THE BASELINE F-35: WHAT IS IN THE AIRCRAFT?

The Baseline F-35: What is in the Aircraft?

The Baseline F-35

An Interview with Michael Skaff, principal engineer for the F-35's pilot vehicle interface.

The F-35 represents a new approach to the development, production, system and sustainment of a fleet of combat aircraft. Additionally, the F-35 takes an innovative approach to collaborative upgrades over the airframe and global fleet's life cycle.

Too often an understanding of the basic aircraft rolling out of production right now is lost in the shuffle. With one exception, the jets in assembly at Lockheed Martin's F-35 facility in Fort Worth are not test aircraft.

They are production aircraft are the immediate forerunners of the IOC USMC aircraft. Put another way, what will the F-35B as a flying sensor system be able to do right out of the box?

And one must remember that the upgrading capability is built into the aircraft, or put another way the aircraft both as platform and FLEET is inherently upgradeable.

But not fully grasped is that the first F-35s are already superior aircraft to any plane they are designed to replace.

To discuss the baseline or vanilla F-35, *Second Line of Defense* talked with a former F-16 pilot and USAF Academy graduate Dr. Mike Skaff who has worked with Lockheed Martin throughout the F-35's development and production process.

In the course of the discussion with Dr. Skaff, 9 key elements built into the aircraft were identified as defining the baseline aircraft.

- A new cockpit and helmet which enable the pilot to function as a tactical decision maker;
- A fusion engine which brings together and integrates the core combat systems on the F-35;
- The fusion engines are designed to share information across the combat enterprise, or put in other terms each plane is synergy enabled;
- The plane is built as a weapon system built on a foundational architecture of chip and software upgradeability;
- The software is built to shape a mangeable workload for the pilot;
- Stealth is built into the aircraft and is a core enabler for the entire aircraft;

- As a flying combat system, the F-35's advanced agility is a key enabler of combat operations;
- The power plant of the F-35 enables a long term growth strategy for the fusion engine. Unlike unmanned aircraft, where the power plant is devoted to flying the aircraft resulting in less than optimal sensor and weapons loading, the F-35 has significant growth possibilities;
- The F-35 can fire a full gamut of legacy weapons but lays the foundation for the next generation of weapons as well.

SLD: Can you tell us a bit about your background?

Skaff: I was an F-16 pilot out of the Air Force Academy. I was prior enlisted, and I've been with Lockheed Martin for about 23 years working on the F-35 cockpit since '95. I flew out of MacDill, Shaw, and Luke during the Cold War.

SLD: The cockpit enables the pilot to function as a tactical decision maker, which makes lots of sense from a fighter pilot perspective. So what is it about the basic cockpit that you get with the basic plane that makes this plane different?

