suited to participate in competitive bids for both large and small components. Once contracts were awarded and work begun, Lockheed Martin continued to provide on-site support, as required.

"As prime, Lockheed Martin is responsible for managing the supply chain, although we have delegated some of that to Northrop Grumman and BAE. Performance oversight of

Workers at Lockheed Martin in Fort Worth, Texas, prepare the fourth F-35 Lightning II, an F-35B version, for rollout from the factory. Dozens of Tier I, II, and III contractors and subcontractors across the United States and around the globe are part of the F-35 program.

Photo courtesy of Lockheed Martin

the companies in the supply chain is provided by the prime contractor, our delegated subs, and the local Defense Contract Management Agency," Burbage explained.

"Everybody who builds parts for front-line weapons systems has a resident contract group on site, as do our international partners. I don't know if the U.S. and its partners actually co-inspect, but the U.K., for example, would have a similar agency overlooking companies building parts for its programs."

Northrop Grumman Aerospace is responsible for the F-35 center fuselage, mission systems software, courseware training for pilots and maintainers, and major stealth components. The firm's Electronic Systems unit in Baltimore, Md., is providing the JSF radar and 360-degree distributed aperture system, while the Information Systems Sector in Washington is responsible for the integrated communications, navigation, avionics, and Identification Friend-or-Foe (IFF) systems.

"As you take on major complex weapons systems development, every program has its challenges, as this program has, through weight savings redesign, finalizing development, and getting ready for transition and production," noted Mark Tucker, vice president and JSF program manager at Northrop Grumman Aerospace. "That is very similar to other programs where we were teamed with other major aerospace companies.

"Our relationship with Lockheed is probably more integral than those, perhaps due to the structure of the JSF integrated product teams (IPTs). In the past, you typically had a well-defined structure and autonomy to control whatever was within those boundaries. On this program, given the fact technology has enabled us to work more virtually, we are an extended piece of the Lockheed team and, in many situations, our work content is an integral part of a product that is part of the Lockheed IPT. For example, we have a significant statement of work to develop software code as part of the larger mission systems IPT for Lockheed."

That approach has both pros and cons, often directly related to program "growing pains," he acknowledged.

"I don't think there has been a program that has taken on this magnitude of infrastructure, getting people working on common approaches and vernaculars. But, overall, it has been a tremendous success for Lockheed to leverage the capabilities of the supply team, including us, without having everything centrally located in Fort Worth," he said. "To a very large extent, where we have subcontracted some of our structure and vehicle emission systems

responsibilities, we have linked our suppliers into the same integrated database and design information that we are using through the program's virtual network.

"It is an evolution in how we work with our suppliers rather than revolutionary. It is a similar approach to that taken on the B-2 (bomber) when we teamed with Boeing, Vought, and GE. The digital age has enabled that to be even more powerful. And I think our subs have responded very favorably. It certainly allows them to feel more connected to what is going on with the program at a macro level, without as many hand-offs and pass-throughs, so there is a greater opportunity to introduce changes into the effort. So I think they would say it is a favorable experience."

BAE's share of the work includes the fuel system, crew escape, life support systems, prognostics health management (PHM) integration, Electro-Optical Targeting System (EOTS), a significant share of autonomic logistics, especially the support system, and flight test and mission systems as part of the Integrated Test Force.

Tier II contractors – some of which are other divisions of the three primaries – are responsible for manufacturing and sustaining entire systems on the aircraft. Those include Northrop Grumman Radio Systems (radar), Lockheed Martin Missiles and Fire Control (Eectro-Optical Targeting System), BAE-Nashua (major electro-mechanical systems), Moog-Parker (hydrostatic actuators), Goodrich (landing gear), and L3 (panoramic cockpit displays).

Even for components of the big three, the F-35 often has represented new territory, from the size of the program to end-users. Lockheed Martin Missiles and Fire Control, for example, does most of its work for the Army. According to Don Bolling, senior manager for Advanced Targeting Systems, their biggest challenge has not been groundbreaking technology, but packaging.

"We were allocated a very small area in the aircraft and internal E/O systems of this variety had not been done before on a fighter, nor combined with a targeting FLIR (forward-looking infrared)," he said, adding their greatest frustration has been the inability to incorporate, to the extent they would prefer, technology changes that have evolved in the past decade. "That has been frustrating, because we know we could make adjustments – which we will, in due time, with block upgrades to the airplane – but that is just the way it is with JSF acquisitions.

"Technologically, on our side, we've been frozen in system design and development, despite rapid advances in ISR (intelligence, surveillance, and reconnaissance) capabilities because of the war. At the time our sensor was frozen in the JSF design, it was a leading-edge technology; nobody else was even close. But as we get closer to fielding, that will certainly be less so. It is still the first and only E/O-compliant sensor combining those two disparate capabilities. But other sensors now have HDTV, IR pointers, and other things that have continued to move along while we have been marching in place."

Tier III contractors are those providing equipment going into the Tier II systems, such as computer processors, machine parts, and composites.

"The actual chokepoint in going up to high-rate production is not the prime factories, but the capacity of the spindles in the machine shops and the composite factories to put out the volume to support one aircraft a day," Burbage said. "And their capacity is driven by their ability to get tools, which sometimes can take three or four years in the machine shops.

"So there is a constant matching, trying to open up capacity at the real rate of receiving orders, not the ideal rate. And that is quite a challenge. With nine countries buying airplanes and all facing budget pressures and Europe facing economic problems that didn't exist nine years ago, there has been a lot of change."

The supply chain does not end there, of course. Below Tier III are the small components – rivets, nuts, etc. – commodities and raw materials such as aluminum, titanium, composite fiber, etc. By coordinating common requirements across the supply chain, the program has been able to place orders to keep the mills and small parts manufacturers working and reduce costs due to "economies of scale" purchases.

At the same time, a great many of those subcontractors and suppliers – certainly from Tier III down, but a few Tier II, as well – are facing requirements they've never seen before. Those range from the need to produce what may be


Photo courtesy of BAE Systems

a record number of some component far more quickly than any previous requirement, to working, perhaps for the first time, under the pressures inherent in a major U.S. DoD program (plus national and regional program and economic realities).

"We have a best-value approach (to selecting suppliers), which is more than price. It includes quality, on-time delivery, and a number of different parameters. We monitor those closely and give report cards on a regular basis," Burbage explained. "If you show for some extended period of time you don't need that intense oversight, you become a gold supplier that self-inspects. We have a number in that category.

"On the other hand, if we have a supplier that gets in trouble, whether because of reliability problems with their parts or design problems, we will mobilize a team and actually go in residence with them. And if they don't perform at all, which is pretty rare, we will shut down and move to a new contractor. It doesn't do us any good to have a supplier that is not performing."

The size of the F-35's international supply chain also created a number of challenges, especially related to those without previous experience in such an effort.

"A lot of companies had never done business with us or any U.S. prime. And, to be honest, we are hard to do business with because of government requirements. Not all the things we do are done in other countries," Burbage said.

"Then there is ITAR (International Traffic in Arms Regulations). A few years ago we did a number of outreach programs, sending an IPT with representatives from the State Department and technology transfer organizations and contractors on the road to hold workshops showing companies how to work with that."

The F-35 has been a complex program from inception. As only the second fifth-generation fighter in the world – and the first involving an extensive international supply chain and market – it faced the difficult task of satisfying both U.S. and allied multi-service requirements as the replacement for several legacy aircraft now performing a wide range of missions. Add to that a global economic crisis developing just as it went into LRIP and already heavy demands on money and equipment after a decade of war, and the complexities have continued to grow.

"When I look at the overall value proposition of the program – and sometimes we wonder why it doesn't get a higher level of recognition – it is both a recapitalization of the joint service and coalition multi-role fighter and economies of scale that have never been seen before, but, underpinning that, economic and industrial ties for the future. I think that is very important and not always well understood in terms of what the F-35 program can bring to the table," Burbage said.

"When people ask what keeps me up at night, it's nothing technical, but making sure we right-size the supply chain and

OPPOSITE: BAE Systems in Samlesbury, England, builds, among several other major components, the left-hand boom of the F-35 aft fuselage. The component is shown here loaded for machining.

ABOVE LEFT: An F-35C Lightning II, with Goodrich landing gear, undergoes drop testing to simulate aircraft carrier landings.

ABOVE RIGHT: Northrop Grumman builds the F-35's AN/APG-81 AESA radar.

Photo courtesy of Northrop Grumman

Photo courtesy of BAE Systems

infrastructure to the real demand of the program. That's our biggest challenge going forward."

At the same time, he added, the scale of international involvement has provided all of the partners much greater insight into what motivates the others, as well as where each has developed what Burbage terms "pockets of real excellence."

"The U.S. does not have a lock on all the really advanced technologies going into the F-35. The Netherlands, for example, provides the science that allows the airplane to diagnose its own health and can warn a maintainer that there is not yet – but may soon be – a problem," he said. "A lot of such technologies are coming from our overseas partners, which has been quite a discovery; we have benefited from having partners beyond just the financial."

Burbage also believes having nine international partners heavily vested in the program – not just as potential buyers and operators of the F-35, but in creating a diversified international manufacturing and technology infrastructure through the global supply chain – brings additional stability at a time when big-ticket military programs are primary targets for budget cutters.

"Any time you have a big program like this, you have to be concerned that some dynamic will truncate production short of its full objectives. I think this program has more support than specialized airplanes sponsored by a single service, as all three services have their own variant," he said. "But we are still vulnerable to cost pressures and decisions to reduce quantities, which drives up cost. So we're trying to keep the program on track, but you always have to worry about that.

"I can't think of a program that has actually gone to the full expectation set for it when it started. In some cases, like the B-1 and F-22, it has been way short. Being part of a partnership and leveraging each other's requirements makes the F-35 much more affordable; even if the cost goes up beyond what might have been expected, it is still minor compared to what it would cost anyone to do it on their own. So you have complexity with nine partners, but also stability."

As the F-35 moves from the midpoint of LRIP to the first production deliveries around mid-decade, all of the pressures the program has faced to date are likely to increase, especially for all the companies, large and small, within its vast supply chain.

"I don't think we, Lockheed, have told the real story of this program, with this many international partners trying to push a revolutionary capability and do it with a backdrop of media frenzy in a nonstop news cycle, trying to keep everyone together across many time zones and many agendas," Bolling said.

"Given that, I think the program is doing very well and that will be proven out when the aircraft comes out. Look at the F-22. When it came out, people admitted it was better than they had ever imagined – and I think the F-35 will exceed that experience."

# PILOTING THE F-35A

## Flight Testing the Air Force's Joint Strike Fighter

BY ROBERT F. DORR

**"IT FLIES LIKE A FIGHTER, LIKE IT SHOULD FLY."**

Those are the words of Lockheed Martin test pilot Bill "Gigs" Gigliotti in an October 2010 telephone interview, referring to the F-35A, the Air Force's conventional takeoff and landing (CTOL) version of the F-35 Lightning II Joint Strike Fighter (JSF).

While plenty has been written about the JSF program, not so much has appeared in print about the view from the cockpit in the F-35A and how the aircraft will feel to the men and women who take it aloft.

All three versions of the JSF have won praise from pilots. "In flight, they're all the same," said Lockheed Martin chief test pilot Jon Beesley in a January 2010 telephone interview. The F-35A, F-35B, and F-35C are "all a little different in taking off and landing," he added. "The CTOL airplane is a faster accelerator and costs less than the other two."

A veteran of the F-117 Nighthawk and F-22 Raptor programs, Beesley became the first person to pilot a Joint Strike Fighter when he took off at Fort Worth, Texas, in the first F-35A (manufacturer's number 2AA-001, known in shorthand as AA-1) on Dec. 15, 2006. That day, Beesley went to an altitude of 15,000 feet. Beesley reported that the aircraft handled "marvelously." A minor software glitch, not atypical on a first flight, reduced the maiden journey from an hour to 35 minutes.

### CTOL Characteristics

Apart from its "low observables" or stealth characteristics designed to make it difficult for an adversary to detect on radar, the F-35A is remarkably straightforward in design and appearance. To retain stealth, it must rely on an internal bay for ordnance that might be carried externally by other fighters. Otherwise, the F-35A is unremarkable to the viewer – "not the prettiest plane I've ever seen," said one observer, "but not that bad-looking, either."

It's a mid-wing, twin-tail, tricycle-gear aircraft powered by a single engine – like its predecessor from the same planemaker, the F-16 Fighting Falcon, but unlike most of the world's fighters, which have two engines. The power plant is the 25,000-plus pound dry thrust Pratt & Whitney F135 turbofan, which offers 40,000-plus pounds of thrust in afterburner, more than enough to enable an F-35A pilot to accelerate while flying straight up. The F-35A and other JSF models will be built as single-seat aircraft only. This follows the pattern of the F-22, but differs from past fighters that came off the production line in single- and two-seat variants. Officials acknowledge that second seat would be especially useful in the early stages of pilot training, but say they can work around the issue with extensive use of simulators.

The F-35A will use a Northrop Grumman AN/APG-81 active electronically scanned array (AESA) radar and will have electro-optical sensors distributed over the aircraft as part of the AN/AAS-37 system that can aid in navigation and night operations but also acts as a missile warning system. It will be armed with an internal 25 mm GAU-12/U cannon with 180 rounds, the first new gun in an Air Force fighter for generations. The first F-35A equipped with the cannon is the airframe known as AF-3, and the gun will appear in all low rate initial production Lot One (LRIP 1) airframes beginning with AF-6. Air Force officials downplay speculation that if the GAU-12/U should be delayed in its development, the current mainstay M61A1 might be employed instead, at least temporarily.

The internal weapons bay of the F-35A is an unusual feature for a jet fighter, but is essential to preserving the stealth properties of the aircraft. The bay, or "hole" as pilot Beesley calls it, requires new thinking about the design of the entire aircraft.

"We were asked to build a combat airplane – one that can perform both air-to-air and air-to-ground missions," said Beesley. "That entails a weapons bay. A hole is very heavy, by the way." Nevertheless, said Beesley, the idea works: "From the moment of takeoff, I'm in combat configuration while the other guy may not be." Beesley noted that the thrust-to-weight ratio of the F-35A – roughly 1:1 – is criticized by some, "but that's because we carry everything for the mission inside the aircraft. We need no external tanks."

Among the important features that set it apart, the F-35A is noteworthy in that it is a powerhouse of net-centric sensors and communications equipment, yet dispenses with the now-traditional head-up display (HUD). "All sensors are on the airplane now and they're all ready to go," said Beesley. "We have all sensors on the airplane working the way they're supposed to. We're completely configured to go into combat, yet we can

**"WE WERE ASKED TO BUILD A COMBAT AIRPLANE – ONE THAT CAN PERFORM BOTH AIR-TO-AIR AND AIR-TO-GROUND MISSIONS. ... FROM THE MOMENT OF TAKEOFF, I'M IN COMBAT CONFIGURATION WHILE THE OTHER GUY MAY NOT BE."**

Lockheed Martin photo

F-35A AF-1 during flight testing at Edwards Air Force Base.

Wyle congratulates the JSF Program on their achievement of yet another important milestone towards the goal of delivering the F-35 Air System to the Warfighter.

## Wyle Tackles the Tough Jobs

Wyle's team of engineers, scientists and flight crew tackle the tough jobs, such as completing the first airborne refueling of the Joint Strike Fighter F-35B short takeoff/vertical landing variant. With 16 years of dedicated support for the JSF program, Wyle provides engineering and program management support; foreign military sales management; flight test support; threat reprogramming, analysis and assessments; and basing and ship suitability services. For more information, go to www.wyle.com

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Experts for the 21st Century

An F-35A displays open weapons bays during flight testing. While the bays make the aircraft heavier, Chief Test Pilot Jon Beesley pointed out that the aircraft is in combat configuration from the moment of takeoff, with no need to jettison external stores in order to fight other aircraft.

match airplanes that are in an air show configuration." Air Force officers use the term "fifth generation" to separate the F-35A, as well as the F-22 Raptor, from current fighters that employ fewer sensors and earlier technology.

### In the Cockpit

"My general impression: a lot of power, handles well, crisp in all axes, and well behaved," said Gigliotti.

Like the F-16, the F-35A uses a sidestick controller located off the pilot's right arm, rather than a stick between the knees. A common complaint about the F-16 was that the controller didn't have enough "play" or "feel."

"In the F-35A we provided more tactical feedback with greater motion to the stick," Gigliotti said. He pointed out that some F-35A pilots will not be F-16 veterans and will not previously have flown an aircraft with a sidestick. "It comes very naturally to you and it's easy to use."

Gigliotti said the F-35A is equipped with the Martin Baker US16E version of the Mk. 16 ejection seat, a derivative of the seat employed on the Eurofighter Typhoon and the Beechcraft T-6A Texan II. The seat is credited with saving the lives of several pilots in both aircraft. A scare that followed the loss of a pilot in a Typhoon incident turned out to be a false alarm: A mistake in crew preparations for flight, not any flaw in the seat, caused the mishap.

The seat, said Gigliotti, "has specifications that far exceed legacy seats: We can escape at 600 knots, where in legacy aircraft at 450 knots we were taking the pilot's life and rolling the dice."

Gigliotti said, "The cockpit setup on all three JSF models is identical. If I strapped you into an F-35 you wouldn't know if you're in an A, B, or C model. The only difference among the three is the 'hook/STOVL button': It deploys a tailhook in the A and C models. In the B model, it activates the STOVL (short takeoff/vertical landing capability). The similarities are reassuring. The real difference is how we take off and land in the terminal phase of flight."

"The cockpit is incredibly clean and has very few switches," said Beesley. "The F-35 cockpit is not as spacious as the Raptor's, but it works very well. We have a panoramic display and a helmet-mounted display. It has a sidestick controller more like the F-22's than the F-16's. The throttle and stick give you whatever 'feel' you want them to have.

Lockheed Martin photo


Lockheed Martin photo by Tom Reynolds

The afterburner is an active sensor device. The thrust out of the engine has been very impressive so far."

The F-35A is optimized as a 9*g* airplane in contrast to the F-35B (7*g*) and F-35C (7.5*g*). Beesley made a point of emphasizing that the F-35A handles *g*s well at very low altitude, where the atmosphere is denser and an aircraft can be more easily stressed.

When this volume went to press, F-35A aircraft AA-1 was at China Lake, Calif., where, after 91 test flights, it is to be destroyed in live fire tests – although some veterans of the program are launching an effort to save it for museum display. Aircraft AF-1, AF-2, AF-6 and AF-7 are being tested at Edwards Air Force Base, Calif. Aircraft AF-3 and AF-4 are flight science airframes currently at Lockheed's Fort Worth facility. AF-6 is the first of the LRIP 1 aircraft.

### Stealth Fighter

A lengthy quote from test pilot Gigliotti addresses those who wonder about some of the F-35A Lightning II's high-tech features. Gigliotti spent much of his career as a naval aviator and acknowledged that the Navy lags in "low observables" capability.

"The Air Force embraced stealth at its infancy," said Gigliotti. "This aircraft moves stealth to a next phase. The mission system on the F-35 incorporates the best of all of our legacy platforms. All of the components contribute to the situational awareness of the pilot in the cockpit. The pilot will have a helmet-mounted display. There is no HUD on the aircraft. Our helmet incorporates HMDS (helmet-mounted display system) and night vision capability. A HOTAS (hands-on throttle and stick) switch will call up imagery on the helmet: The pilot can see (downward and in all directions) through the structure of the jet using sensors – forward sensors, top and bottom, and side-looking sensors." Said Beesley: "The helmet-mounted display was one of the higher risk items on the airplane, I thought, but it is worth it. We have the benefits of an off-boresight cueing system and we have a night distributed aperture system that uses infrared."