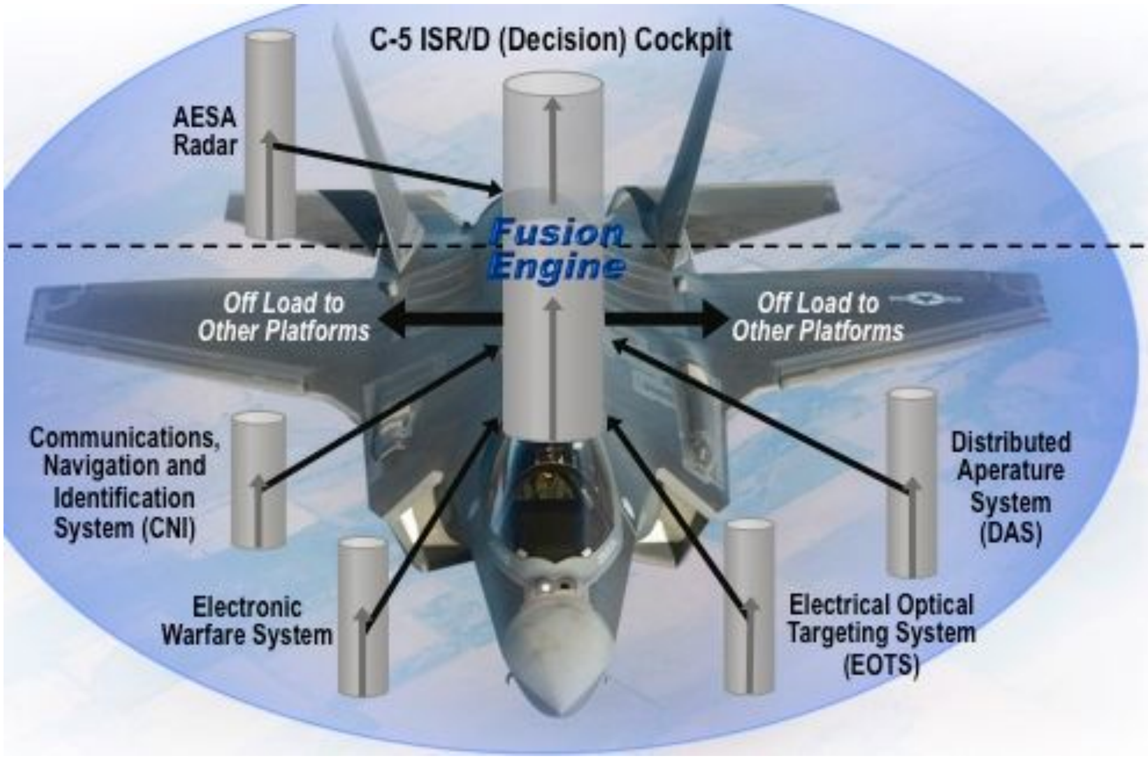
Skaff: When we designed the cockpit, we started with a design philosophy called "return the pilot to the role of tactician." And the reason we did that was because while the F-16 I flew and the F-15 and the Gripen the Rafale, are all good airplanes, managing their sensors overloads the pilot.

Rather than doing tactical things, the pilot spends his time controlling and tilting radars. So we said, "We've got to get away from that. We've got to return this pilot to the role of tactician and let advanced processors and fusion do the kinds of things that they can do really well that just burden the pilot."

In other words, let computers do what computers do best and let pilots do what pilots do best.

Computers can do algorithmic functions extremely well and fast. Pilots do heuristic 'thinking' very well, but only when they have time to do it. We've got to return time to the pilot."

And so with that philosophy, we wanted to make sure that the airplane gave the pilot situational awareness and a manageable workload.



Graphic Credit: Second Line of Defense

- *F-35 Individual Pilots Internal to Their Cockpit Will Have the Best Real Time Data Base of Knowledge in History*
- *Each F-35 Will Be Able To Network and Direct Engagements in 360-Degrees of 3-Dimensional Space by Off Loading Tracks to Other Air/Land/Sea/Space Platforms – Including UAVs and Robots*
- *Fusion Engine Can Drive Unity of Purpose in Focusing World Wide IR&D and R&D on Enhancing C5ISR-D Cockpit Because Each Discreet System Can Be Improved Independently*

SLD: So you're getting a basic cockpit for each platform in a fleet of cockpits built into the fleet. And this cockpit is built on a man machine interface and this man machine interface gives you the second capability, which is the fusion "engine", which brings together and integrates the core combat systems on the F-35. So talk a little bit about the fusion "engine" and the relationship to the fusion "engine" to the cockpit.

Skaff: The fusion "engine" is the heart of the airplane and is the core capability enabler which gives the pilot the situational awareness and the manageable workload.

It is gathering all of this information that is external to the airplane through the sensors fusing, correlating them and giving the pilot a single picture that's very easy to interpret.

SLD: What's the advantage of this fusion "engine" bringing together multiple things that have really been historically stovepiped?

Skaff: It does three things for us, and the first one is that it presents an easy way to interpret big picture of the view outside of the airplane.

The second thing it does is tasks the sensors to fill in missing data, and the third thing it does is share this picture with everybody on the network.

And so for the very first time, we're all seeing the same picture.

In the previous generation airplanes, we may have had a radar warning display and a radar display and some other federated sensor display, now we have one display with the entire picture on it.

SLD: So you are arguing that the combination of the new cockpit display and helmet with the fusion engine creates a new situation for the pilot. It's sort of like looking at your iPad screen and pushing the application you think you need for the task at hand rather than having to integrate in your head 25 applications in order to be able to know which button to push. Is that a fair analogy?

Skaff: Yes, that's exactly right.

SLD: Let us discuss an additional capability inherent in the baseline aircraft. The fusion engine allows you to share information across the combat enterprise or another way to look at it is each plane is synergy-enabled. Talk a little bit about what's happening already with the plane?

Skaff: In our fourth gen airplanes, like F-15 and F-16s, there's a little bit of synergy, but it's only the synergy that the pilots can come up with talking on the radio. Because we're sharing this picture and sharing some sensor tasking through the network, we have synergy built into the aircraft.

This means that the information we are sharing has significantly greater combat value added than we used to have.

Photo: The F-35B aboard the USS Wasp for Ship Trials, October 18, 2011. The twin transformational USMC aviation elements, Osprey and the F-35 Bravo are seen together in this shot taken by Second Line of Defense. The cover photo was from the same date and source.

It means that you and I can get airborne and we get more than the sum of the parts, and we get two radars operating at the exact same time. You may be looking high and I'm looking low, but we both get the benefit now of a bigger picture view.

SLD: In effect, using your approach, the F-35 is a "flying synergy system."

Skaff: That is a good way to put it.

SLD: But is that fair to say the radio would be the center piece of sharing in the legacy system and with the F-35 it is a shared COP. You're going from a radio to the COP, the Common Operating Picture. Is that fair?

Skaff: That's exactly right.

And previous to this, you and I, we would build the picture verbally and you would try to explain to me as a young wingman what you're saying and what am I saying and you would try to correlate battle space and we would, in our minds, build a picture.

Now we have computer power that can build the picture for us. And we can discuss from the same COP which we both can see and share knowledge.

SLD: One thing that we know for sure is not widely understood is that the plane really isn't a plane, it's a weapon system and it's built on the foundation of a chip and software upgrade ability.

Put another way, the architecture is built from the ground up so that chips can be swapped out and software can be upgraded.

Let's talk a little bit about the importance of chip and software upgradability compared with the classic approach to upgrading combat aircraft.

Skaff: From the beginning, we designed an airplane that would take tech refreshes, and we've already had a couple of tech refreshes during the System Development and Demonstration or SDD phase.

We knew the technology would change and we would upgrade both hardware and software in this early phase, and we planned ahead for that.

In previous airplanes, sometimes we didn't plan for that. We would build the airplane and then decide after the fact: Well, we need to upgrade the new hardware and new software.

Because it wasn't planned for upgradability, it cost us as taxpayers quite a bit more and took longer to do, but now we've planned for tech refresh.

It is similar to what you find with your computer at home knowing that you could swap out a better graphics card in the future because you picked a bus that was going to be around for a while. And when you were ready, you went to Best Buy and you bought the next card for your graphics processor.

Another aspect, which is important to understand, is that this chip and software architecture is common to all variants of the aircraft, the three U.S. services and the global F-35 partners as well.

Although the airframes are different between the A, B, and the C, the software inside, the sensors inside, the pilot vehicle interface is identical. It is sort of like Intel inside for basic computers.

As a result, we get economies of commonality and we get the economy of scale and so we will all, the U.S. services and our partners, upgrade simultaneously and share the benefit.

SLD: An additional aspect of the basic airplane is stealth. For many, stealth is the DEFINING characteristic, which makes it a 5th generation aircraft, but in reality it is an enabler for a very different approach to sensor synergy integration.

What role does stealth play in the equation?

Skaff: From the war fighter point of view, at least for now, it gives me more time. I can get closer before the enemy knows I'm there or I can get away from somebody easier.

And that's part of our asymmetry, the stealth that's built into the airplane.

Then there is the manufacturing aspect. The tolerances are so tight that the entire manufacturing process enables stealth. It makes a better product, better tolerances.

It is an enabler of the other capabilities of the aircraft, rather than being the defining characteristic.

SLD: The other part of stealth that's not completely understood it is not simply a coating. It's how the engines are built in. It is the fact that one doesn't have to put weapons external unless one chooses to do so. It is because the sensors are built in a certain way. The radar and associated combat suites are built into the nose cone in a specific way.