Once the aircraft is in motion, the actual piloting of the F-35A is a real joy, according to pilots. Said Gigliotti: "This aircraft accelerates and rolls like an F-16. In fact, it is much smoother. It has a solid feel when you fly it. The roll response is better and smoother than the F-16 and is more predictable. The roll response from 150 knots to supersonic speed is very good. The pitch rate is better than with legacy fighters. It accelerates better than a Block 50 F-16, clean.


OPPOSITE: F-35A AA-1 over Edwards AFB with an F-16 chase plane. Test pilot Bill Gigliotti said that F-16s have to use afterburner in order to climb with the F-35A when it is at military power.

LEFT: Beesley praises the F-35A's high angle of attack capabilities and its networked cockpit.

Lockheed Martin photo

**"THIS AIRCRAFT MOVES STEALTH TO A NEXT PHASE. THE MISSION SYSTEM ON THE F-35 INCORPORATES THE BEST OF ALL OF OUR LEGACY PLATFORMS. ALL OF THE COMPONENTS CONTRIBUTE TO THE SITUATIONAL AWARENESS OF THE PILOT IN THE COCKPIT."**

"We often fly with F-16s accompanying us," said Gigliotti, referring to what most would call a chase plane. In this case, the term is apt. "When we do a normal mil power climb (without afterburner), that F-16 needs to be in burner to stay with us. The chase F-16 needs external fuel to keep up with us. We carry 18,000 pounds without having to scab on (attach) those external fuel tanks. We removed external tanks and brought in an internal weapon with a much greater strike capability."

### Landing the F-35A

One area where the F-35A sets a high new standard is in its ease of landing.

"A good landing in an F-16 has always been a crapshoot, because when it lands it's still at flight speed," Gigliotti said. "The F-35 is the easiest airplane to land that I've ever flown."

In the fighter world, the standard for a light-as-a-feather touch-down on the runway is set not by the F-16 but by the F-15 Eagle, which has a giant "barn door" speed brake extended from its dorsal area and – like all but a handful of F-16s – requires no braking parachute. Even critics of other features of the F-15 applaud the remarkable gentleness with which it makes its final


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Bill Gigliotti (left) and Jon Beesley, F-35 Lightning II test pilots for Lockheed Martin.

U.S. Air Force photos/Lockheed-Martin courtesy photos

descent to terra firma. Gigliotti has extensive F-15 flight experience and said the F-35 lands even more gently – "even better than the F-15, which established the threshold for smooth landings."

"It has tremendous brakes that have worked very well," Beesley said. "The brakes are sized for 54,000 pounds and we've been landing in the mid-30,000s. We've had bays open at 450 knots at 10,000 feet" – a necessary measure to assure that the F-35 will be able to release weapons in combat.

So do you want to be in the cockpit of an F-35A if a MiG jumps you? Some observers say that while the F-35A is clearly a superb air-to-ground weapons platform, its role in air-to-air combat remains unproven. But pilots say the F-35A is well equipped for both distant battles that occur beyond visual range (BVR) and for close-quarters dogfights.

"It has high AOA (angle of attack) capabilities very much like the F-22," said Beesley. "The helmet mounted display is a multiplier in BVR combat: It will tell you where the other guy is. Within visual range the helmet display will enable you to see, engage, and point. The aircraft has a datalink. It's a single-seat fighter but it's very important to understand that it's not a single-seat war. The pilot will be connected to everybody in the battlespace."

Not mentioned often enough is the claim of F-35A advocates that the aircraft is easy to maintain: Although the F-35 will offer special challenges to maintainers because of its stealth technology (which requires a compartmentalized security clearance, heightening personnel costs), airmen on the flight line and in the back shops say they like the F-35's modular approach to digital engineering: "It will be easier to work with than any previous fighter," said one maintainer.

It's hard to find any pilot who doesn't feel the Joint Strike Fighter is the right choice for 21st century warfare. Proponents point out that it will be stealthy, will have both air-to-ground and air-to-air prowess, and will be able to field a variety of "smart weapons" that are useful in combating conventional adversaries as well as insurgencies, including the satellite-guided small diameter bomb.

But will the future belong to unmanned aerial vehicles, now being officially called remotely piloted aircraft (RPAs)?

Jon Beesley said he was asked that question when he first strapped into the F-22. Now, Beesley is in charge of the company's F-35 flight operations.

"People ask me if I'm flying my last manned fighter," he said. "I tell them this is my second last manned fighter."

# PACE OF DISCOVERY

## Flight Testing the F-35B at NAS Patuxent River

BY ERIC TEGLER

When BAE Systems test pilot Graham "GT" Tomlinson touched down after completing the first successful vertical landing in the F-35B on March 18, 2010, the noise from the fighter's Pratt & Whitney F135 turbofan engine was considerable. In contrast, the noise from critics who predicted problems for the short takeoff/vertical landing (STOVL) F-35B on its first vertical descent to landing vanished.

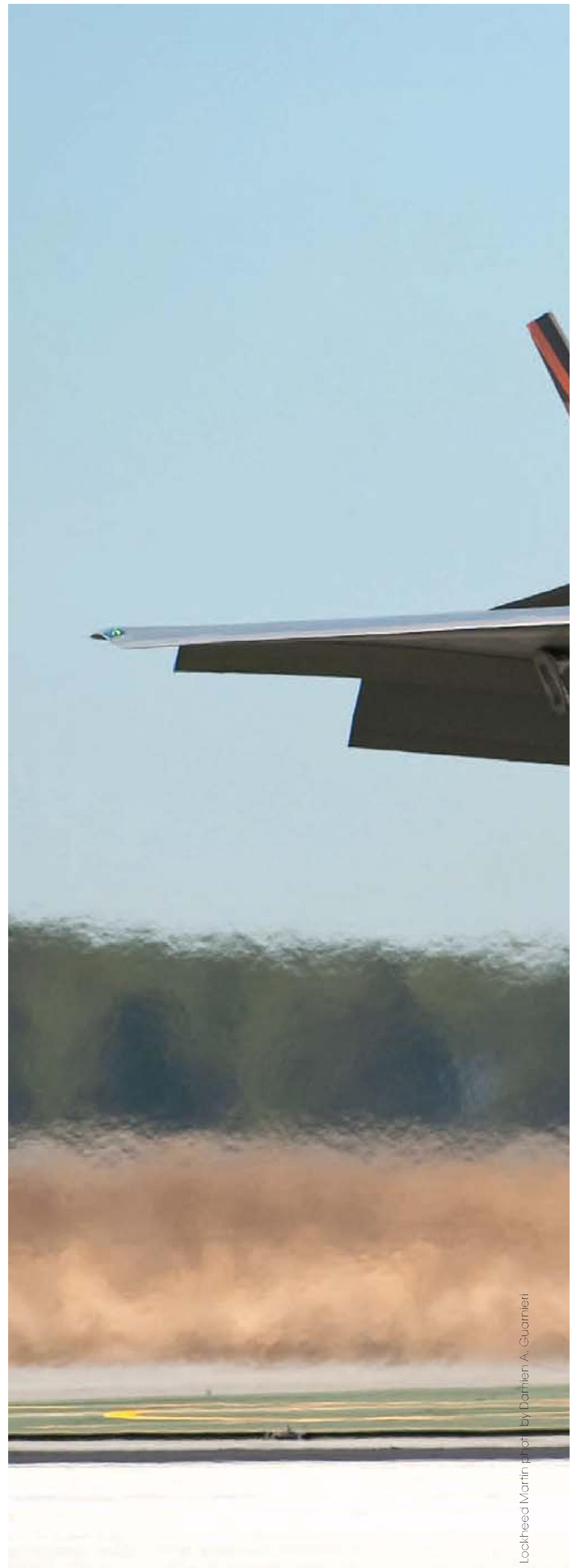
The figurative hush didn't surprise Tomlinson, whose work as a Royal Air Force fighter pilot and BAE test pilot spans three-and-a-half decades and aircraft from the early Harrier GR3 to the Panavia Tornado and various commercial and civilian aircraft.

"I think technology has changed what we can do," Tomlinson reflected, "and as a result, the balance between design and test has changed dramatically. In the good ol' days, you had a 60 to 70 percent design-fixed airplane when you began testing and you found a lot of problems. You had to redesign for those problems in the test period. Because of modern technology, we're now at the stage where the airplane has been 90 to 95 percent designed before we start testing. I do not expect to find many problems in our testing. I expect to find a few little ones but I think the big design bow wave is behind us now. From here on, it should be a downhill ride."

The problems to which Tomlinson referred are often called "discoveries" in the flight test community. Developmental flight testing is designed to produce discovery before an aircraft's design is finalized for production. The five F-35 STOVL prototypes now at Naval Air Station (NAS) Patuxent River in Maryland (BF-1, BF-2, BF-3, BF-4, and BF-5) will be flown at a rigorous pace to turn up what discoveries the F-35B may produce but mostly to refine the design, analysis, and computer modeling already done.

With the JSF program scheduled to enter low-rate initial production (LRIP) before developmental testing is over, the prototypes will play a vital role not only in proving the design of the F-35B, but the multi-variant concept as a whole. The first prototype, BF-1, arrived in November 2009, and BF-4 arrived in early June 2010. The fifth and final STOVL prototype, BF-5, arrived at Pax River July 16, 2011. Three CV (carrier variant) prototypes are also at Pax River. The flight schedule for each of the prototypes is based on a ramp-up rate that sees the aircraft make three flights a month for the first two months, six flights in months three and four, eight flights per month for two months and on to 10 flights a month for two months, leading to the desired sustained flight rate by month nine.

"By the ninth month here we think we'll have the maturity we want with the jet and we'll be looking at about 12 flights a month," Lockheed Martin Integrated Test Force (ITF) Site Director



Lockheed Martin photo by Damien A. Guarnieri

F-35B BF-1 achieved the first vertical landing on March 18, 2010. Graham Tomlinson was the pilot.


F-35B airframe BF-4 shown during flight 46, undertaking short takeoffs and hovering from the runway.



William Coutts explained. A former U.S. Air Force fighter pilot with extensive experience in the military and civilian test community including stints as vice (test) center commander at Edwards Air Force Base (AFB) and ITF Site Director at Lockheed's facility at Fort Worth, Texas, Coutts feels that the flight test schedule, though aggressive, is achievable.

"There may be some efficiencies we develop along the way and we may not have the unknown unknowns that you normally have in test programs because of the amount of modeling, simulations, and integrated labs in place back in Fort Worth. Testing could go faster; however, there normally is an unknown unknown that comes up and slows things down. We think we're adequately resourced. We think we can execute the schedule and we'll find out as time goes on what the aircraft reliability is."

He pointed out that the total 28 sorties flown from January through March exceeded the 24-flight ramp-up rate originally planned for the first three months of 2010. ITF chief engineer at Pax, Andrew Maack said the F-35B test schedule has a basis in past programs.

"We came up with these goals considering both Air Force and Navy legacy experience with regard to what we can expect to generate. It's not the op tempo that holds you back during these kinds of programs, it's the discoveries during the course of development."

With arrival of BF-4, a fuller range of discoveries became possible. Unlike its three stable mates, BF-4 is equipped with an early version of the mission systems suite with which the F-35B will operate. The aircraft brings together baseline stealth characteristics with the JSF's distributed aperture system, electronically scanned array (AESA) radar, electro-optical targeting system, and other combat systems.

"We'll go out and see how those systems operate in an integrated fashion," said Coutts, who explained that the mission systems in BF-4 represent a baseline Block 0.5 level. Basic communications, navigation, and identification testing will go forward to support LRIP aircraft. Mission systems work up to Block 1.0 can and will be undertaken at Pax as its aircraft receive upgrades.

In April, flight testing was limited as the three resident aircraft received maintenance and upgrades that would give them the most robust systems to take into the heart of the test process. The prototypes themselves are half of the test equation at NAS Patuxent River, which provides the right environment and infrastructure.

"Our whole goal here is to support flight test," U.S. government Site Director Lt. Col. Fred Schenk (USMC) affirmed. An AV-8B Harrier pilot, U.S. Naval Test Pilot School graduate, and former F-35 STOVL project pilot at VX-23, Schenk added, "We have the range facility and multiple (control) rooms so we can work multiple airplanes at the same time. The airspace is right off the end of the runway. We've built some unique facilities here for the STOVL airplanes – the hover pads, an expeditionary runway, and a ski jump. Everybody's focused on supporting the flight test mission – whether its search and rescue, the airfield, tanker support – all of those assets are here."

The hover pads, expeditionary airfield, and ski jump are among the physical infrastructure assets most specifically geared to F-35B. The expeditionary airstrip consists of 4.5 square miles of AM2 aluminum airfield matting, allowing test pilots to perform short takeoffs and vertical landings in the kind of unsanitized forward operating environment Marine Harriers have used to tactical advantage in Iraq and Afghanistan. Its total length is approximately 1,280 feet. A portion of the area is configured in the shape of a large deck Navy LHD-class amphibious assault ship. Simulated shipboard approaches can be made to this area, which will also allow basic vertical ship landing clearances to be established.

"The expeditionary strip is out there to allow us to work toward the Marines' big requirement – austere site operations where they'd takeoff from an LHD, then go sit on a rough strip which has just been taken over," Schenk explained. "We can do the clearance work for that."

"The ramp here was built based on the existing ski jump on the Invincible-class carriers because that's what we had data for," BAE's Tomlinson stated. "When we throw the F-35B off the ramp here, we'll be able to calibrate it against a known ramp, and if the ramps (built for various carriers) are slightly different, it's a relatively easy adjustment (to) change the models and write ourselves a clearance before we go out to the new ships."

Transitioning to the F-35B from the Harrier or beginning STOVL training *ab initio* should be relatively easy as well, according to Tomlinson, who said the Lightning II will take much of the burden of STOVL operation off of the pilot.

"There's a multi-generational difference between the Harrier and the F-35. The Harrier first flew in 1960 when computers didn't really exist. Most TV was black and white. To me, the big difference between the Harrier family and the JSF family is that because we've had fly-by-wire capabilities under our belt for 20 years, we can build safety into the airplane. The F-35 doesn't need looking after by the pilot. The pilot can close his eyes and do silly things with the stick and the throttle and the pedals and the airplane looks after him. Because it isn't fly-by-wire, the pilot has to look after the airplane in the Harrier family. That is the fundamental difference between the two."

That difference shows up most obviously in the STOVL phase of flight, Tomlinson added, and it allows JSF pilots to focus on the mission.

"What we can do with this airplane is not forget about that phase – the environment that you operate these airplanes in is different from any other. But it will be minimized to a degree. My honest belief is that because we've made the F-35B, and all three variants of the airplane, so safe by taking away Harrier problems, that the training workload for the F-35B will be lower than it is for the F-35C. Landing a helicopter on a ship is a no-brainer. Landing an F-35B on a ship will be a no-brainer. They're no longer difficult vehicles. They're a Hertz car. You pick up the key, you go drive it. You're thinking about where you're going, about the mission, not about how to drive the car."

The benefits go beyond mission focus to a system that is easier to train for and to adapt to, a significant plus for a multinational aircraft program. Ensuring that F-35B shipboard operations are smooth will be a challenge for the test team at Pax, but far from a major headache. Schenk points out that with the same landing aids and visual cues, landing an F-35B at sea won't be much different task-wise than landing a Harrier. The U.S. Navy is already at work, verifying that the topside systems on its LHAs and LHDs are suitable for JSF testing. Among the issues to be considered is foreign object damage (FOD).

BF-1 in the hover on March 17, 2010.

Lockheed Martin photo by Andy Wolfe

"The Harrier has a FOD problem," Tomlinson explained, "because the engine intakes were relatively close to the ground and in front of them there's a nosewheel and a front puffer, which is open on takeoff and landing. It's basically squirting air onto the ground in front of the airplane so it tends to pick up pebbles. Our configuration doesn't have that. We've got a lift fan which is a long way from the intakes."

Though its intakes are a healthy distance from the lift fan, the F-35B's engine exhaust nozzle that cants down in STOVL mode can be within a couple feet above the deck on touchdown, possibly creating blast and heat issues. These may be aggravated given the precision with which the aircraft can be landed in the same spot time after time, and analysis is under way to determine whether deck landing spots will need reinforcement or insulation.

Equipment on carrier decks is typically firmly secured to the deck and personnel are likewise cautious about their positions and movements. The downwash created by the 41,000 pounds of thrust that the B's engine will put through the lift fan and exhaust is nearly twice the thrust of early Harriers, Maack observed. Taking that downwash into account is another of the myriad details the JSF ITF and the Navy will analyze and ultimately test.

Flight test will be the final word on JSF performance, but a historic amount of analytical work has already been undertaken that could allow JSF developmental testing to move forward faster than previous programs. The modeling and simulation have left a marked impression on pilots at Patuxent River, Fort Worth, and Edwards AFB, Schenk related.

"One of the most common comments you hear from the test pilots when they land is, 'It flew just like the simulator.' I think that's a real testament to the modeling and analysis that's

BF-1 performing a short takeoff, flight 111, April 4, 2011.

Lockheed Martin Photo by Andy Wolfe

**"LANDING A HELICOPTER ON A SHIP IS A NO-BRAINER. LANDING AN F-35B ON A SHIP WILL BE A NO-BRAINER. THEY'RE NO LONGER DIFFICULT VEHICLES. THEY'RE A HERTZ CAR. YOU PICK UP THE KEY, YOU GO DRIVE IT. YOU'RE THINKING ABOUT WHERE YOU'RE GOING, ABOUT THE MISSION, NOT ABOUT HOW TO DRIVE THE CAR."**

been done. You walk into a test mission prepared and ready to execute because the simulation is so close to what you're actually flying. It's a huge benefit."

Tomlinson cautioned that modeling and simulation have their limits, however.

"Traditionally, modeling is great until you get to extreme angle-of-attack where airflow starts to break down – 99.9 percent of the modeling has been perfect, but there are a couple of areas which have surprised us.

"The upper lift fan door behind your head, which opens into the airflow, creates vortices. In retrospect we think we weren't modeling correctly the airflow through the lift fan when the fan wasn't spinning. There's a period of time when you have the door open and the lift fan isn't spinning. One of the first things we found upon opening the doors was that our modeling of the 'dead flow' and the effect that disturbed air from the upper lift fan door had on the rudders, tails, and horizontal stabilizers was not what we would wish. So we took the flight test data and we re-did the models for airflow through the lift fan when it's not spinning and for nonlinear airflow across the (empennage) when the upper door is open. In simple terms, the back end was working a lot harder than we expected it to, so we re-did those models."

Refining the models and simulations run prior to flight will no doubt be a necessary exercise for the Patuxent River ITF. Nevertheless, the proportion of aircraft capabilities that will have been verified through labs, a flying test bed, and subject matter analysis across the JSF program is well over 75 percent, representing a paradigm shift in developmental testing. Supporters and critics of the JSF program have taken note of this balance, and if it proves effective, flight testing may henceforth be regarded as the "final polish" on a test program rather than a basic part of its construction.

The use of ground-test articles like BG-1 (a full-size F-35B non-flying or "static" prototype) is not new to developmental testing, but what the JSF program learns from static test is as important as ever. A considerable amount of information has been exchanged between the ITF at Pax and the team testing BG-1 at Lockheed Martin's Fort Worth facility. The F-35B's auxiliary inlet doors are a good example of that exchange, ITF Chief Engineer Maack said.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"Analytically, we think we have a good handle on what the in-flight loads are going to be when we start the program. Discovery happens and maybe there's a vortex type phenomenon or maybe a sensitivity to side-slip that wasn't expected. Whatever, we may encounter loads that were unexpected and our envelope needs to be expanded. In the case of the doors, we then go back to the static test article and test to a further design point, not where they had been tested to previously. That's been very successful. You don't need to split hairs with regard to how good your analysis is, you can double the size of your envelope very quickly and safely. Having access to those assets and being able to go back to them during flight testing is very valuable."