So in a certain sense the seventh factor is that the F-35 is a very agile fighter, And agility is a key enabler of combat operations.

Skaff: Agility from a fighter pilot point of view is fighter performance. A classic example was the YF-23. It was a phenomenal interceptor, but that's all it could do. It couldn't turn. It didn't have great agility, fighter performance.

They went too far with the stealth enabler, and you had an extremely stealthy airplane, but they paid for it in lack of fighter performance. There's got to be a balance there.

The B2 is another example. It is extremely stealthy and a fantastic airplane. As far as I know, it's never been tracked by anybody.

But if anybody should see it, particularly by an enemy fighter, they'd be in real trouble. They have adapted by flying at night and hopefully denying a visual acquisition.

We're not going to have that problem in an F-35.

SLD: The agility is part of your survivability. The stealth is part of your survivability. Survivability is a function of multiple variables. It's not simply an attribute to stealth alone is your point.

Skaff: That is exactly right.

SLD: The eighth factor built into the basic plane that is often overlooked is the power plant in the F-35.

And one thing it's not completely understood when people are comparing UAVs to manned aircraft is the impact of the power plant of a fighter aircraft in driving a lot of sensor capability. For UAVs, as significant capacity of the power plant is just for flying the airframe and the rest for the sensors and it's not very large form fit anyway.

So talk a little bit about the power plant for the F-35 and its role and impact on the capability of the F-35 as a weapon system.

Skaff: For the war fighter point of view, this is the largest single engine fighter ever produced. It produces a tremendous amount of thrust and also from the pilot point of view, it doesn't require pilot management.

Engine technology has gotten better and better and now they're controlled by the FADECs, the Full Authority Digital Engine Controllers, the pilot can just command thrust with the throttle however he or she likes to. It doesn't matter.

You don't have to manage the engine and so it kind of goes back to this workload reduction. You do whatever you want and Pratt & Whitney will take care of the engine.

From the maintainer point of view, it's relatively easy to maintain, easy to remove and replace, especially important on a carrier deck or on an LHD where there's not much room at all. It only takes some minimal set of tools to do that.

SLD: The F-35 is a single engine fighter. Would it be better to have two engines?

Skaff: At the heart of the answer is rather simple: Engine reliability has grown to such a level that one engine is more than sufficient.

SLD: Finally, let us address the capability of the F-35 to carry weapons. Clearly, the plane will be able to carry most legacy weapons but is well positioned for the next generation of weapons as well.

Could you speak to the weapons aspect of the basic plane?

Skaff: It was designed to carry just about every weapon that a legacy airplane could carry, F-16 for instance. We have a combination of internal and external carriages.

Stealth is important during the first few days of an operation when you're busting down the integrated air defense system. Under those circumstances, you would carry your weapons internally. And in fact, your internal weapons payload is just about the same as an entire F-16 complement of weapons on all of its stations. So the F-35 can do really well in that regard.

If you're not worried about stealth, we can carry external weapons. In fact, we can carry 18,000 pounds of weapons total.

When I first started flying the F-16, that's what the airplane weighed; 18,000 pounds. So it's like carrying an entire F-16 on the wings and internal. We can also have 18,000 pounds of internal fuel in the airplane and so you can take your F-35 fully loaded with internal fuel and external weapons and it's like carrying two F-16s on the airplane.

And of course internal has many advantages other than stealth, which goes back to our flexibility and performance and agility. I can be fully loaded and still have an airplane that has easy supersonic capability, that is still very maneuverable whereas we put all those weapons external on an F-16 or F-18 and now it takes away all of that fighter performance.

SLD: And the basic plane, which you have described in terms of 9 basic parameters, is coming off of the assembly line today.

Skaff: The airplane's coming off the assembly line right now at low rate of initial production. The airplanes we're talking about have all the hardware in them, and they will have the complete software package in the near term to do everything we've talked about.

The first block two software is flying now and eventually the Marine's will go IOC with that since they're going to go IOC first.

But everything we talked about are in those airplanes that are coming off the assembly line. The future is ready now.

SLD: A final point. Could you explain software upgradeability to our readers?

Skaff: We talked about the iPad and the fact that Apple has you stuck in a throwaway mode. They come out with this new retina display iPad and a lot of people will throw away their iPad 2 and go for the better hardware and better software, an extremely nice device. There's no doubt about it, but it's expensive.

As opposed to the Kindle Fire, their approach has been different.

So they have a relatively low cost, half the price, hardware and they have upgraded the software repeatedly to give new features. So they initially introduced a piece of hardware that they could build upon. They've done that effectively, and they have attracted the crowd that wants an eReader or some device, but they don't want to spend for an iPad.

Lockheed Martin has provided several White Papers which progressively explain key elements built into the baseline F-35. These White Papers follow and can be found on the Second Line of Defense White Paper section along with slide shows which further explain baseline capabilities.

Building a 21st Century Fighter from the Ground Up

Advanced stealth – built in from the beginning – is a defining characteristic for 5th Generation combat aircraft. It is not however the only one.

The F-35 provides a glimpse of the 5th Generation fundamentals in action. From the ground up, the F-35 was built to be an integrated fighter capable of playing a pivotal role in joint and coalition operations. It's designed for the future and developed on a foundation of more than 40 years of real world combat experience. In a real sense, the F-16 and F-22 were the risk reduction programs for the F-35. Many lessons learned were incorporated into the F-35.

With its integrated systems and software upgradeability, the F-35 is laying the groundwork of ever-evolving capabilities for decades to come. Stealth is just one enabler of a 5th Generation fighter and in actuality we've had stealth in the past, but until the F-22 it wasn't coupled with combat agility. Consider the B-2 and F-117. Both are very stealthy but lack agility, so much so that they could only be deployed at night.

The F-22 and the F-35, which also employ stealth, were designed for agility. We want to fly them day and night and in all combat conditions. They are not designed to be specialized aircraft for narrowly defined mission sets.

Building the airplane from the ground up means that what used to be on the outside of the airframe must be moved inside. This includes sensors, fuel and weapons. The sensors are integrated through the fusion engine, which is another discriminator that makes the F-35 a 5th Generation aircraft.

True 5th Generation stealth must be built into the aircraft. It can't be added post production. It's just not possible to make a 4th Generation aircraft stealthy because you've got to hang tanks and stores and pods external to the airplane's exterior. Consequently, agility and radar cross section are compromised. You also lose agility because there's a huge aerodynamic penalty for hanging anything outside the airplane.

So, that's what caused us in the beginning to say the airplane must be agile and it must be stealthy, which requires us to put the fuel, weapons and sensors inside the aircraft. One of the challenges we had was to make an airplane that had the low speed characteristics of the Hornet and the high speed of an F-16.

The Hornet can fly slow extremely well and get to high angles of attack and point the nose all around. The F-16 can't do that as well, but the F-16 can fly extremely fast and can recover energy quickly. The Hornet does not do that very well. Once they get into an energy deficit, it's hard for them to recover because of the low thrust to weight ratio and the aerodynamic penalty of sensors and weapons in the airstream.

The F-35 incorporates the best of both in flying qualities: it will fly slowly at high angles of attack; it can fly supersonic for extended periods of time; and it regains energy quickly because of its large engine.

The engine is another example of building stealth into the airframe from the ground up. In a legacy aircraft, the power plant creates a significant element of combat visibility. This impact to radar cross section comes from the front and rear of the engine. Ideally, the engine is totally hidden from view as in the B-2 and F-117. This approach impacts agility so a different design is found in the F-35. In front of the F-35's engine is a bifurcated diverterless intake which totally blocks line of sight to the compressor face while not severely impacting performance. At its rear is a reduced signature nozzle.

A final consideration with regard to building from the ground up is how stealth is manufactured into the aircraft. The F-35 is manufactured with stealth built in as well.

As Bill Grant, Lockheed Martin F-35 Supportable Low Observables Integrated Product Team leader, has put it:

From day one, supportable LO has been a key entity on the program and has had a profound influence on the very design of the airplane. In fact, the element that is manufactured into the skin was an initiative brought about by our LO maintenance discipline. We've also had a profound influence on the selection of the materials and then once they were decided upon, we helped refine the properties to make them more workable for field use.