The commonality of the respective F-35 variants is just as valuable. Test points undertaken at one site with one variant will often be relevant for the other variants undergoing testing at another site. As such, communication between site and ITF teams is vitally important. Coutts explained that ITF at Pax River holds staff meetings at 1000 and 1500 each day. In the morning meeting, the team gives the Lockheed Martin vice president of F-35 Test and Verification, Doug Pearson, an update on the jets' condition and a plan for the day. In the afternoon, the team reports on what developed. The Pax River ITF also generates a daily report distributed to JSF sites and the Program Office.

"We can pick up the phone and talk to our counterparts out at Edwards, which everyone does regularly. The site directors all have a weekly teleconference on Thursdays, so there is a lot of communication between the locations," Coutts said. He also confirmed that one site may be asked to fly test points for another.

"It's not just flying test points. We're going to detach airplanes out to Edwards and they'll detach planes here to Patuxent River. We'll have a lot of cross-talk between us and I imagine it will only grow as testing grows bigger."

JSF program test pilots will move from site to site, Schenk added, particularly Lockheed Martin pilots, including chief test pilot John Beesley, who will routinely make the rounds and fly sorties at each site. If something is uncovered during flight testing at one, the other sites will know about it promptly, he added.

"There are procedures in place so if we have a significant discovery, we activate a certain call-tree to make sure that information gets out whether folks need to stop flying, those kinds of things."

Commonality isn't just confined to the F-35, however. The multi-site nature of the program has convinced the respective test teams to harmonize the range systems and procedures at the key sites.

"Although we have very different ranges and facilities at Patuxent River and Edwards," Maack observed, "the program has gone to great lengths to make sure we're using common systems with regard to (test monitoring) displays in control rooms. A particular technical discipline can use the same (type of) screens and files that we have here on the Atlantic test range out at Ridley Field at Edwards or at Fort Worth. With past programs, that would not be the case. We would be operating differently at the Atlantic Test Range and at Ridley."

Other common points include the training of maintenance personnel, many of whom came to NAS Patuxent River from Edwards AFB for hands-on experience with the F-35B, as Edwards had yet to receive its first conventional takeoff and landing (F-35A) prototypes. Noteworthy as well is the inclusion of Navy, Air Force, and Marine maintainers at a hands-on level unseen in previous test programs. They are joined on the Pax River ITF facility hangar floor not only by Lockheed contractor personnel but by JSF international partner personnel from the U.K. and Italy.

Much of the success of the F-35B program will hinge upon how robust the aircraft turns out to be. Like the Harrier, it has been described as delicate but rugged. Its strength will be put to the test as sorties from Pax River ramp up in the months to come.

"The more we fly, the more we learn," Maack admitted. "One of the biggest challenges in developmental testing is that we have limited assets which are configured differently. Each one of these airplanes will often be at a different systems phase, whether it has the latest (systems) or a generation prior. So building time across the fleet is not the most critical factor (in indicating reliability) because each airplane is so different."

Though their confidence is high, senior members of the ITF team at Patuxent River are aware of the expectations, challenges, and differences in the JSF program as a whole and with the F-35B in particular.

"I think the concurrency that we have between rolling into production and just getting into testing is a different challenge," Maack offered. "In the legacy programs I've been associated with, if we made a bad decision, we had some time ahead to be able to fix it or change course. With LRIP airplanes being produced, we have to be very careful that we don't make mistakes because they can have implications immediately. The services will feel them very quickly. That's the unique challenge from other programs."

Schenk observed that while communication is paramount in any test program, its importance to F-35 testing is still higher.

"I think the complexity and the interdependencies of this program are different. We have three sites, three variants all leveraging each other and operating simultaneously. I don't think we've done that in the past. I think V-22 is the only program that I know of that has spanned multiple sites. That can be a huge benefit for us, but we also have to be cautious. If we get isolated, which we're trying hard not to do, we could have discoveries that aren't shared."

Overcoming whatever issues arise with the F-35B should give those testing the F-35A and C variants a head start, Coutts said. He believes the ITF will ultimately win over some program critics and added that the vital work his team is doing couldn't go forward without the support it receives at NAS Patuxent River.

"If you think about what we've done, we've designed and started initial flight test on the most technically challenging aircraft there is. CV (carrier variant) and CTOL (convential takeoff and landing aircraft) ought to be relatively simple compared to what we're doing with STOVL. When Graham did the vertical landing, many people thought we were going to have issues with flying qualities, with thermal properties. That didn't happen. It was a perfect landing. We have a lot of critics. I don't know if we get credit for having done the most technically challenging (variant) first.

"I was the vice center commander out at Edwards at one time. I had never been to Patuxent River but I've been absolutely impressed and pleased with the amount of support we've gotten. The day of the vertical landing we had an issue with our search and rescue helicopter. They went out and took rescuers off the helicopter, put them into boats and sent them into the (Chesapeake) Bay so that we could fly our test. We've had great support from Pax, from the Program Office and from Fort Worth."

# WHY STOVL MATTERS

BY J.R. WILSON

Perhaps the most technically difficult of the three Joint Strike Fighter (JSF) variants is planned to be the first to go into active service – the F-35B short takeoff/vertical landing (STOVL) aircraft for the U.S. Marine Corps.

Despite some delays in the System Development and Demonstration (SDD) phase of the program, the Marine Corps is still anticipating Initial Operational Capability (IOC) for the F-35B in 2012 or 2013, at the latest – up to four years before the Air Force F-35A conventional and Navy F-35C carrier variants. For the Marine Corps F-35B, IOC is defined as a squadron of 10 aircraft able to execute the full range of TacAir-directed mission sets and to deploy on F-35B-compatible ships and to austere expeditionary sites.

"There are two reasons STOVL makes sense for the Marine Corps," said Lt. Gen. George Trautman III, formerly deputy commandant for aviation. "One is we are an expeditionary force that has to be ready to go to austere locations rapidly when the nation needs us to go there. That doesn't make us better than any other service, it just makes us different. And we have to have equipment that can do those kinds of things rapidly.

"Second, our amphibious ships, both large and small, really serve the nation well as part of the Navy's global persistence presence. The big carriers get a lot of press, which they deserve, as do our MEUs (Marine Expeditionary Units). But having the ability to have tactical aircraft on small-deck amphibs is key for us in the future."

A major issue is the uncertainty of adversaries, types of conflict, and mission requirements for Marine aviation in the future. According to Richard Aboulafia, a senior analyst for the Teal Group, the types of missions assigned to the Marine Corps would seem to boost both the need for and utility of a fifth-generation STOVL fighter.

"If you are up against a near-peer adversary and only had the AV-8B, you couldn't operate autonomously. If you were only up against a lesser adversary, you might do better," he said. "In both Gulf Wars, the Harrier was only good for fire support; it helped a lot in terms of providing an on-the-spot, fast attack capability, but really was nobody's idea of a fighter and had

Lockheed Martin Photo by Andy Wolfe

F-35B Lightning II BF-1 in STOVL mode during testing. The F-35B will add stealthy, supersonic, fifth-generation capabilities to the proven STOVL advantages the Marine Corps has enjoyed with its Harriers.

no range and payload compared to what the blue water Navy could do. So it was fine in a small fight, for relatively limited operations, but was more an adjunct capability.

"The STOVL F-35 and V-22 can be seen together as a way to allow the Marines a greater degree of autonomy and expeditionary warfare as an autonomous unit. If the F-35B offers much of the range and payload of the A-model, with greater basing flexibility in terms of shipboard and land, it would be a game-changer. But that is a tall order. I think it probably will get closer than anything before, but not enough to (make) obsolete the concept of traditional takeoff jets. But it does help the Marines, who have always thrived on basing and deployment flexibility, make the case for getting a bigger share of the mission and the budget."

STOVL has been a major target capability for decades, with the earliest efforts dating back to the development of the helicopter, a Marine Corps mainstay since the Korean War.

Tom Burbage, executive vice president and F-35 Program Integration general manager at prime contractor Lockheed Martin Aeronautics, said there have been more than 50 attempts to develop fixed-wing aircraft that can fly in the vertical mode, incorporating a wide range of propulsion concepts – direct, shaft-driven, multi-engine, etc. The F-35B uses a patented shaft-driven LiftFan propulsion system Lockheed Martin says overcomes many of the temperature, velocity, and power challenges of direct-lift systems.

"Of those (previous attempts), only two ever really went into production – the Russian Yak-38 and the Harrier. And now the F-35B, so it's been a pretty limited success pool, primarily because of physics," Burbage explained. "The design challenges of trying to integrate supersonic flight, stealth, and STOVL characteristics challenge the laws of physics you can package into an aircraft with any real range and payload. Being stealthy and supersonic also drive some design requirements that are contradictory to historical ways of looking at STOVL flight.

"The direct lift concept of the Harrier, for example, required you to move the engine over the center of gravity of the airplane, which causes shaping problems for supersonic flight. One of the real advantages of our shaft-driven LiftFan is it allows you to keep the engine in the back of the airplane, the same as the conventional version, so you can do the weight and balance necessary to go to high supersonic speed, as well as the shaping required for stealth, which requires the main engine to be in the back of the airplane. Integration of those design elements was a very major step forward. I'm not sure anyone believes we could have done it before this because we did not have the computing power and engineering models and kinds of things we have employed to integrate this design."

Those included environmental factors around the aircraft, such as downwash and heat blast. For those, the F-35B benefited from design and flight experience with the Harrier, a subsonic jet initially built for the British military by Hawker Siddeley in the late 1960s and designated the AV-8A by the Marine Corps. BAE and McDonnell Douglas extensively remodeled it in the 1970s and '80s as the AV-8B.

Entering service about the same time as the F/A-18, the Harrier gave the Marine Corps substantially upgraded aviation capability, with both the supersonic multi-role Hornet and the AV-8B able to operate from either land bases or Navy carriers. Both aircraft were also acquired by several U.S. allies, many of whom are now actively involved in the F-35 program or are considered likely buyers.

As a replacement for both aircraft, the STOVL variant of the F-35 will provide the speed of the Hornet and the operational versatility of the Harrier, but with the added benefits of stealth and significantly advanced avionics.

"A challenge in the past has been an extremely high pilot/vehicle interface workload and a high accident rate with the Harrier," Burbage said. "So we've spent a lot of time on fully integrating the flight and propulsion controls.

"Almost every previous method has been terminated due to accidents, mostly due to the fragility of the physics and a flight control system that can control the airplane

in all the flight modes. The integrated flight/propulsion control system on the F-35B is much more logical, intuitive, and safer than in the past for pilot/airplane interfaces."

With an internal fuel capacity of 7 tons, the F-35B has an unrefueled range of more than 900 miles without external tanks, enabling it to operate in full stealth mode with a standard internal weapons load of two AIM-120C air-to-air missiles and two 1,000-pound GBU-32 JDAM guided bombs. Depending on the mission, those can be replaced or augmented with up to six GBU-38 small-diameter bombs and a wide variety of air-to-ground missiles, dispensers, and guided weapons.

The internal weapons bay can be reconfigured to accommodate all current air-to-ground and air-to-air ordnance or a blend of both. A missionized internal version of the 25 mm GAU-22A cannon also is an option. When the mission does not require stealth, external pylons increase the aircraft's weapons payload to more than 15,000 pounds, compared to 18,000 for the other two variants.

The USMC and potential foreign operators see STOVL as a major enhancement to fifth-generation fighter capabilities. While nearly identical in size to the conventional "A" variant, the F-35B can go places normal tactical aircraft cannot – and do so from smaller decks and austere fields.

"Look at the number of runways now built around the globe where you can take an F/A-18 or F-16 compared to a Harrier,"

**"THE CORPS IS AN EXPEDITIONARY FORCE, A LIGHT FORCE, THAT DEPENDS ON ITS AVIATION ELEMENT TO ENABLE IT TO MANEUVER WITH IMPUNITY AND TAKE EXTRA RISKS."**

U.S. Navy photo by PH3 Jonathan Carmichael

OPPOSITE: An AV-8B Harrier aircraft hovers above the flight deck of the amphibious assault ship USS *Bataan* (LHD 5) as the pilot makes a vertical landing. The *Bataan* was dubbed a "Harrier carrier" during Operation Iraqi Freedom. Stealthy, supersonic, STOVL F-35Bs multiply the capabilities of small-deck amphibious warfare ships as well as existing small carriers in fleets and those being built today.

LEFT: STOVL capability allows the F-35B to go places and do things normal aircraft cannot.

U.S. Navy photo by Liz Goettee

Burbage noted. "There are five times more places you can go without using a Marine support squadron to build or extend an airfield or ask permission for the use of abandoned fields. That greatly expands the places we can go, without even taking into consideration roadways and other places. Conventional tactical air needs a lot of runway or arresting gear."

At the same time, it offers all the advantages of fifth-generation aircraft supersonic cruise without afterburners; stealth; fully fused and highly integrated multimode/multifunction sensors providing the pilot with unprecedented situational awareness; and the ability to share that information with the rest of a network-centric battlespace.

To Trautman, the F-35B is merely the latest in a long line of Marine Corps innovations in aviation – usually despite early problems.

"The Corps is small and we think things through as best we can, so we tend to get out in front of innovations, such as the helicopter. The Corps saw the value of that in the early 1950s as enabling maneuver faster than the enemy could get where we wanted to go," he recalled. "STOVL tactical air is another. The Harrier is a glorious machine, the first of its kind, and has had to overcome the kinds of struggles and challenges the first of a kind aircraft always must overcome.

"The V-22 Osprey, like the helicopter and Harrier, has had a long struggle, and I think the Corps' persistence – or obstinance – has enabled us to drive these aircraft to where they now are. Helicopters are broadly accepted by everyone – the past two wars have been called helicopter wars. The V-22, although still in its infancy, changed the nature of battle in Iraq and Afghanistan, decreasing the size of the battlespace and speeding up operations. All of which has proven we were right about those aircraft."

When the Marines first went into Afghanistan in 2002-03, there was little or no basing capability for F/A-18s, F-16s, or F-15s. Instead, the Corps used a 14-plane Harrier squadron that flew more than 1,200 sorties and nearly 700 tactical air requests from an austere forward operating base. Without needing to fly the extra hours back to ships or larger land airfields, the Harriers did not require a lot of air refueling, freeing those assets for other operations.

There also was one more major advantage, according to Trautman: "You can refuel in the air, but you cannot re-arm in the air, so absent the ability to land and reload ordnance, you are a very limited platform."

The improved internal safety margin provided by advanced computers and avionics will help avoid some of the safety issues resident in the AV-8B, he added, while combining STOVL with longer range, higher speed, stealth, and increased interoperability will enable Marine pilots to do everything they have been doing, but better.

An AV-8B Harrier II from the Spanish aircraft carrier *Principe de Asturias* (R 11) prepares to land after a live fire exercise as part of a passing exercise with ships assigned to Standing NATO Maritime Group Two (SNMG-2). Countries building or operating small carriers, and current Harrier operators hoping to retain and enhance their ship-based fast jet capability, are likely customers for the F-35B.

U.S. Navy photo by Mass Communication Specialist Leonardo Carrillo

"The Corps is an expeditionary force, a light force, that depends on its aviation element to enable it to maneuver with impunity and take extra risks. We are not backed up by a lot of tanks or heavy artillery when we maneuver, either in regular warfare or COIN (counterinsurgency) operations. Aviation provides the cover to enable us to do those things," Trautman said. "The beauty of the JSF is its stealth capability, which will enable it to provide that cover in environments that heretofore have been impossible.

"You must roll back an integrated air defense system before you do anything else, which leaves the MEU waiting. The F-35, in many ways, will speed that along by days or even weeks – and the tempo of operations, one that exceeds the ability of the enemy to react and counter your moves, is key. Second, the F-35's sensing and computing power will dwarf the sensors resident on any other platform ever built. It is truly startling to watch that technology – not being developed, but already resident in the platform today. They will enable us to see, observe, and understand what the enemy is doing at a scale far beyond what anyone can do today."

The program office expects current Harrier operators to be the primary customers for the STOVL variant, although other nations looking for a ship-based fifth-generation capability without requiring a large-deck carrier or the ability to operate from austere land bases also may consider the F-35B.

For the foreseeable future, any nation interested in a STOVL aircraft with even some fifth-generation capabilities will find alternatives non-existent.

"There obviously has been work done, primarily in China and Russia, in trying to develop the kind of capabilities we have in the F-22 and F-35 (currently the world's only fifth-generation fighters). It has taken us a long time to get to the point where we understand this technology and can integrate it," Burbage said. "It's one thing to try to recreate a shape or design based on pictures, another to fully integrate the technology, which has been and will continue to be very tightly controlled by the U.S.

"The (Russian Sukhoi) T-50, for example, has some of the same kind of shaping you might find in an F-22, but, to the naked eye, there appear to be some fairly obvious shortfalls. There is a huge investment being made by the U.S. and our partners and there is no evidence of that kind of investment by these other countries."

In a joint statement to the Seapower and Expeditionary Forces Subcommittee of the House Armed Services Committee in March 2010, Trautman, Rear Adm. David Philman, and Sean J. Stackley, assistant secretary of the Navy (Research, Development and Acquisition), described the value of the STOVL variant to the Marine Corps – and potential allied operators, as well.

"The F-35B STOVL variant combines the multi-role versatility and strike fighter capability of the legacy F/A-18 with the basing flexibility of the AV-8B and the potential for electronic warfare dominance of the EA-6B," they testified. "The Marine Corps intends to leverage the F-35B's sophisticated sensor suite and the very low observable (VLO) fifth-generation strike fighter capabilities, particularly in the area of data collection and information dissemination, to support the Marine Air Ground Task Force (MAGTF) well beyond the abilities of today's MAGTF expeditionary attack, strike, and electronic warfare assets.

"Having these capabilities in one aircraft will provide the joint force commander and the MAGTF commander unprecedented strategic and operational agility. The F-35B and F-35C will provide the Expeditionary Strike Group and Carrier Strike Group commanders a survivable, 'day-one' strike capability in a denied access environment with the tactical agility and strategic flexibility to counter a broad spectrum of threats and win in operational scenarios that cannot be addressed by current legacy aircraft."

Former Royal Air Force Harrier pilot Graham Tomlinson, now a BAE test pilot, made the first F-35B flight in June 2008 – a 45-minute subsonic test with conventional takeoff and landing. In January 2010, Tomlinson engaged the aircraft's STOVL propulsion system in flight for the first time, marking the start of the most important, multiple milestone year in the F-35B SDD effort.

In August 2009, the first aerial refueling of an F-35B was accomplished, using the probe-and-drogue system common to the U.S. Navy, Marine Corps, and many NATO nations for in-flight refueling. While the STOVL aircraft's ability to operate from and land to refuel at airfields much closer to their targets than the other two variants makes air-to-air refueling less crucial than it is for the F-35A and C variants, that success nonetheless marked a major accomplishment for the flight test program.

In March 2010, Tomlinson demonstrated three additional firsts – the aircraft's ability to hover, make short takeoffs, and land vertically. For the hover test, he began the transition from horizontal to vertical mode at 200 knots airspeed, slowed to 60 knots as he approached the landing zone, then decelerated to zero as the aircraft began its first in-flight hover 150 feet above the runway.

"Today's vertical landing onto a 95-foot-square pad showed that the aircraft has the thrust and the control to maneuver accurately both in free air and in descent through ground effect," he commented at the time, adding the advanced control system significantly reduced the pilot workload compared to the Harrier. "Together with the work already completed for slow-speed handling and landings, this provides a robust platform to expand the F-35's STOVL capabilities."

**"FOR THE FIRST TIME IN MILITARY AVIATION HISTORY, SUPERSONIC, RADAR-EVADING STEALTH COMES WITH SHORT TAKEOFF/ VERTICAL LANDING CAPABILITY. THE SUPERSONIC F-35B CAN DEPLOY FROM SMALL SHIPS AND AUSTERE BASES NEAR FRONT-LINE COMBAT ZONES, GREATLY ENHANCING COMBAT AIR SUPPORT WITH HIGHER SORTIE-GENERATION RATES."**

In June 2010, Marine Corps Lt. Col. Matt Kelly took the second F-35B test aircraft supersonic for the first time (in 2008, an F-35A test aircraft was the first JSF to break the sound barrier).