And Grant added:

Our system requirement was for end of life, which means that throughout the 8,000-hour service life of the jet, it is to remain fully mission-capable. So we anticipated that the amount of maintenance that would be done over the life of the airplane and anticipated that in the design.

So when we deliver the jet, it's delivered with a significant margin of degradation that's allowed for all of these types of repairs over the life of the airplane, again, without having to return to the depot for refurbishment.

There may be some cosmetic-based reasons why the jet might go back to a facility to get its appearance improved, but from a performance-standpoint we recognize no need to do that.

An example of the new approach to stealth and the new combat systems can be seen in the Northern Edge 2011 Exercise. This exercise is a major U.S. joint forces exercise held in Alaska which tests the ability of the various elements of the forces to work together.

With the new emphasis on the Pacific or the Asian Pivot, the exercise highlights the working of U.S. forces in dealing with the Pacific challenge.

In this exercise, fifth generation aircraft each played an important role.

The F-22s demonstrated their air dominance role, and then shifted to an air battle management role.

The F-35 combat mission systems flew in the exercise on a test bed aircraft.

As a Joint Program Office release underscored:

Participating in Northern Edge for the second time, F-35 Joint Strike Fighter sensor capabilities were tested in Alaska's premier multi-operational environment from June 13-24, 2011. Hosted by Alaskan Command, Northern Edge is a biennial U.S. Pacific Command exercise that prepares joint forces to respond to crises throughout the Asia-Pacific region.

This year provided an invaluable opportunity to observe the performance of the F-35 JSF systems in multiple robust electronic warfare scenarios.

The AN/APG-81 active electronically scanned array radar (AESA) and AN/AAQ-37 distributed aperture system (DAS) were mounted aboard Northrop Grumman's BAC 1-11 test aircraft. Making its debut, the AN/AAQ-37 DAS demonstrated spherical situational awareness and target tracking capabilities. The DAS is designed to simultaneously track multiple aircraft in every direction, which has never been seen in an air combat environment.

A return participant, the AN/APG-81 AESA demonstrated robust electronic protection, electronic attack, passive maritime and experimental modes, and data-linked air and surface tracks to improve legacy fighter situational awareness. It also searched the entire 50,000 square- mile Gulf of Alaska operating area for surface vessels, and accurately detected and tracked them in minimal time.

Navy Cmdr. Erik Etz, Deputy Mission Systems Integrated Product Team Lead from the F-35 JSF Program Office, said the rigorous testing of both sensors during NE 2011 served as a significant risk-reduction step for the F-35 JSF program. "By putting these systems in this operationally rigorous environment, we have demonstrated key war fighting capabilities well in advance of scheduled operational testing," Etz added.

Having the exercise in June had its seasonal weather challenges for system operators to adapt and overcome. Inclement and cloudy weather hampered in-flight visibility. The DAS was significant in providing clear and discernable horizons, and views of ground features and nearby aircraft. It also wasn't dark enough for testing night vision functions. A surrogate test visor was used for displaying DAS imagery to the operators.

"The implications of F-35 JSF sensor systems for air-land-sea battle are immense," said Peter Bartos, Northrop Grumman's Test Director.

http://www.jsf.mil/news/docs/20110627_NORTHERNEDGE.pdf

In short, during this important joint exercise, the presence of 5th Generation fighters in the air package increased the overall forces' mission effectiveness by enhancing survivability and lethality for entire package.

It showed as well that 5th Generation fighters enhanced battlespace awareness enhanced overall mission effectiveness of the entire mission package.

And finally, the exercise showed that 5th Generation fighters with this enhanced SA tend to function as Air Battle manager for entire package. Even when F-22 was weapon bingo it stayed in fight as battle manager!

In other words, the exercise highlighted the cross between current and future capabilities, which are central to the future of airpower.