"For the first time in military aviation history, supersonic, radar-evading stealth comes with short takeoff/vertical landing capability," Bob Price, Lockheed Martin's F-35 Marine Corps program manager, said at the time. "The supersonic F-35B can deploy from small ships and austere bases near front-line combat zones, greatly enhancing combat air support with higher sortie-generation rates."

In October 2010, the F-35B reached Mach 1.32 – as well as reaching its maximum design loading of 7 *g*. By May 2011, the F-35B test fleet had recorded more than 100 vertical landings.

The Joint Strike Fighter has been a controversial aircraft since it was first conceived nearly two decades ago. Technological and budget challenges, stretched out and delayed buys, and other factors common to any major development and procurement program have plagued it all along. And applying some of the most difficult – often even counterintuitive – physics inherent in STOVL to an aircraft with some 95 percent commonality to two other variants (on top of no previous success in meeting both Air Force and Navy requirements with a single aircraft) has made the F-35B an exceptional challenge.

In the end, for the Pentagon it boils down to the B-variant's success in meeting flight test, operational, maintenance, mission, and fly-away cost requirements, with enough orders to trigger economies of scale. For the Marine Corps and other operators, however, the real measure of success will be what a fifth-generation STOVL aircraft brings to the fight, whether against a technologically sophisticated major power or in another COIN conflict, such as Afghanistan.

"You really need a stealthy, supersonic, multi-role combat aircraft that allows that greater degree of autonomy against near-peer adversaries," Aboulafia concluded. "That is the F-35B."

# SENSORS

## The F-35 Lightning II Is a Lethal Network Node

BY SCOTT R. GOURLEY

Among the myriad recent program milestones for the F-35 Lightning II stealth fighter, a significant new tactical capability was established in early April 2010 with the first flight of the initial mission systems-equipped aircraft. The aircraft was BF-4, a short takeoff/vertical landing (STOVL) variant.

Ushering in what has been described as "the most powerful and comprehensive sensor package ever to fly in a fighter," the first flight, which took place at Lockheed Martin's Fort Worth, Texas, plant, included verification of engine response at varying throttle settings, a series of flight-qualities maneuvers, and checking the operation of the aircraft's mission systems.

Marking that first mission systems flight, Eric Branyan, Lockheed Martin F-35 deputy program manager, observed, "Today's flight initiates a level of avionics capability that no fighter has ever achieved. The F-35's next-generation sensor suite enables a new capability for multi-role aircraft, collecting vast amounts of data and fusing the information into a single, highly comprehensible display that will enable the pilot to make faster and more effective tactical decisions."

The F-35's full mission systems suite includes: the Northrop Grumman AN/APG-81 Active Electronically Scanned Array (AESA) radar, providing long-range, multiple simultaneous air-to-air and air-to-ground targeting, as well as a synthetic aperture radar (SAR) terrain mapping capability; the Lockheed Martin Electro-Optical Targeting System (EOTS), providing long-range, passive infrared search and track, air-to-air, and air-to-ground targeting capabilities; the Northrop Grumman Electro-Optical Distributed Aperture System (EO-DAS), providing passive, spherical, long-range threat detection, source of infrared video and night-vision projection onto pilot's helmet visor for a spherical view around the aircraft; the BAE Systems Electronic Warfare (EW) system, providing simultaneous geo-location of multiple threats and targets; the Vision Systems International Helmet Mounted Display System (HMDS), integrating helmet, virtual head-up display, targeting information, look-shoot capability, and video/night vision projected onto the helmet visor; the Northrop Grumman Integrated Communication, Navigation and Identification (ICNI), providing friend-or-foe identification; automatic acquisition of fly-to points; secure multi-wave, multi-band, multimode wireless communications and data links; the Lockheed Martin Integrated Core Processor (ICP), which supports radar, EOTS and DAS sensor processing, navigation, stores management fire control and fusion of sensor and off-board information; the Honeywell Inertial Navigation System; and the Raytheon global positioning system.

As noted by industry team representatives, at the time of the first flight of BF-4, the F-35 avionics already had undergone "more than 100,000 hours of laboratory testing, including sensor-fusion testing in the program's Cooperative Avionics Test Bed, a highly modified 737 airliner incorporating the entire F-35 mission systems suite, including an F-35 cockpit. F-35 software has demonstrated remarkable stability, and sensors have met or exceeded performance predictions."

Identified general test objectives for BF-4 included providing data for mission systems Block 0.5 functionality in the F-35 flight environment, evaluating hardware and software implementation and integration, and providing data to support mission systems component development.

The Block 0.5 software incorporated important capabilities, including air-to-air search and synthetic aperture radar modes, identification friend/foe transponder, integrated UHF/VHF radios, electronic warfare radar warning receiver, and navigation functions. In November 2010, BF-4 flew with the upgraded Block 1 software installed.

Information from the aircraft sensors is presented to the pilot through state-of-the-art cockpit and helmet displays.

In addition to its onboard mission systems, the F-35 avionics also process and apply data from a wide array of off-board sensors based on the land, in the air, or at sea, enabling the jet to perform command-and-control functions while providing unprecedented situational awareness to air and surface forces.

And it is that synergistic combination of both onboard and off-board capabilities that mandates a new way of thinking about JSF.

According to Steve Weatherspoon, who has been with the Joint Strike Fighter program for more than a decade and is currently serving as F-35 U.S. Navy program manager at Lockheed Martin, "People tend to think of sensors in the classic mode of sensors operating aboard an airplane: You track it and you are able to shoot it. But our concept from the very beginning has been an integrated set of sensors that provide consolidated precision target coordinates that becomes part of the network – either shared in the network of JSFs or shared in the larger network in the theater."

Based on this unique approach, he stressed the importance "first, to fuse the diverse sensors that we have together into a single target; second, to give it precision coordinates; then third, to get it into an integrated tactical picture relative to the environment that can be shared throughout the battlespace."

Noting that "people have been 'chipping away' at some of these challenges for quite a while, with things like sensor handoffs from one sensor to another," Weatherspoon pointed to the unique F-35 ability to present an integrated display "that incorporates all of the EW, radar, and EO information into a single tactical picture.

"Now, we still have flexibility with our panoramic cockpit display, basically a single sheet of glass, to bring up individual sensors – primarily the EO sensors – for target interrogation and recognition purposes," he said. "But mostly, when the pilots start flying this they go to that tactical situation display and 'fight.' They are 'tacticians' rather than 'sensor operators' or 'airplane drivers.'"

He added, "Another interesting piece is that we have a pretty straightforward pilot/vehicle interface where we are able to bring a range of pilots into the simulators with this brand-new panoramic cockpit display, with helmet-mounted display, and with voice recognition. And within about a day-and-a-half we are able to bring them up to some pretty complex and high-threat scenarios to operate the system; scenarios that they would never even dream of bringing a legacy airplane into. And these pilots include backgrounds from U.S. F-22 pilots all the way to Turkish F-4 pilots."


Lockheed Martin Fort Worth photo

The F-35's sensors include the AN/APG-81 AESA radar, the Electro-Optical Targeting System (EOTS), the Distributed Aperture System (DAS), and other systems linked to the pilot through the HUD, panoramic multi-function display, and helmet-mounted cueing system (HMCS). Together with secure network links, the F-35 gives its pilots unmatched situational awareness.

Asked about the risk of pilot "information overload," Weatherspoon acknowledged, "There is always that risk. And, as a pilot, I am not going to say that we have got it totally solved until I see it flying and I see it operating in the real environment. But every indication and every tool that we have, including pretty high-fidelity simulators, indicate that they can do a good job with this."

In addition to establishing the capabilities for these "tacticians," as a node in the larger network the F-35 also shares information through multiple levels.

"Obviously, the first thing is fusing everything in the cockpit into a single integrated tactical picture, so you are not transmitting a bunch of raw data out," he explained. "Then the first 'level' that you transmit to is within your flight of aircraft of F-35s.

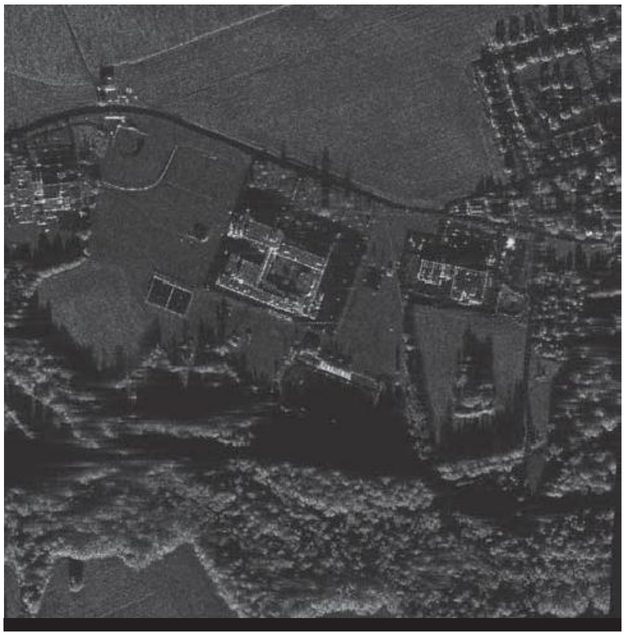
"We use the Multifunction Advanced Data Link (MADL) to provide that single integrated tactical picture across all of the airplanes in the flight," he said. "That's a low probability of intercept system. It's a brand-new design. We had to develop what is basically a 'stealth data link,' because when we are going into these high threat areas with our great stealth signature, we can't 'beacon' ourselves by transmitting information back and forth."

MADL was developed with partner Northrop Grumman.

"That first level compares with a modem with a high-bandwidth cable operation – it's got very high data rates protected with low probability of interception. You are able to near-instantaneously get a common picture across all four or eight or however many members are in the flight. For instance, only one aircraft pilot may take a SAR map, which is a very high-resolution radar image of a ground scene or target. That map can then be sent to all members of the flight. And those visual images can be 'pretty high bandwidth burners.' But the MADL has got the bandwidth to be able to take that and transmit it very quickly, so that with only one guy transmitting his radar, all members of the flight see the same radar picture. And they can stay silent, even further enhancing their stealth," Weatherspoon said.

"When you have that common operating tactical picture it is amazing how much less radio chatter there is," he observed. "You are able to send target assignments digitally across the data link. It is a very silent operation. You might think they have a secret radio communications device that they are using, but it really is quiet. Target assignments are all de-conflicted. Each member of the flight has their own assignments so they are not 'double hitting' the same target. And each member of the flight knows each other's status in terms of fuel, weapons, and position. That also means you are not constantly trying to determine the status of your wingman. It's visually shown for you on the panoramic cockpit display.

"As a result of that (data link display), we are able to fly much wider formations," he added. "I don't want to go too far into the tactics, but what has developed is that they are flying much more spread apart, which is a much more offensive positioning with that kind of dispersal while you are still able to provide full mutual support."



A synthetic aperture radar (SAR) image from the F-35's AN/APG-81 Active Electronically Scanned Array (AESA) radar. Because an AESA radar uses many small radiating and receiving elements rather than a single dish, sections of the radar can be devoted to different tasks. While the radar can produce high-fidelity SAR images of a target area, for example, it can also be working in an air-to-air mode.

Northrop Grumman image

He continued, "There's also a second level (of sharing information). Not every fight will have you 'going downtown' in the highest threat country in the world. So we are also able to integrate fully with legacy forces, primarily with the Link-16. We have a full transmit and receive capability with Link-16, so we can not only transmit our great picture from deep in enemy territory, but we can also receive pictures from legacy assets, such as Aegis, E-2, AWACS, and so forth.

"There are some beneficial outside capabilities here," he noted. "You have a long-range airplane like an F-35 with stealth capabilities allowing you to go places you have never gone before, which gives you the opportunity to draw all kinds of sensor information from deep inside enemy territory. And that 'non-traditional ISR' really contributes to the theater commander's common operational picture. In some cases he now will have 'eyes' where he didn't have them before. Now, you can either MADL that information out of the harm's way area or go direct Link-16 into an E-2 or an AWACS that can do a relay. And because of the power of the MADL itself, which is recognized by the Air Force, there are other plans to incorporate that into B-2, F-22, and other stealth assets."

One similarity between F-35 and other programs is the emergence of new and sometimes unanticipated tactics, techniques, and procedures as the platforms get into the hands of warfighters.

"We have a lot of former warfighters on the staff here that have a lot of experience in operating stealth airplanes in theater," Weatherspoon said. "In many cases, they can add a touch of realism. But they are former warfighters. So we actually bring in the current warfighters as well. And when they get their hands


The Electro-Optical Targeting System (EOTS) provides high-resolution imagery, automatic tracking, infrared search and track, laser designation and rangefinding, and laser spot tracking at more distant standoff ranges than typical today. The EOTS is integrated into the F-35's fuselage through a stealthy, low-drag, sapphire window, and with the electro-optical sensors of the Distributed Aperture System (DAS) forms the Electro-Optical Sensor System (EOSS) for the aircraft.

Lockheed Martin photo

on this flexibility and these tools we see many new things. They also bring in experience from subcomponent advancements in other legacy airplanes out there and how they use those. When we meld all of that together we get some new approaches. You will fight this airplane considerably differently than you fight a legacy airplane. And a lot of those differences have been identified by the warfighters and how they handle the aircraft."

He added that the program also benefits from the different service cultures and tactics that different users bring to the F-35 program.

"There is a lot of cross-feeding between the Navy, Air Force, Marine Corps, and international partners on this program," he said.

Although Weatherspoon emphasizes that the industry team is currently "focused like a laser on delivering what we call the final 'Block III' operational requirements document capability," he added, "When that is done, (the joint program office) recognizes that there are things that we learn in flight test or other things happening as we go along in this development program that should or could be added to the airplane. And hopefully we have the right architecture in place, with our very flexible computer architecture with C+ based programming, to be able to take on those additional capabilities."

As they are identified, those future capabilities are being incorporated into a JSF program office "Block development roadmap" and "capability decision tree."

While declining to address the specifics of any government planning, Weatherspoon pointed to "legacy programs" that have "'Blocks' of two-year or three-year update cycles. Those might incorporate a hardware upgrade, a software upgrade, or both. And we are looking at a similar situation that goes on beyond SDD.

"And much of the (Block) content that is voted on by the warfighters – and that's how it has been developed by the joint program office: input from the services – is associated with network capability and enhanced connectivity with other legacy forces," he added.

Reiterating the concept of "a node in the network," Weatherspoon said, "The F-35 is really so much different from just operating your sensor and then killing something with your AMRAAM. Almost anything out there has the potential to be a node in the network. And there are many platforms out there. But this is a lethal node in that network. If you have this netted operation of all of these sensors, and you start to bring them together like F-35 already does, you have one node out there that is carrying weapons.

"If you think of that network of diverse sensors out there, these are the ones that are deep in hostile territory for you. And wherever they are, they are providing a great sensor platform that is also armed and able to provide quick reaction strike on fleeting targets," he added.

"And the other part of that message involves the basing flexibility of that capability and this airplane," he concluded. "The Air Force airplane will provide numbers or aircraft on conventional fields. The Marine Corps STOVL, of course, provides flexibility with austere basing and amphibious class ships. And the Navy airplane enhances the unequalled capability, anywhere in the world, to put a nuclear carrier anywhere we want in international waters to drive deep with a long-range, catapult-launched, stealth airplane."

# ARMAMENT Digital, Not Dumb

BY SCOTT R. GOURLEY

Ferried to Edwards Air Force Base, Calif., in the first multi-ship, long-range F-35 flight on May 17, 2010, the primary role of AF-2 (F-35A) will be weapons testing. That testing will highlight the broad weapons capabilities designed into the Lightning II design.

"When JSF was envisioned, we were supposed to replace some platforms that were already out there in the inventory; primarily the F-16, the AV-8, and the F/A-18 A through D," explained Charlie Wagner, Weapons Integrated Product Team (IPT) lead for the Joint Strike Fighter program. "Because we were replacing them and taking on their missions, our initial weapons requirements were for everything that those three platforms already carried. So we had to be able to address everything from Vietnam-era conventional bombs up through what was, at that time, the latest and greatest in HARM (High-speed Anti-Radiation Missile)/Maverick/Harpoon-type weapons.

"(The Weapons IPT) actually came together back during the CDA (Concept Demonstration Aircraft) days – the concept demonstration timeframe – and worked with both Lockheed and Boeing to address what the work requirements were going to be in order to be able to carry all those different weapons on the airplane. And we worked with the contractors to figure out the best way to fit them all into a package that would fit on a jet," he added.

Photo by Senior Flight Test Photographer Andy Wolfe

According to Wagner, the biggest challenges facing the IPT in the early days involved trying to decide which weapons should be carried inside the jet in a weapons bay environment and which weapons should be carried on the outside.

"Some of the 'legacy' weapons that are currently on the F-16 and F-18 are pretty darn big weapons," he observed. "As examples, the 2,000-pound laser-guided bombs or the Harpoon and SLAM (Standoff Land Attack Missile) missiles are very large. And trying to figure out exactly which weapons we needed to fit into the airplane – and then build the airplane big enough for them to fit into it – and which ones were appropriate to carry on the outside of the plane were the big challenges in the beginning. We figured all of that out over time, based on which weapons fit which missions, which missions needed stealth, and which missions didn't. And that whole process helped us coalesce down to the list of weapons that we currently carry inside the airplane, while still keeping the capability to carry a collection of weapons on the outside of the airplane to suit missions that don't have to be as stealthy."

Asked about weapons-related issues emerging from early test activities, he noted, "There are two of them we are still working that we have been following since the early part of the program. The biggest one is the internal environment; the noise and the heat levels inside an internal weapons bay on a supersonic airplane are extreme. And weapons that were originally designed to be carried outside of an airplane and are now being carried inside of an airplane are definitely 'challenged' by both the thermal environment and the noise that we are expecting to see inside the plane. So we have done a lot of analysis early on, and we have got a little bit of test data, so far, but we expect to be getting a lot more test data to go and address that as we go forward.

"Another challenge we are looking at is something that the (F-22A) Raptor folks have already done, but we have to go and do all over again. And it involves rail launching from an internal weapon bay: being able to carry a missile, turn it on, and then stick it out into an air stream and rail launch it. That's not a simple thing to do," he said.

"Most of the weapons have not been designed to be carried internally on an airplane, so making them work there, and making that mechanization work, is something that we've been working on for a while and is something that we are going to continue to work on," he added. "We'll catch it eventually. We'll certainly get it done. It's been done on other platforms so we will work it out."

Along the way, the Weapons IPT has also worked with an evolution of user requirements.

Wagner recalled, "Early on in the program, after we down-selected to Lockheed Martin, we got together with all of our users and basically asked them, 'Are you serious? Do you really want us to carry all of this old Vietnam-era stuff?' And they went back and looked at their mission requirements again. That led to a process where they started weeding out some of the older weapons that they just never envisioned having to put on the airplane.

"We made a decision early on with the users that we were going to take the step into the 21st century and become an all-digital platform, so that we would only 'talk' to weapons that could 'talk' on what's called a Mil-Standard 1760 standardized digital interface. Because of that, some of the older legacy weapons dropped off, and they decided that we were not going to invest the money necessary to make the airplane compatible with those older weapons. That process was something of an evolution, where we started picking up some of the newer weapons – the JDAM (Joint Direct Attack Munition) family of weapons, the AMRAAM (Advanced Medium-Range Air-to-Air Missile), and the newer weapons that were compatible with that digital interface," he said.

"Also, as political times have changed, cluster bombs and things that might have been accepted with useful mission requirements back in the '80s or '90s are no longer in vogue,"

Lockheed Martin photo

OPPOSITE: F-35B aircraft BF-2 is shown after its first flight with weapons loaded (AIM-120 and GBU-12). The F-35B will have a smaller weapons load than the other two variants.

ABOVE: F-35A AA-1 with its weapon bays open, showing JDAMs and AMRAAMs.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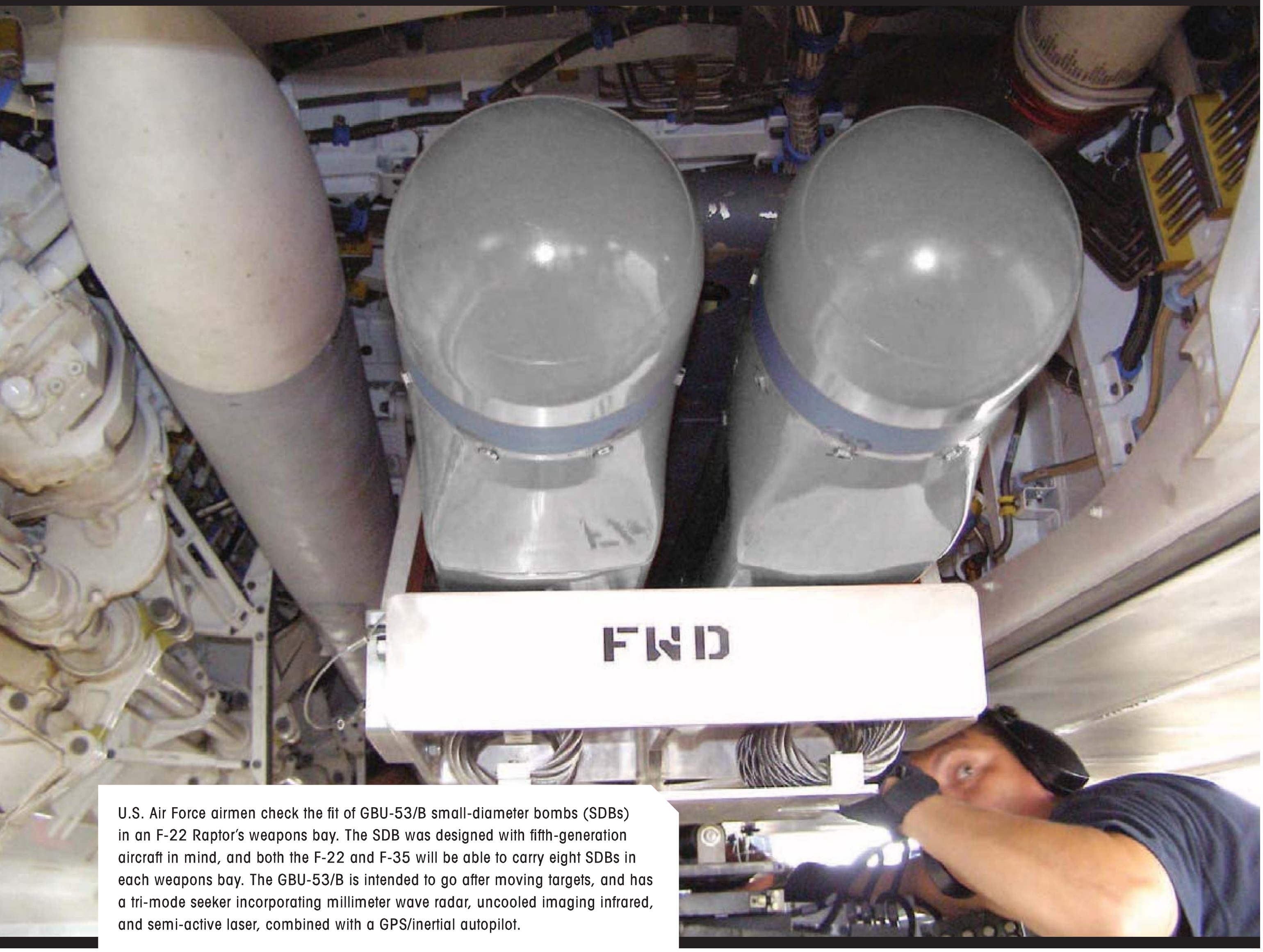


U.S. Air Force airmen check the fit of GBU-53/B small-diameter bombs (SDBs) in an F-22 Raptor's weapons bay. The SDB was designed with fifth-generation aircraft in mind, and both the F-22 and F-35 will be able to carry eight SDBs in each weapons bay. The GBU-53/B is intended to go after moving targets, and has a tri-mode seeker incorporating millimeter wave radar, uncooled imaging infrared, and semi-active laser, combined with a GPS/inertial autopilot.

Photo courtesy of Raytheon

he added. "So we are also getting rid of those and not worrying about putting them on the airplane."

As far as direct contributions to the warfighter in terms of weaponry, Wagner focused on the synergistic aspects of the entire platform.

"As far as the weapons on the airplane and looking with a myopic view of what the weapons bring to the airplane, we are really not bringing anything more than what the current legacy platforms are providing from a weapon-by-weapon basis," he began. "All of the weapon functions are the same on the JSF as they are on an F-16 or an F/A-18. That said, what we do bring, though, is the sensor suite and the mission systems capabilities that the airplane has. We have the integrated sensors, fusing all of the radar and the electro-optical (E/O) systems and displaying information to the pilot in a simplified manner on his helmet. All of that improves his targeting abilities, which makes the JSF system much more lethal than anything else. But that lethality is less a weapon function doing it than the overall weapons system that is making the improvements. It's the synergy of all of those subsystems."

Achieving that level of platform synergy has mandated close cooperation between the program IPTs.

"For example, on my weapons team, we are responsible for integrating and making sure that the weapons work properly on the airplane," Wagner noted. "So, from a government perspective, my team has people who look at aircraft software; at the hardware necessary to put it on the plane; at the different engineering disciplines to looking at loads and flutter and flying qualities; and at all the different aspects that a weapon carried on an airplane affects. And we go out and work, day after day, with the people who are developing the airplane to make sure that the weapons requirements have been properly factored into all of the different technical disciplines, to make sure that it all works."


CG-1, a ground test article for the Lockheed Martin F-35C carrier variant, is positioned for its final drop test at Vought Aircraft Industries in Dallas, Texas. The series of drop tests was designed to mimic landing conditions on a carrier deck and resulted in no load exceedances or structural issues. The photo provides a good view of the external weapon stations of the F-35C, which differ slightly from the two other variants.

Photo courtesy of Vought Aircraft Industries

He continued, "On the contractor side, because Lockheed Martin has total responsibility for the design of the airplane, they have actually gone out and subcontracted with all of the weapons suppliers that are currently going on the airplane. And they bring the ordnance organizations from Raytheon, Boeing, Lockheed Martin, and others and make them part of the team to interact with those weapon suppliers on a regular basis to make sure that the people that are developing the weapons and have the design responsibilities for the weapons are satisfied that we have properly factored their requirements into the airplane. So as we design the jet we have designed it with their approval that we will be providing a friendly environment for their weapons."

Looking toward the future, Wagner expects to see a continuing evolution of the weapons package and lethal capabilities for the platform.

"We have a group that is looking at future requirements – called our Air Systems Requirements Group – and they are constantly looking at: What's next? What new weapons are being developed? What new threats are out there? And then they try to determine what the best systems are for us to put into the airplane to counter those coming threats," he said.

"As far as the weapons packages, initially our first rounds of evolution are going to be to upgrade some of the newer weapons," he added. "In the industry, weapons evolve faster than airplanes do. And even though we have been trying to keep pace with that weapon evolution, in some cases we are still not up to the current standard with some of the new weapons that are currently being fielded on some of the other platforms. So we will upgrade to be compatible with the current evolution of weapons. And I expect that as we move forward, and when our pilots get their hands on this airplane and start seeing the capabilities that the full integrated JSF brings, that will start helping weapons evolution as well – to make them more compatible with the capabilities that the JSF is going to bring to the fight, so that warfighters will be able to take full advantage of what they have got.

"We are doing the best that we can to make sure that we are listening to the warfighters who are telling us what they want," he concluded. "We are taking their recent experiences in Iraq and Afghanistan and factoring those into what we are doing to try to give them the best and most relevant capabilities that we can. So that when they actually do get this airplane it will be something that they are going to want to fly and want to take into combat."

# AIRFRAME

BY SCOTT R. GOURLEY

F-35As will comprise the greatest number of airframes. Some of the aircraft's stealth shaping as well as the diverterless inlets are shown in this photograph.

Lockheed Martin photo by Matt Short

The F-35 Lightning II Joint Strike Fighter (JSF) emerged from the Joint Advanced Strike Technology (JAST) Program, which itself had been built upon a strong foundation of earlier technology exploration and concept developments (see "History, Concept, Design, Status" on page 56). That JAST concept demonstration phase had begun in early 1997. Although the name was changed to Joint Strike Fighter, early efforts had focused not on the development of a new aircraft but rather on the maturation of technologies that a new series of tactical aircraft could employ.

Program participants at the time recall that the big push during the concept demonstration phase had been on the development of the science and technology aspects of the demonstrator aircraft. Those efforts were also supported by parallel activities, such as a Composite Affordability Initiative that explored new and innovative ways of using composites on aircraft.

One resulting example of that innovative exploration can be found in the aircraft inlet ducts, which use composite stiffeners to save weight and enhance performance.

**WITH TODAY'S LIGHTNING II VARIANTS TAKING TO THE SKIES, IT MIGHT BE EASY FOR SOME TO OVERLOOK THE FACT THAT THOSE AIRCRAFT REPRESENT THE SUCCESSFUL COMPLETION OF THREE AIRCRAFT DEVELOPMENT PROGRAMS THAT WERE OVERLAPPING IF NOT SIMULTANEOUS. AS SUCH, THEY PROVIDE ICONIC EXAMPLES OF MYRIAD SUCCESSFUL TECHNOLOGY INVESTIGATIONS, COUPLED WITH COOPERATIVE DESIGN ACTIVITIES.**

The F-35B has the most unique capabilities of the variants, and has posed the most challenges. The B has a somewhat "humpbacked" fuselage shape aft of the cockpit due to the LiftFan. The canopy is also slightly different than the other two variants'.

Lockheed Martin photo by Andy Wolfe

Eventually, the synergies of the complementary development efforts allowed the migration of program focus toward "commonality" and "cousinality."

Those synergies are now reflected in the resulting series of stealthy, supersonic aircraft, featuring three variants designed to replace a wide range of aging fighter and strike aircraft for the U.S. Air Force, Navy, Marine Corps, and allied defense forces worldwide. A conventional takeoff and landing (CTOL) F-35A variant is the primary air-to-ground replacement for the Air Force's F-16 Falcon and the A-10 Warthog aircraft, and complement to the F-22A Raptor; the F-35B short takeoff/vertical landing (STOVL) variant is a multi-role strike fighter replacing the Marine Corps' F/A-18C/D Hornet and AV-8B Harrier aircraft; and a carrier-suitable F-35C variant (CV) provides the Navy a multi-role, stealthy strike aircraft to complement the F/A-18E/F Super Hornet.

Describing the terminology differences between terms like "commonality" and "cousinality," program participants acknowledge a greater degree of "commonality" between CTOL and STOVL variants – meaning that many parts are interchangeable/replaceable – but also point to unique design-driven requirements where that might not be possible. A bulkhead, for example, might be in the same location with the same attachment points, but performance mandates might call

The F-35C has much larger wing and tail surfaces for better controllability in the carrier landing environment.

Lockheed Martin photo by Tom Harvey

for a different size or thickness. Those instances reflect the "cousinality" piece – same basic materials or same basic structure.

And from an airframe standpoint, the maximum preservation of commonality and cousinality translates to cost savings.

Additional affordability traits have resulted from the planning and implementation of streamlined assembly methods across the industry team, where final assembly of the F-35 will take place at Lockheed Martin Aeronautics Co. in Fort Worth, Texas (which will also manufacture the forward fuselage and wings), and major subassemblies will be manufactured by Northrop Grumman Corp. in Palmdale and El Segundo, Calif. (mid-fuselage), and by BAE Systems in Samlesbury, England (aft fuselage and tails).

With today's Lightning II variants taking to the skies, it might be easy for some to overlook the fact that those aircraft represent the successful completion of three aircraft development programs that were overlapping if not simultaneous. As such, they provide iconic examples of myriad successful technology investigations, coupled with cooperative design activities.


The fourth production model of the F-35 Lightning II, conventional takeoff and landing aircraft AF-9, takes off on its second flight May 16, 2011, from Naval Air Station Fort Worth Joint Reserve Base.

Lockheed Martin Fort Worth, Texas, photo by Angel DelCueto

## F-35A Conventional Takeoff and Landing

The CTOL F-35A is a multi-role, supersonic stealth fighter that has extraordinary acceleration and 9 *g* maneuverability and agility. Equipped with tremendous processing power, open architecture, powerful sensors, information fusion, and flexible communications links, the F-35A is designed to be "a key net-enabling node in a system of systems" – an information gatherer and transmitter in a vast network. Its capabilities will make the F-35 an indispensable tool across the spectrum of any future conflict, from homeland defense to joint/coalition irregular warfare and major combat operations.

The F-35A internal weapons bay is reconfigurable for all modern air-to-ground ordnance, all U.S. air-to-air ordnance, or a blend of both. When stealth is no longer required to execute a mission, the F-35A external pylons can be loaded with ordnance, giving the aircraft a weapons payload of more than 18,000 pounds.

## F-35B Short Takeoff/Vertical Landing

The Lightning II industry team highlights the F-35B STOVL variant as "the first aircraft in history to combine stealth with short takeoff/vertical landing capability and supersonic speed. This distinction gives the F-35B the unique ability to operate from small ships, roads

| F-35A Conventional Takeoff and Landing | |
|---|---|
| HEIGHT (FEET) | 15 |
| LENGTH (FEET) | 51.1 |
| SPAN (FEET) | 35 |
| WING AREA (SQUARE FEET) | 460 |
| WEIGHT EMPTY (APPROX.) | 26,500 pounds |
| MAXIMUM WEIGHT | 60,000-pound class |
| INTERNAL FUEL (APPROX.) | 18,000+ pounds |
| SPEED | Mach 1.6+ (approx. 1,200 mph) |
| RANGE (INTERNAL FUEL) | ~1,200 nm |
| ENGINE | One P&W F135 or one GE F136 |
| ENGINE THRUST DRY | 25,000 |
| ENGINE THRUST (WITH AFTERBURNER) | 40,000-pound class |
| VERTICAL THRUST | n/a |
| INTERNAL WEAPONS | Typical:<br>2 air-to-air missiles<br>2 precision air-to-surface weapons<br>25 mm cannon |
| EXTERNAL WEAPONS | Variety; 15,000+ pounds on 4 hardpoints;<br>2 under-wing missiles |
| PAYLOAD VS. LEGACY | 1.4 X |
| RANGE VS. LEGACY | 2.5 X |

# We are flight ready.

**The Lockheed Martin F-35 Lightning II... unquestionably unique... and one of the most important military aircraft programs in history. Designed to satisfy the diverse needs of international air forces and navies around the world in the pursuit of freedom, the F-35 is emerging as the world's most advanced multi-role fighter ever.**

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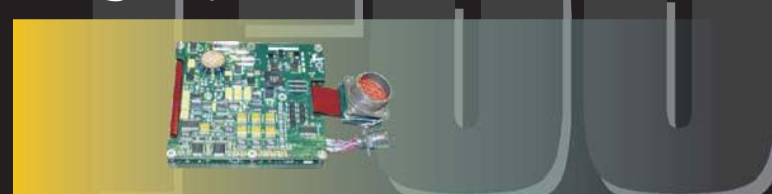


## ▶ Stores Systems

**Hamilton Sundstrand**

A United Technologies Company


The F-35B Lightning II short takeoff/vertical landing variant test program achieved its 100th vertical landing at Naval Air Station (NAS) Patuxent River, Md., on May 12, 2011.

Lockheed Martin photo

| F-35B Short Takeoff/Vertical Landing | |
|---|---|
| HEIGHT (FEET) | 15 |
| LENGTH (FEET) | 51.1 |
| SPAN (FEET) | 35 |
| WING AREA (SQUARE FEET) | 460 |
| WEIGHT EMPTY (APPROX.) | 30,000 pounds |
| MAXIMUM WEIGHT | 60,000-pound class |
| INTERNAL FUEL (APPROX.) | 13,000+ pounds |
| SPEED | Mach 1.6+ (approx. 1,200 mph) |
| RANGE (INTERNAL FUEL) | Approx. 900 nm |
| ENGINE | One P&W F135 or one GE F136 |
| ENGINE THRUST DRY | 25,000 pounds |
| ENGINE THRUST (WITH AFTERBURNER) | 40,000 pounds (Afterburner is not used in STOVL mode. Shaft-driven LiftFan augments engine's lifting force.) |
| VERTICAL THRUST (STOVL)* | 39,700 pounds |
| INTERNAL WEAPONS | Typical: 2 air-to-air missiles 2 precision air-to-surface weapons |
| EXTERNAL WEAPONS | Variety; 15,000+ pounds on 4 hardpoints; 2 under-wing missiles; cannon: 25 mm missionized, in stealth pod |
| PAYLOAD VS. LEGACY | (AV-8B Harrier) 2 X |
| RANGE VS. LEGACY | (AV-8B Harrier) 1.8 X |

and austere bases. The F-35B deploys near front-line combat zones, dramatically shrinking the distance from base to target, increasing sortie rates and decreasing the need for logistics support."

F-35B STOVL operations are made possible through the use of a patented shaft-driven LiftFan propulsion system that overcomes many of the temperature, velocity, and power challenges associated with direct-lift systems.

In addition, a reconfigurable internal mission bay allows for a dedicated weapons load of either air-to-air or air-to-ground ordnance or a blending to meet projected mission requirements. A missionized version of the 25 mm GAU-22A cannon is installed or removed as needed. When stealth is not required to execute a mission, the F-35B external pylons are loaded with ordnance, giving the aircraft a weapons payload of more than 15,000 pounds.

Significantly, the F-35B STOVL reflects the success of myriad cooperative design activities, such as the STOVL Weight Action Team (SWAT) initiative, which aggressively addressed early weight estimates through a combination of design and material solutions.

## F-35C Carrier Variant

The F-35C carrier variant, the U.S. Navy's first-ever stealth aircraft, will operate from the service's large carriers via catapult launch and arrested recovery. Larger wings and control surfaces and


The third F-35C carrier variant, aircraft CF-3, arrives at Patuxent Naval Air Station, Md.

Lockheed Martin photo by David Drais

| F-35C Carrier Variant | |
|---|---|
| HEIGHT (FEET) | 15.5 |
| LENGTH (FEET) | 51.4 |
| SPAN (FEET) | 43 |
| WING AREA (SQUARE FEET) | 668 |
| WEIGHT EMPTY (APPROX.) | 30,000 pounds |
| MAXIMUM WEIGHT | 60,000-pound class |
| INTERNAL FUEL (APPROX.) | 19,750 pounds |
| SPEED | Mach 1.6+ (approx 1,200 mph) |
| RANGE (INTERNAL FUEL) | Approx. 1,400 nm |
| ENGINE | One P&W F135 or one GE F136 |
| ENGINE THRUST DRY | 25,000 pounds |
| ENGINE THRUST (WITH AFTERBURNER) | 40,000-pound class |
| VERTICAL THRUST | n/a |
| INTERNAL WEAPONS | 2 air-to-air missiles<br>2 precision air-to-surface weapons |
| EXTERNAL WEAPONS | Variety; 15,000+ pounds on 4 hardpoints; 2 under-wing missiles; cannon: 25 mm missionized, in stealth pod |
| PAYLOAD VS. LEGACY (F/A-18) | 1.3 X |
| RANGE VS. LEGACY (F/A-18) | 2 X |

the addition of wingtip ailerons allow the F-35C pilot to control the airplane with precision during carrier approaches. Additional modifications include beefier landing gear and a stronger internal structure to withstand the forces of carrier launches and recoveries.

Representing "The World's Only 5th-Generation Carrier Aircraft," the F-35C introduces the first radar-evading stealth capability to a carrier deck in naval aviation history. Combined with its weapon systems integration, lethality, maintainability, combat radius, and payload, the F-35C is credited with bringing "true multimission power projection capability from the sea." In parallel with its lethality traits, the F-35C matches a fifth-generation survivability with major advances in network-enabled mission systems, reliability, and supportability to allow warfighters to dominate their adversaries on the first day of war.

As with the F-35B STOVL, the internal weapons bay is reconfigurable for all modern U.S. air-to-ground ordnance, all U.S. air-to-air ordnance, or a blend of both. In addition, a missionized version of the 25 mm GAU-22A cannon is installed or removed as needed and, when stealth is not required to execute a mission, the F-35C external pylons can be loaded with additional ordnance, giving the aircraft a weapons payload of more than 18,000 pounds.

## Ejection Seats

The development efforts behind the Lightning II have been supported by a powerful matrix of prime and subcontractor industry relationships. One good example can be found in the ejection seats, where Martin-Baker has been supporting the program from the early days of the JAST, when the company provided its US16B ejection seat on both X-32 and X-35 aircraft.

Noting that "both Boeing and Lockheed Martin competed the supply of the ejection seat which resulted in both primes independently selecting Martin-Baker on best performance/best value criteria," Martin-Baker representatives added, "For the System Development & Demonstration (SDD) phase of the JSF program, Lockheed Martin competitively selected the US16E to meet the JSF Contract Specification (JCS) escape requirements. The US16E is an ejection seat from the Martin-Baker Mk. 16 stable which has been developed specifically to meet the JCS requirements. The US16E provides the widest aircrew accommodation, and eight years of testing has demonstrated the greatest ejection performance of any ejection seat yet fielded. This has been achieved with affordability at the heart of an integrated modular design which demands that the life cycle costs and seat mass have been truly minimized, with one seat configuration to be installed into all three F-35 variants."

According to program descriptions, innovative solutions have been introduced to meet the challenging terrain clearance and neck injury criteria. The Multivariate Cases 1 through 8 are accommodated through seat bucket travel, whole seat tilt and seat-mounted helmet mounted display (HMD), and Life Support (LS) systems. The US16E is compatible with any torso style or Integrated (seat-mounted) harness. Lockheed Martin had selected the Integrated harness in order to minimize life-cycle cost as the Integrated harness will accommodate the entire aircrew range and has demonstrated the required restraint through test.

# Robust Stealth for Real-world Operations

BY JOHN D. GRESHAM

From the very beginning of the Joint Strike Fighter (JSF) program, one clear goal was to produce a stealty strike aircraft capable of operating from expeditionary land bases as well as aircraft carriers and large amphibious ships. Heat and ultraviolet light from the sun, rain and humidity, dust, and saltwater spray are going to be what the JSF will face during its career, and the stealth systems and coatings it will use had to be designed and developed to operate and survive in these harsh environments. These are hardly the near-pristine storage and maintenance conditions that were required during their service careers of the first-generation F-117A Nighthawks, which cost taxpayers a small fortune to operate and maintain. With plans to manufacture thousands of production F-35 Lightning IIs, creating a stealth system with similar low-observable (L/O) qualities to the F-117A, but with operations and maintenance costs similar to the F-16 and F/A-18 was a critical goal.

The first problem for the JSF designers was how to shape the new strike fighter, since more than 90 percent of radar cross section (RCS) is a direct result of shaping. This would also allow more of the airframe to be built of materials like aluminum, which is easier and cheaper to work than composites. To this end, the Lockheed Martin designers at the Skunk Works in Palmdale, Calif., and Fort Worth, Texas, fell back on the well-proven shape of their F-22A Raptor air superiority fighter. Several compromises had to be made, however, which would make the F-35 less stealthy as a B-2A Spirit or F-22A Raptor.

The first was the requirement for an Electro-Optical Targeting System (EOTS) under the F-35's nose, much like the system on the F-117A. The JSF AAQ-40 EOTS is based on the Lockheed Martin Sniper pod, and lives in a stealthy fairing beneath the nose composed of faceted transparancy panes much like the Nighthawk's cockpit. However, there is a limit to what designers can do with a "bump" like the EOTS with regard to RCS, and the EOTS turret is something of an RCS "hot spot" on the F-35. Another issue that drives the stealthiness of JSF is cost, or more specifically, the need to use a conventional engine exhaust rather than the more expensive two-dimensional "tail feathers" seen on the F-22A's F119 powerplants. The lack of any serious engine exhaust treatements on the JSF's F135 engine means an increased heat signature around the rear of the aircraft. Designers and developers, however, have done what they could to reduce both the RCS and infrared signatures of both.

That last 10 percent of RCS reduction is where the fiscal and manpower costs begin to spiral upward. Beyond a good (L/O) shape, making an airplane really stealthy is all about attention to the details. Every panel line, hatch opening, and door has to fit like like the back of a fine watch and be able to maintain that fit for the 20-plus years of the JSF's probable service life. Where possible, radar-absorbing structures and materials (RAS and RAM respectivly) are incorporated into the F-35 design, particularly along the wings and fuselage chine. And, like earlier Lockheed Martin stealth designs (A-12 Blackbird, F-117A, F-22A, etc.), there are the kinds of design tricks you expect to see from the legendary Skunk Works. For example, the radome allows the F-35's APG-81 active electronically scanned array's (AESA) outbound radar waves to penetrate but is impermeable to enemy radar waves.

**HEAT AND ULTRAVIOLET LIGHT FROM THE SUN, RAIN AND HUMIDITY, DUST, AND SALTWATER SPRAY ARE GOING TO BE WHAT THE JSF WILL FACE DURING ITS CAREER, AND THE STEALTH SYSTEMS AND COATINGS IT WILL USE HAD TO BE DESIGNED AND DEVELOPED TO OPERATE AND SURVIVE IN THESE HARSH ENVIRONMENTS.**

Another detail treatment in stealth technologies is the use of RAM coatings, putty, and tape. These have been specifically formulated to survive and operate in the harsh environmental conditions described without needed regular replacement or touch ups. Over sections of the airframe that rarely require access for maintenance personnel, often gaps in access panels and bay doors are sealed with RAM tape and/or putty before the application of paint coatings. This final finish is much tougher than that of earlier stealth designs like the F-117A and B-2A Block 10 aircraft, which had to be kept out of rain and direct sunlight to avoid degradation of their low-observable qualities. The result, however, is a stealthy fifth-generation combat aircraft that can operate under the harsh expeditionary conditions that have become the norm for the U.S. military. There is a price to be paid, of course, for this durability. In terms of metrics, the Air Force has described the F-35 as having the RCS of a metal golf ball, as opposed to a marble for the F-22A and a bumblebee for the B-2A Block 30. But combined with the backbone of stealth aircraft operations – proper route planning around radar and defensive sites – it is likely that the various models of the F-35 will be as successful and difficult to deal with as the pioneering F-117A was during its generation of service.

Lockheed Martin photo

An unpainted F-35C gives some idea of the various stealth materials and coatings used on the aircraft.

# POWER

BY JOHN D. GRESHAM

It is a basic tenet of mechanical engineering that any vehicle must have an outstanding powerplant to fulfill its full potential. Perhaps the ultimate example of this was the NA-73 fighter, originally created by North American Aviation (NAA) for the British Royal Air Force (RAF) in 1940 to help replace Spitfires and Hurricanes lost in the Battle of Britain. Created in just 102 days, the NA-73 was a fantastic design, capable of incredible performance at low and middle altitudes for RAF squadrons doing ground attack. But the World War II air war was being fought against Luftwaffe aircraft like the Bf-109G and FW-190, often waiting in ambush at high altitudes. The problem for the NA-73 was its anemic Allison V-1701 engine, which lacked a two-stage supercharger. For a time, it looked like the NA-73 would be an "also ran" in World War II, until the idea of fitting a better engine was tried. NAA fitted one of the NA-73s with a supercharged Rolls-Royce Merlin, which powered the Spitfire. The result was, perhaps, the greatest combat warplane of all time and the fighter that arguably saved American strategic bombing in World War II: the P-51 Mustang.

When the managers of the Joint Strike Fighter (JSF) program began to hand out development contracts in the 1990s, they did so with the knowledge that the first major subsystem that would have to work properly was the engine. Without a world-class powerplant, the three planned versions of the JSF would, literally, never get off of the ground. Furthermore, the production JSF engine would need to deliver a range of capabilities never before asked of a single family of fighter engines, and have to deliver the greatest power-to-weight ratio of any jet engine in history.

## Jet Engine Evolution

The JSF engine story really started in the late 1930s, when visionary designers like Frank Whittle of Great Britain began to envision the first generation of what would become jet airplanes. Piston engines with propellers as the means of powering aircraft were clearly beginning to hit their theoretical performance limits prior to World War II, and air force leaders around the world were already demanding planes with greater ranges and speeds. The answer, of course, became jet engines, which take in air at the front of the engine, mix it with fuel, combust the mixture, and then expel the greatly enlarged mass of gases out of the rear of the engine with great speed and force, or thrust.

Those early jet engines of the 1940s and 1950s were wondrous creations to the aircraft designers of the era, and top speeds jump from about 500 miles per hour (mph) to more than 1,400 mph in just over a decade. But those first- and second-generation turbojets also had their vices, especially in combat. Evolved second-generation turbojets like the classic Pratt & Whitney (P&W) J-79 that powered the F-4 Phantom and Lockheed F-104 Starfighters smoked badly, even when out of afterburner. In addition, their fuel consumption proved to be a major factor in planning combat operations, limiting range and engagement time over targets, even with robust airborne tanker support as in Vietnam. These shortcomings had engine designers going back to the drawing board to design a new generation of fighter engines: "fighting turbofans."

Turbofan engines are similar to turbojets in principle, but have a much higher air-to-fuel ratio, usually with a larger central core fan section. In addition, turbofans use significantly more air than turbojets, diverting much of it through what is called "bypass," allowing more complete burning and higher combustion temperatures at the rear of the powerplant. This means that turbofans are much more efficient in how they burn fuel, and thus do not smoke as much. This is why airlines immediately picked turbofans to power the first generation of commercial jumbo jets in the late 1960s, and why fighter designers wanted them in tactical aircraft designs. Making a turbofan into a suitable fighter engine was a more difficult problem for designers, but by the late 1960s american engine manufacturers were able to offer first-generation high-bypass engines with afterburners like the TF30 and F100 for third-generation fighter designers of aircraft like the F-14 Tomcat, F-15 Eagle, and F-16 Fighting Falcon.

This is not to say that these first-generation fighting turbofans did not have their problems. On the contrary, the very qualities that make turbofans desirable from a power and efficiency point of view also make them difficult to operate and maintain. One particular problem with fighting turbofans is that they tend to stall or "flame out" as they transition between subsonic flight and about Mach 1.4, which can be disastrous in a close-turning dogfight. Eventually, refinements from engine manufacturers overcame these problems and led to the installation of systems like Full Authority Digital Engine Control (FADEC), which made turbofans into the fighter engines of choice in the 1980s and 1990s. These second-generation fighting turbofans, like the F100-PW-229 and F110-GE-129, could deliver almost 30,000 pounds of thrust in afterburner across the full range of possible flight conditions, without a significant risk of stall or other malfunction. In addition, they would provide the basis for the next generation of turbofan engines for fighters when a new capability would be needed: stealth.

## F-35 Engine Origins

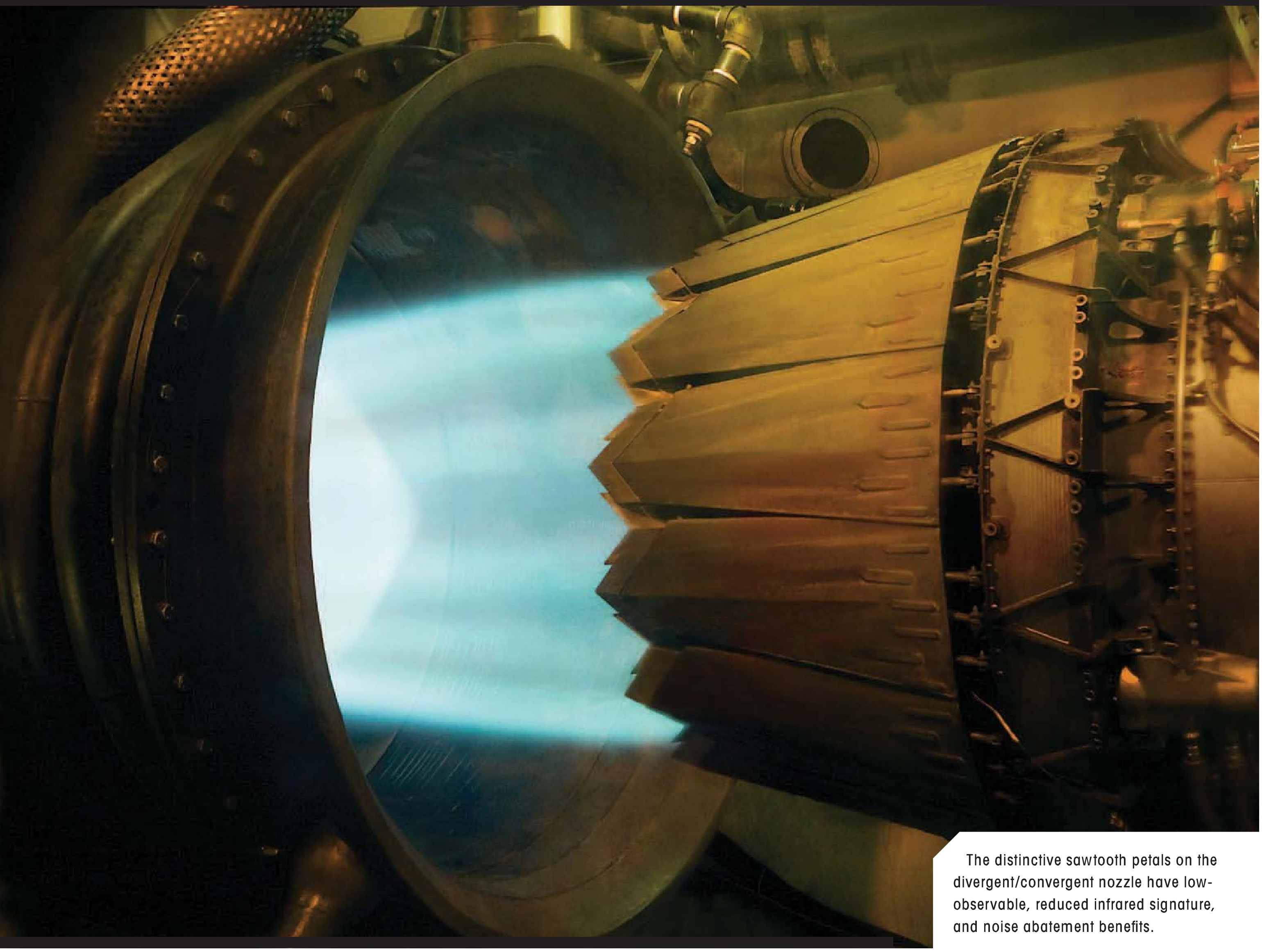
Beginning with the Lockheed Martin F-117A Nighthawk, turbofan engines with stealthy characteristics became a real issue for aircraft designers around the world. While the engines for the Nighthawk were modified F404-F1D2s from the U.S. Navy (USN)/U.S. Marine Corps (USMC) F/A-18 Hornet strike fighter program, the obvious desirability of third-generation fighting turbofans that could power fifth-generation stealth combat aircraft made their creation inevitable. The first such effort was the Advanced Tactical Fighter (ATF) program, which eventually resulted in the Lockheed Martin F-22A Raptor air-supremacy fighter.

The ATF was a true "fly-before-buy" competition, with actual "head-to-head" competition not only with flying prototype aircraft, but engines as well. In the case of the ATF competition, the engine "fly-off" came down to the P&W F119 and the General Electric (GE) F120. Both engines were designed to an ambitious and challenging set of standards, including:

- **Stealth** – Both engines were required to minimize the radar and infrared signatures of the ATF prototypes. This was done


Lockheed Martin photo by Damien A. Guarnieri

The STOVL system of the F-35B, with a shaft-driven LiftFan, three-bearing swivel nozzle, and roll-posts together providing more than 40,000 pounds of thrust in the hover, is a major achievement.



The distinctive sawtooth petals on the divergent/convergent nozzle have low-observable, reduced infrared signature, and noise abatement benefits.

GE/Rolls-Royce Fighter Engine Team photo

through the use of specially designed engine ducts on the ATF prototypes, along with two-dimensional exhaust nozzles.

• **Power** – Both ATF prototype engines expanded on the work done by P&W and GE on the earlier 129-/229-series fighting turbofans, the resulting powerplants delivering around 35,000 pounds of thrust in afterburner. Even more impressive, however, was the ability of the ATF prototype engines to deliver enough trust to allow both ATF fighter prototypes to cruise supersonically at up to Mach 1.72 without afterburning.

• **Agility** – As good as the second-generation fighting turbofans have been in combat since 1979, the ATF program was committed to producing a fighter with qualities that would put even the newest fourth-generation fighter designs to shame. Both ATF engine designs provided vastly improved power and throttle response than second-generation turbofans, with significantly better fuel efficiency. These new third-generation fighting turbofans allowed a new level of fighter maneuverability, literally known as "supermaneuverability," easily making the ATF the best close-in dogfighter in the sky.

Both prototype engine designs delivered on the ATF specifications, and the winning design, the P&W F119, is in service today with the F-22A fleet. But even before the first squadron of Raptors came online, engine manufacturers were looking forward to a third-generation fighting turbofan engine procurement that would dwarf the ATF program in size and numbers: the engine for the Joint Strike Fighter.

Technology never really stands still, and as good as the engines from the ATF program were, there was still room for improvement. In 1986, engineers at Lockheed were beginning to look at the possibilities of creating a new stealthy short takeoff/vertical landing (STOVL) strike fighter for the USMC that could replace the AV-8B Harrier. Realizing that they would need a new engine capable of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powering the new aircraft not only at supersonic speeds but also in a hover configuration, Lockheed turned to P&W to design an engine to drive its concept aircraft. This research and development effort became part of the Defense Advanced Research Projects Agency's (DARPA) Joint Advanced Strike Technology (JAST) program, which eventually evolved into the JSF.

From the very beginning of the JAST/JSF programs, engineers and designers knew that their new fighter engine was going to need to be a classic from day one. The simple fact was that more was being expected of the new engine than any aircraft engine in history, and these multiple features and performance expectations would need to be delivered a decade before the first production U.S. Air Force (USAF) F-35A Lightning IIs entered service on the steamy ramps at Eglin Air Force Base (AFB), Fla. These included:

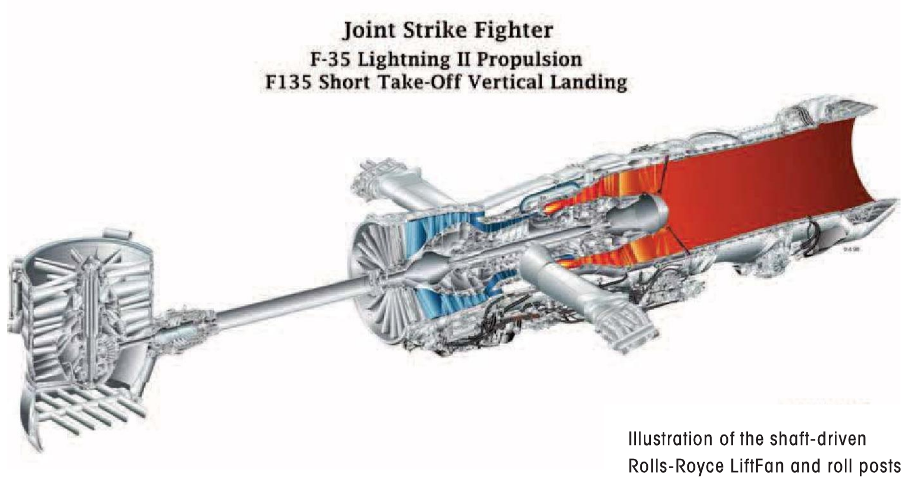


Illustration of the shaft-driven Rolls-Royce LiftFan and roll posts attached to the F135 engine.

• **Stealth** – The JSF engine would power a state-of-the-art fifth-generation fighter bomber, with a stealth configuration exceeded only by the B-2A Spirit bomber and F-22A Raptor fighter. The JSF aircraft/engine designers did this by building on the basic technology of the Raptor, which was designed by Lockheed to operate without any moving/variable inlet ramps or active airflow modification devices. The present-day F-35 does this through an elegantly designed fixed inlet design that takes the air at any speed and angle of attack from stall to Mach 2, and delivers it to the first-stage fan in a configuration that allows the FADEC system to accept the airflow. It does this without ever allowing enemy radar to "see" the first-stage fan, and actually acts as part of the JSF's overall stealth package.

• **Power** – The JSF engine needs to deliver more raw power, in both military power and afterburner, than any other fighter engine in history. It also needs to deliver all this power across a wider range of aircraft/flight configurations and conditions than any new aircraft engine ever has. This would include eventually being rated at more than 50,000 pounds of thrust.

• **STOVL Operations** – The unique STOVL operating requirements of the USMC, RAF, and other overseas JSF clients meant that the JSF engine actually had to deliver power to the F-35B version through both the rear nozzle and a unique Rolls-Royce LiftFan in the middle fuselage. In this configuration, the engine version delivers almost half of its power to a clutched shaft, which then feeds power to the fan. This system delivers more than 41,900 pounds of thrust in a hover configuration, with the LiftFan system producing upward of 20,000 pounds of thrust alone. This will allow an F-35B to bring back two AIM-120 advanced medium-range air-to-air missiles (AMRAAMs) and two 1,000-pound bombs for recovery with adequate fuel for divert contingencies.

• **Reliability/Efficiency** – Like all fighter engines, the JSF powerplant was designed to be the best possible balance of reliability and efficiency. From the very beginning, the JSF specification mandated vastly improved reliability and efficiency ratings from the engine designers than had been required for the earlier ATF engine competition that resulted in the F119 used in the F-22A. This meant that the engine had to be capable of delivering the required numbers in both areas, while also meeting service requirments for operating costs and maintainability.

• **Costs** – No 21st century combat aircraft is going to succeed if it does not give maximum value to air forces and taxpayers alike. To that end, the JSF engine family has been designed to be as fuel efficient and reliabile as technology allows. In addition, commonality across all versions of the powerplant should ensure the lowest possible procurement costs for repair parts and components across the entire F-35 fleet worldwide. Also designed into both the F-35 and the engine are the easiest possible access and installation/repair procedures possible.

With all of these challenges defined in the JAST/JSF specifications, the P&W design team had its work cut out for it. The P&W concept engine, originally called the "F100-229 plus" demonstrator, used components from a variety of existing designs, including the new F119 stealthy turbofan designed for the F-22A Raptor, and the existing F100-220/229 engines used on the F-15 and F-16. The F136, developed by a GE/Rolls-Royce team, was also being developed as an optional engine, on a later timescale. Unlike the F135, the F136 was an all-new design. Accommodations had to be made to fit both powerplants into a common engine bay configuration being designed for the JSF, which was included in both prototype aircraft configurations being produced by Lockheed Martin (X-35) and Boeing (X-32).

The F135 engine family powered both JSF prototypes during their competitive fly-off. The new powerplant proved to be a worthy match to both designs, and was selected to become the

Pratt & Whitney image

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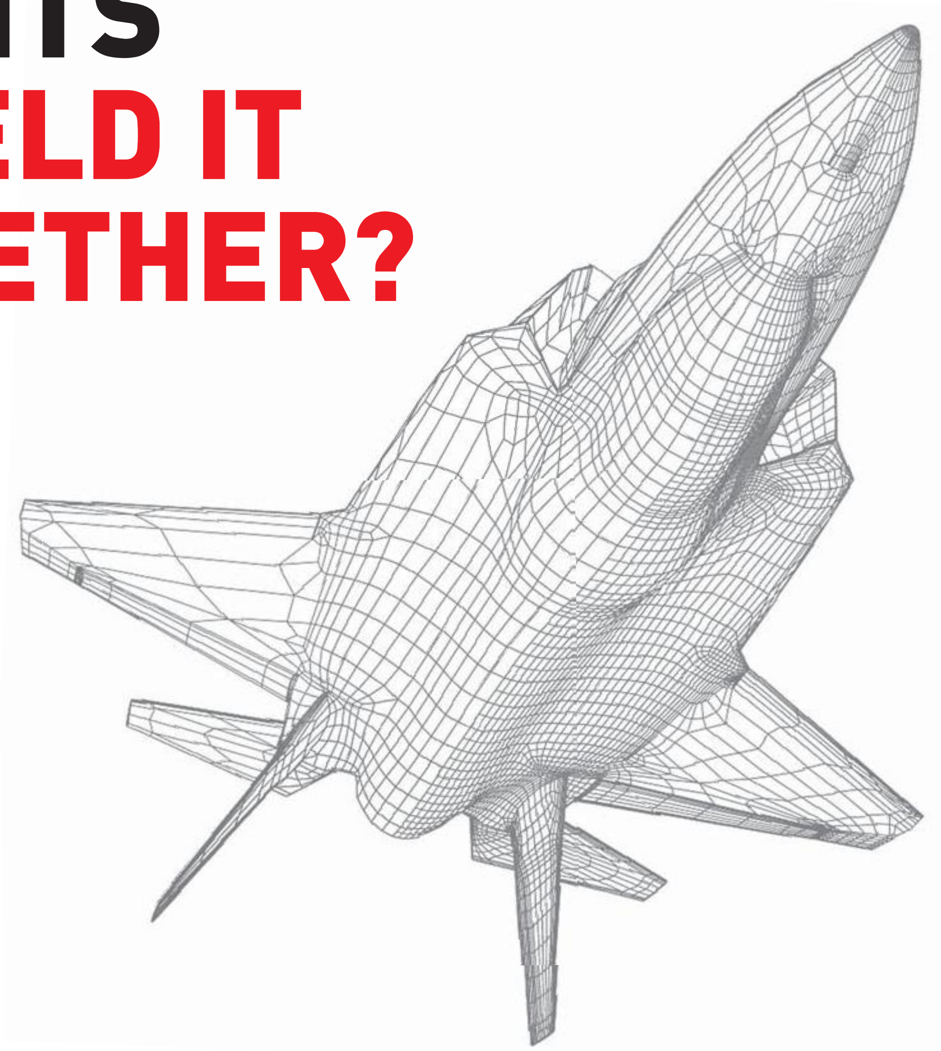
# 14 YEARS OF WORK
# 13 TEST AIRCRAFT
# 9 GOVERNMENTS
# 3 VARIANTS
# WHAT HELD IT ALL TOGETHER?



The F-35 brings together a staggering array of innovations and collaborators. We're proud to be among them. From the very start our structural bonding technologies enabled new design efficiencies. Since first flight, we've been in lockstep with our partners, bringing on board lessons learned. Now the ultimate test, production. An engineering marvel is ready for the hard realities of economic manufacture, each strike fighter held together by more than 50,000 Click Bond components. Our fastener products save over 5,000 manufacturing hours per aircraft while enhancing durability and airframe longevity, reducing life cycle cost. Congratulations on first delivery. Onward and upward.

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An F-35A with afterburner lit. Development examples of its engine have put out more than 50,000 pounds of thrust.

Lockheed Martin photo

production engine for the new Lockheed Martin F-35 Lightning II. Today, the first F135s are being delivered to the USAF's 33rd Fighter Wing at Eglin AFB.

## Engine Variants

The F135 family of true third-generation turbofan fighter engines is likely to see service well into the second half of the 20th century. The current configurations break down this way:

• F135-PW-100 – This is the basic afterburning version of the F135, which will be used on the conventional takeoff and landing version of the F-35A.

• F135-PW-400 – The -400 series F135 engines will power the carrier-borne variants of the Lightning II, the F-35C.

• F135-PW-600 – This is the LiftFan version of the F135, which will power the STOVL F-35Bs.

Presently, production F135s are rolling off the P&W assembly line and are among the most trouble-free subsystems of the entire JSF program. Despite the impressive requirement that was part of the original JAST/JSF requirement, the engineers at P&W have thus far met every challenge presented to them. In addition, further development of the F135 continues today, to deliver even more thrust to the F-35 family of strike fighters, along with improved reliability and reduced procurement and operating costs. Already the goal of a basic "flyaway" F135 engine with costs lower than the much more mature F119 is within sight.

Engineers and designers across the globe are likely looking at variants of the F135 for applications ranging from powering the next generation of unmanned aerial vehicles (UAVs), to maritime/public utility power generation. Already, in the world of combustion engineering, the F135 has become an icon for highly evolved gas turbine powerplants, taking its place among the great engines of all time.

# F-35 INTEGRATED TRAINING CENTER

BY SCOTT R. GOURLEY

Located at Eglin Air Force Base, Fla., the F-35 Integrated Training Center (ITC) is a first-of-its-kind facility that will provide initial training for the next generation of both pilots and maintainers for 13 military branches across nine countries. As with other aspects of the Joint Strike Fighter program, the ITC has emerged against a background of affordability benefits.

**"WE HAVE TRIED VERY MUCH IN OUR CONCEPT HERE TO USE THE SAME KINDS OF TOOLS AND THE SAME TYPES OF PROCESSES AS MUCH AS POSSIBLE ACROSS BOTH PILOT AND MAINTAINER SIDES. AGAIN THAT'S FOR AFFORDABILITY, BECAUSE IF THERE ARE EVER ANY AIRCRAFT CHANGES COMING OUT THEY WOULD AFFECT THINGS ON BOTH SIDES."**

### F-35 Training Concept

"Eglin Air Force Base was picked by Congress – it came out of the BRAC (Base Realignment and Closure process) – to be the Joint Strike Fighter Integrated Training Center," explained JoAnne Puglisi, director of F-35 programs at Lockheed Martin Global Training and Logistics. And what that entailed was that all three (participating) U.S. services – Air Force, Navy, and Marine Corps – would have squadrons there as part of the training group.

"The other big concept that we – Lockheed Martin – had proposed in an Integrated Training Center was to bring maintainers into the same infrastructure and facility as the pilots, to leverage long-term affordability," she said. "So that also came through, that all the services and partner nations would train their maintainers at the facility. So it is 'one of a kind,' and will be what we call the F-35 Master Training Center.

"The system has been designed so that the training can be integrated," she noted. "You can put pilots and maintainers together to train together in a facility infrastructure. Or you can separate them out with a pilot training center at one location and a maintenance training center at another. The architecture in the whole system has been designed to accommodate all possibilities of the U.S., our partner nations, and future FMS (Full Mission Simulators)countries and customers."

Offering the integrated ITC approach as the critical foundation for affordable life-cycle training, she began, "As we work through the program over the years and the program grows, this will be 'the pinnacle of the triangle,' what we call the 'Tier 1,' that will have everything in its responsibility – all the maintenance training, pilot training, and everything that's common.

"Then, as the program grows, we get down to what we call our next tier, 'Tier 2,' which will include other pilot training centers, other maintenance training centers, or other integrated training centers around the world," she said.

"'Tier 3' is what we call the operational bases. When you graduate from a training command you leave and go to some operational squadron, where training has to continue for both pilots and maintainers. Maintainers continue to do on-the-job training to stay current in the system. Pilots also do 'currency training' to keep them current in the system. So that's 'Tier 3' and we have trainers that will be going to the operational squadrons for that," she added.

### Simulators

"On the 'pilot side' right now, both at Eglin and at these operational bases, we will have a suite of what are called Full Mission Simulators, which features a 360-degree dome. And we also have a Deployable Mission Rehearsal Trainer (DMRT), with two cockpits in a mil-van. They are the exact same cockpits, exact same software, and exact same instructor/operators stations, except things have been 'condensed.' In other words, instead of having three or four screens at the instructor/operator station, there is one; and instead of having a large 360-degree dome, it is a smaller dome with smaller field of view," she said.

"The DMRT helps because it can be deployed on a ship – a carrier or an LHD for any of the services or partner countries," she noted. "Or, if one of the smaller partner countries doesn't have a big facility to install the bigger FMS, you can put in these.


Northrop Grumman has delivered the first round of F-35 courseware that classroom instructors at the Integrated Training Center, Eglin AFB, Fla., will use to teach pilots how to fly the F-35 and aircraft maintainers how to support and repair the jet. In the photo, Northrop Grumman F-35 instructional system designer Shirley Grimaldi (front) finalizes courseware lesson plans in collaboration with pilot subject matter experts George Ross (left) and Jabus Hamm.

Northrop Grumman photo

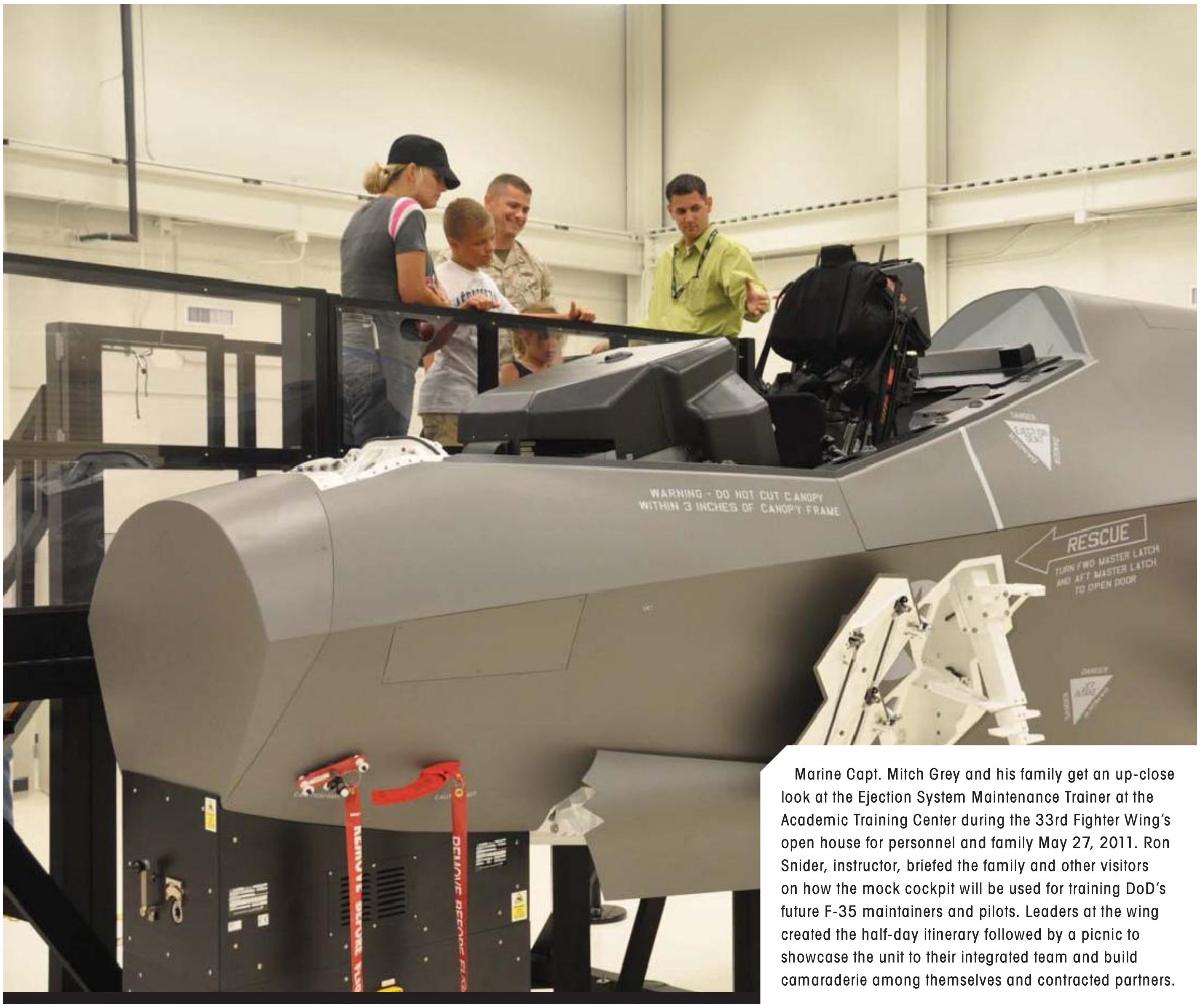
The mil-van can handle the outside environment so you would just need power and you could put it on a 4-inch concrete pad. But it gives you the same capability with software and cockpit. The only difference is the field of view display, which is obviously limited when you go into a mil-van.

"On the maintenance side, the maintenance trainers at Eglin will include a Weapons Loading Trainer (WLT), where we have all three aircraft variants split, because there is a difference in the wingspan between the CV and the CTOL (conventional takeoff and landing) and there is an internal difference between the STOVL (short takeoff/vertical landing), the CV, and the CTOL. So we combined it into one large trainer, where one side had one aircraft configuration and the other side had the other two. Again, that goes to the bottom line on this program, which is affordability. We also have an Ejection System Maintenance Trainer (ESMT), which is a full-sized, front portion of the aircraft, where we teach the maintainers to remove and replace the canopy and the ejection seat. And we also have the pilots use it to learn how to ingress and egress the aircraft. So again it is multifunctional and again it was for affordability reasons. The third maintenance trainer we have is an Aircraft Systems Maintenance Trainer (ASMT), which is a traditional classroom of 12 stations with screens of desktops. And on one side you will have ASMT 'systems,' with graphics, videos, and touch points. It will tell you to go and select pieces of support equipment. You will run through the procedures for a maintainer to learn how to maintain the jet. The students will also use the actual Portable Maintenance Aid (PMA) that is used on the aircraft. They will use the actual PMAs to learn how to log onto the system; how to use the joint tech data loaded on there; and how to interface and do the aircraft maintenance on these other screens. So he is beginning to use all of the procedures and tools as if he was out on the real aircraft."

## Academic Challenges

In planning the training architecture, Puglisi said that the ITC concept attempts to employ the same tools, processes, and procedures – classroom instruction, simulators, hands on aircraft – that both pilots and maintainers will encounter throughout their time with F-35.

"We have tried very much in our concept here to use the same kinds of tools and the same types of processes as much as possible across both pilot and maintainer sides," she said. "Again that's




Marine Capt. Mitch Grey and his family get an up-close look at the Ejection System Maintenance Trainer at the Academic Training Center during the 33rd Fighter Wing's open house for personnel and family May 27, 2011. Ron Snider, instructor, briefed the family and other visitors on how the mock cockpit will be used for training DoD's future F-35 maintainers and pilots. Leaders at the wing created the half-day itinerary followed by a picnic to showcase the unit to their integrated team and build camaraderie among themselves and contracted partners.

U.S. Air Force photo/Chrissy Cuttita

for affordability, because if there are ever any aircraft changes coming out, they would affect things on both sides."

In terms of unique curriculum challenges, Puglisi observed, "Pretty much, 'a pilot is a pilot.' Each country may employ the aircraft slightly differently – the mission of the CV variant for the Navy versus the mission of the CTOL variant for the Air Force or the STOVL variant – but the basic pilot missions are the same, with some tailoring. At the training command at Eglin we will teach all of the common approaches so they will get the opportunity to learn across the different services. Then, when they go to their operational squadrons or the partners go home, that's when they will tailor their uniqueness for their specific countries, missions, or requirements.

"Now, our biggest challenges were on the maintenance side," she acknowledged, "because obviously each of our services and the partner nations do not all have the exact maintainer situation. In other words, not everyone will have all maintainers with 12 different skill sets. Some may have four or five but organize their maintenance differently. So, for all intents and purposes, a 'structures guy' in one service is not necessarily a 'structures guy' in another service, because of different skill sets that the services have in their maintenance communities. As a result, what we did on that – again for affordability – was develop the training materials at the absolutely lowest possible level, for courseware and training materials, and then all we do is take each of those pieces of the puzzle and restructure them for each of the services' skill sets. So let's say a structures guy in one service does 15 tasks but in another service they may do 12 of those plus some from avionics or somewhere else. So what we do is re-map and pull all those pieces together to give them the unique aspects of each of the service skill sets. We aren't starting 'bottoms up' and generating everything new."

## Current Status

"That's been it for the past nine years," she noted. "We started with the contract award in October 2001 and we have been

The first Full Mission Simulator (FMS) was delivered to Eglin AFB in April 2011. Each F-35 base will also have an FMS, which can simulate all of the three variant aircraft.

Photo courtesy of Lockheed Martin

building it up for the different variants, working with the services on the pilot and maintenance sides.

"This past year, we opened our doors and began to operate at Eglin," she added. "The first Mission Rehearsal Trainer (MRT), which has the exact same cockpit and display system as the DMRT (you can take one cockpit and display system out and put them into a regular classroom), arrived in March 2010 in the pilot classroom at Eglin. And we started going through an evaluation of all of its courseware, training devices, and instructors material, because it was anticipated that the (first two LRIP) aircraft would be here and we wanted to make sure that we were down here and operational before the aircraft arrived. So it is there. It is running and operating and we have the pilots who have been assigned to the squadron running through all that material."

The initial training infrastructure took shape in "temporary" facilities at Eglin, while awaiting completion of a new Academic Training Center building.

"The brand-new Academic Training Center was just turned over to us for 'partial building occupancy' on Oct. 18, (2010)" Puglisi noted. "That new center was a very large military construction project that started almost two years ago."

Lockheed Martin delivered the first Full Mission Simulator to Eglin in April 2011, where it will reside in the Academic Training Center after reconstruction.

"The maintenance trainers are also going through their final testing right now and they will start being torn down and shipped to the Eglin site," Puglisi added. At the begining of 2011, training began migrating "into the brand-new Academic Training Center – getting the trainers in, getting the classrooms equipped, and moving all the people in – and start running through what we call small group tryouts. That's a task where we bring in our instructors and the first group of government instructors to run through all the materials and equipment, making sure that everything is linked and connected to teach the guys how to use the system before we actually bring the first student through the door. So we should be ready by the time the aircraft arrive there, next summer (2011) or late next fall, to be fully operational for both the pilots and maintainers.

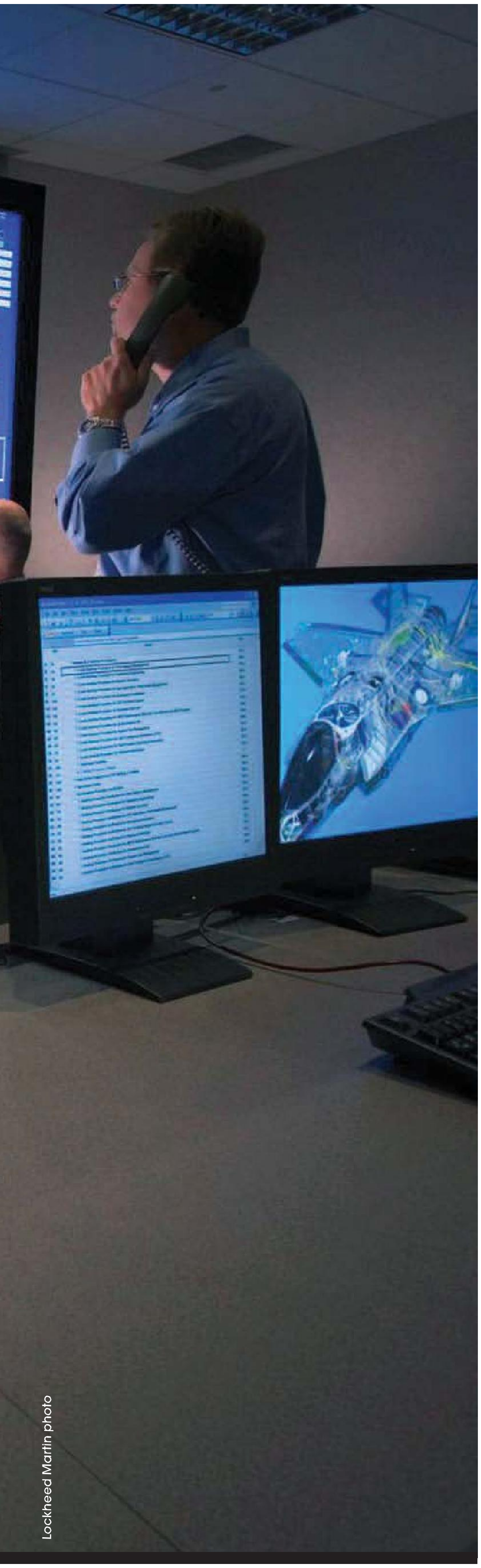
"The maintainers were never planned to be operational this year," she noted. "Lockheed Martin had been planning on using Contractor Logistics Support (CLS) to maintain the jet for the first two years. So we did have the pilot system ready down there if the aircraft had been coming in 2010. But the plan was always to have maintenance only in the new building, because those trainers are so big there were no temporary facilities to put them in."

Summarizing the status of the training infrastructure, she concluded, "Everything is still on track. Right after the first jets, the LRIP 2 and LRIP 3 jets will be coming, as they come off the production line. We wanted to make sure that once the jets got there we would be ready. So we have not stopped anything on building up our training system capabilities at Eglin."

# F-35 SUSTAINMENT

BY SCOTT R. GOURLEY


The Autonomic Logistics Information System gives F-35 operators the ability to plan ahead, maintain, and sustain its systems over the life of the air vehicle.



Lockheed Martin photo

As might be expected from a program as thoughtfully developed as the Joint Strike Fighter, the operational success of the myriad integrated technologies has been assured from program beginnings by a carefully crafted logistics sustainment enterprise.

That critical system is called Autonomic Logistics Global Sustainment (ALGS).

"Sustainment for F-35 began with the concept for the aircraft," explained Kimberly Gavaletz, Lockheed Martin F-35 vice president for Global Sustainment. "We call it an air system. It's not an air vehicle and a separate sustainment system. It's an air system, because sustainment was designed into the aircraft itself. It is completely integral to the aircraft and how it is going to operate through its life."

The five component parts of the ALGS include: the aircraft itself; the training systems for both pilots and maintainers; an integrated information system – called Autonomic Logistics Information System (ALIS) – covering the aircraft from the time it leaves the factory until eventual decommissioning; an integrated support system; and an integrated business approach.

"Underpinning all of those elements is a business approach where, for F-35, you are really buying a service," Gavaletz said. "You want availability and you want it tied to the warfighter. So what does the warfighter need? They need availability of that aircraft when they need it. So this is a set of aligned expectations/requirements not just from when the aircraft is being built but through its operations; signing up for what performance that warfighter needs and then going through the Joint Program Office and being put on a contract to Lockheed Martin and our teammates and suppliers to deliver that level of performance.

"What all of this really gives you is insight that you have never had before into costs and a long-term ability to not only get supportability but also affordability to the aircraft," she said. "And this solution brings 'best value' because supportability was designed into the F-35 from the very beginning. It gives you the capability to lower the life-cycle costs because you see all those different elements – from supply to how the training is working to the support solutions. The integrated information system ties all of that together so we can then go through our business processes to reduce the life-cycle costs throughout time."

**"WHAT ALL OF THIS REALLY GIVES YOU IS INSIGHT THAT YOU HAVE NEVER HAD BEFORE INTO COSTS AND A LONG-TERM ABILITY TO NOT ONLY GET SUPPORTABILITY BUT ALSO AFFORDABILITY TO THE AIRCRAFT."**

She credited much of the design success to the strong partnerships that exist between warfighters, the Joint Program Office, the service maintainers, and down throughout the Lockheed Martin-led "Team JSF."

"And this is being developed concurrently, not only on the technical side but also the business processes and relationships that have been established for the long term to support this aircraft more affordably," she noted.

Multimedia Production Analyst Senior/Senior Aerial Photographer Michael D. Jackson

Emphasizing the need for this sort of affordability mindset, Gavaletz pointed to the challenges represented by current aircraft inventories, in which significantly increased operational tempos (OpTempos) are increasing traditional operations and support costs and lowering reliability in the face of decreasing budget availability.

"But this F-35 sustainment system is designed to maintain that level of performance and lower the cost throughout time," she said. "That doesn't just happen by putting it on a chart, though. You have to have all of those elements aligned, to give you visibility on those costs, to be able to continue to draw them down.

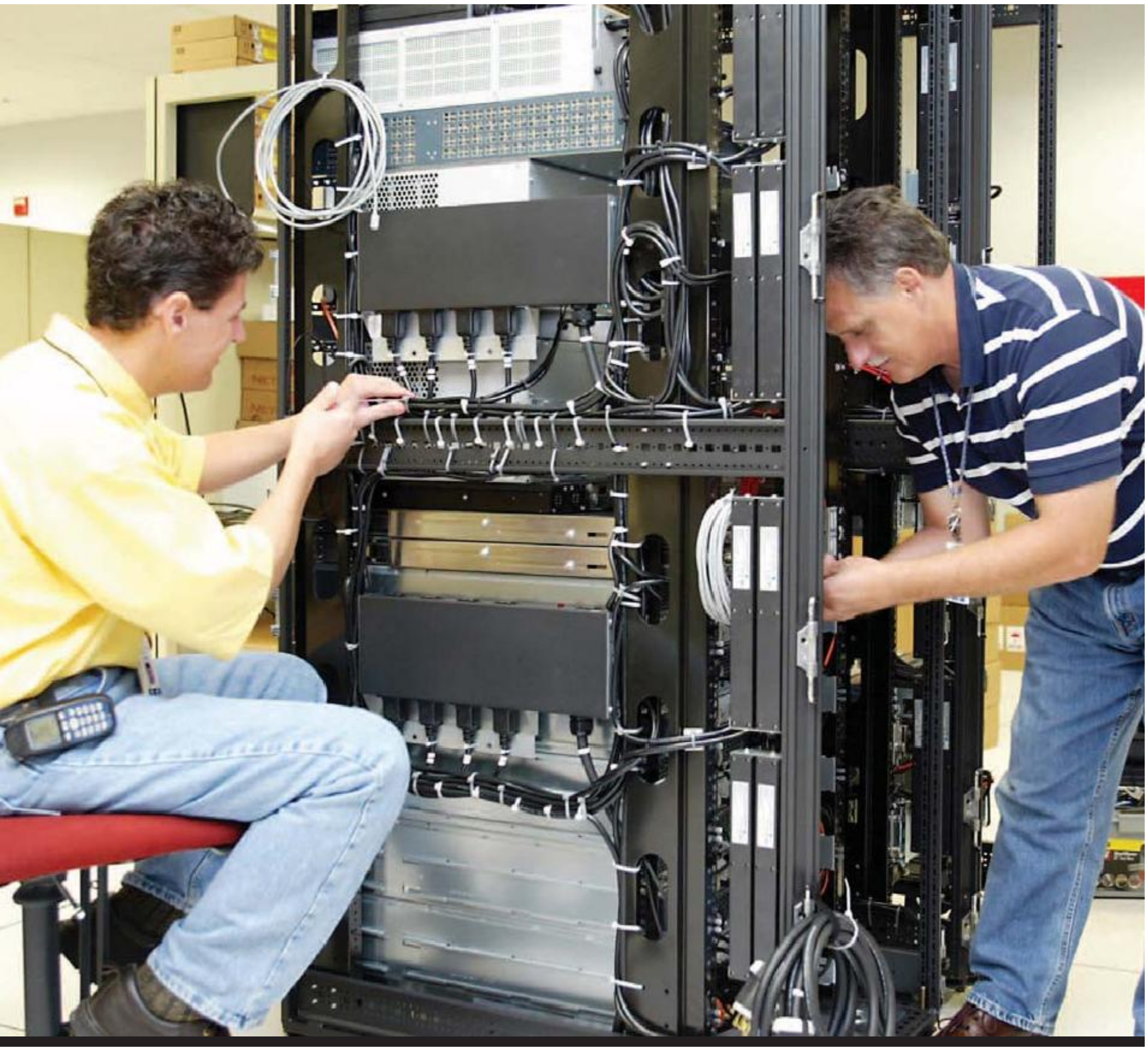
"You hear about 'network-centric warfighting,' when people are talking about aircraft working together," she observed. "Well, this is kind of like 'net-centric logistics.'"

She summarized the net-centric logistics approach as the ability to "work across what were previously more segregated domains and previously groups who were not partnered together, to deliver that sustainment more flexibly and more affordably throughout time."

"The way that's done is by a concept called 'performance-based logistics (PBL),'" she said. "People use that all the time and they often mean different things by it. But what we mean in this concept is that it is all based off the warfighter and getting down to what availability they want, then developing the necessary public and private partnerships to deliver that goal. It pays for performance and not for product. So you are not buying a training system, and then some support equipment, and then an information system. Instead you are buying availability. It is contracted through the Joint Program Office to industry – Lockheed Martin is the prime contractor – to deliver that availability. And that's how we will be 'incentivized' as those aircraft go into the fleet."

The unique approach is also reflective of the "9 nations/13 services" as part of the program building the JSF.

"So you have already got the commonality across the three variants of the aircraft, but you have also got economies of scale, because of the number of services involved," Gavaletz said. "We have a 'common asset management' concept that will feature a joint spares pool across all of the services. And if you do the 'supply chain math' behind that and aggregate those together you will need less supply. So that, in itself, drives a long-term reduction in cost across the system.



OPPOSITE: U.S. Air Force crew chiefs Master Sgt. Timothy Weaver and Tech. Sgt. Lucas Delk from the 33rd Fighter Wing at Eglin Air Force Base work with Pedro Vera, Lockheed Martin Airframe Powerplant Group, inside the F-35C internal weapons bay at Naval Air Station Patuxent River. Seven airmen from Eglin were embedded with the F-35 Integrated Test Facility team to gain hands-on experience on the F-35B and F-35C variants in preparation for the first Joint Strike Fighter arrival at Eglin and start of F-35 training for the Navy, Marine Corps, and Air Force.

LEFT: The Autonomic Logistics Information System provides the IT backbone and capabilities to support current and future warfighters.

Photo courtesy of Lockheed Martin

"When all of the players are signing up on the basis of availability, they don't have to worry if the parts are there," she added. "If the parts aren't there and availability falls, our fee gets decremented and not paid. So what we have gotten is a dynamic where 'parts' are not something that they have to worry about. What they do is contract for the availability. And what we do on the other side to make that happen is the supply chain for any of the components knows how much of their supply is out there. And they are also 'incentivized' by us to not have that be a reason that an aircraft is down. So they can better plan their capacity and 'right size' their inventory."

Acknowledging that the new sustainment paradigm has been accompanied by a significant "cultural switch" for warfighters, she said, "We are not asking for this overnight. This has been a long-term partnership to this point, with all of the services involved in building the solution. Now, as we are in the throes of beginning to deploy that solution, we are using the tools and processes we have developed, where appropriate, for the manufacture of the aircraft and training.

"The products are getting adopted and used much earlier in the life cycle," she said. "Typically these products in sustainment are not even introduced until you are in the operational testing timeframe. But we are using them in the development and flight test phases. They are evolving. But we are using the first few releases.

"The warfighter 'gets it' faster than anybody," she added. "When we are talking, they say, 'Yes, that's what we want!' Again, this is about delivering capability for the warfighter to really maximize the use of the assets they have in the aircraft without having to overspend on the support structure."

New sustainment paradigms were also established in the original key performance parameters (KPPs) for the F-35.

"Half of the key performance parameters for the JSF were for sustainment," Gavaletz said. "That's unheard of – it's never happened before where half of the KPPs were for the performance of the jet and half were for the performance of the sustainment system; things like mission reliability, sortie generation rate, and log (logistics) footprint – weight or volume – that it takes to go to war. Those have been measured from the very beginning and they helped keep the sustainment focus of the program."

She continued, "Also, on the aircraft itself, there is a prognostics management system that is both diagnostic of any failures that might occur when the aircraft is flying and also prognostic as to how much life is left on a particular part. Some other systems have DHM – Diagnostic Health Management – but it is in a much more limited fashion and not integrated into the total sustainment solution.

"We also have extensive reuse of what we call the 'digital thread' that was used to build the aircraft," she added. "We are pulling that digital thread and using those CATIA (Computer Aided Three-dimensional Interactive Application) drawings and engineering artifacts to build the sustainment products. And then we will propagate out in the field as we maintain and service that jet to its full life. So, recognizing all of the investments that have been made in the technology through the past decade to build the jet, we can now pull that digital thread throughout the life cycle. That is not only giving us a lot of reuse but also a lot of stability in that data does not have to be translated so many times to create a lot of different products along the way."

Sustainment benefits were further facilitated in the aircraft's physical design processes that addressed things like accessibility to components behind panels.

"That was all stratified to be able to get easy access to things that have to be changed more often," she said. "But we also did something even more important by making the panels that we did not design to be quick access able to be switched out in the field to quick access panels if we started to have some component begin to fail more frequently than we anticipated. So we designed in the fact that there are always some unknowns and if we have to make those changes we will not have to pay the penalty in the field."

Other design element examples that facilitate sustainment range from a canopy/ejection seat design that does not require canopy removal to change seat ordnance to simplified maintenance of the "low observable" coating features.

"It's all about the jet itself and how it is built so that over the long term we can be twice as reliable while requiring just half the manpower to be able to sustain the system," she said. "You can't do that after the fact. It has to be designed in from the start."

Additional life-cycle cost reductions are derived from the JSF training concept at locations like the first Joint Integrated Training Center now being stood up at Eglin Air Force Base.

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Along with underlying concepts involving parallel paths of training and use of the same aircraft platform, Gavaletz noted that training at Eglin would encompass both pilots and maintainers from "not only the Air Force but the Marine Corps and the Navy and the international partners. We will be bringing their service personnel in and running joint training."

She added, "One long-term reason for bringing all the partners together to build this aircraft is, of course, the synergies you get from the ideas across everyone there. You get funding from all of the 'investors' in the activity. But in the long term, you have also got a set of allies who can operate together better – and that extends not only from operating better in the skies but also on the ground. And when we are doing joint coalition operations that extends to what we are doing in the sustainment world. There's a lot to be gained there in the long term, and we are going to be starting it at the first base – Eglin.

"Overall, this should bring at least a 30 percent reduction in the training system life-cycle cost. We have got over 90 percent software reuse rate. And that 'digital thread' – with the CATIA drawings and the other activities – means we can reuse in courseware as we are training," she said.

Reiterating how the five component parts of ALGS translate to cost benefits for the warfighters and the nation, Gavaletz observed, "For the last six years we have been doing a full life-cycle cost estimate for F-35. And that typically goes about 60 years on the current profile. So we cost out the training, the maintenance, and all other categories for the aircraft for the next 60 years. And every year we insert any new data that we have and derive what changes might happen. We are really looking at any decisions and how they might affect life-cycle costs. And with that visibility you might make different decisions.

"What is key is being able to tie all those pieces together and seeing how a change in one area might impact the overall cost," she concluded. "I think that's really unique on this program. So even though we call this PBL it is so far beyond that. It is recasting, or 're-norming,' the way people think about long-term sustainment of an aircraft. You can make data-informed decisions not just on the performance but also the cost, then tying those two things together."


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