An Overview of the F-35 Cockpit

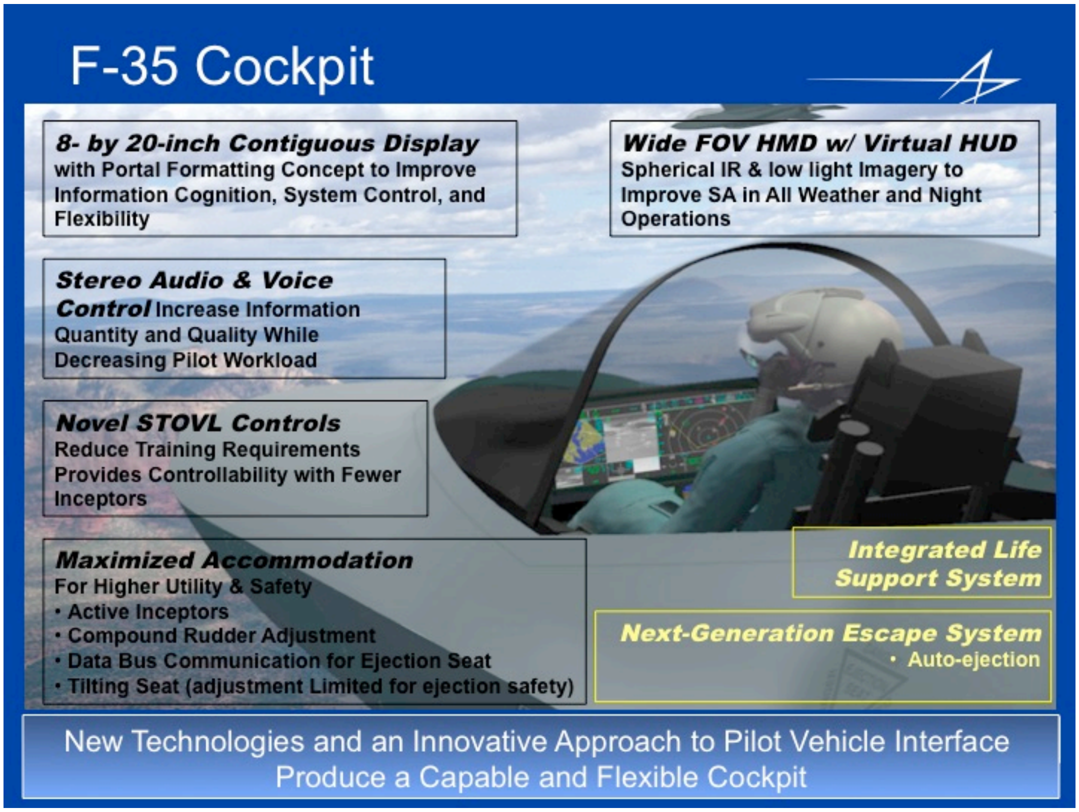
There are several key elements, which make up the F-35 cockpit.

The first is the panoramic cockpit display, a large 20 by 8-inch piece of glass that provides the pilot a big picture view of the battlespace.

While it's not quite as flexible as a Microsoft Windows desktop, it is similar. The pilot can change sizes, locations, and content of windows, including a large window with a tactical situation display. The display can be manipulated through the touchscreen, cursor hooking, or voice control.

The Tactical Situation Display (TSD) is where the output from the fusion engine is displayed. Now instead of a pilot manipulating a disparate set of control panels and interacting with a separate display per sensor, fusion presents a single integrated operational picture on the TSD.

Fusion assembles an easy to interpret picture of the battlespace. It correlates and fuses all of the information from the onboard sensors as well as offboard datalinks and synthesizes a very simple to understand picture in front of the pilot on the TSD.



The resulting picture is 10 inches by 7 inches, or 70 square inches of space. The pilot can have up three different TSDs with two being displayed simultaneously. F-35 pilots will all see the same fused picture on their displays. As an individual airplane builds the picture, it is across the high bandwidth data link (the Multifunction Advanced Data Link or MADL link).

In legacy airplanes, pilots used radios to provide the communication links and to shape the collective understanding of the battlespace. With the F-35, it is the Common Operational Picture or COP that is shared visually.

Another aspect that enhances awareness is the use of the same symbols across the service and international fleets of F-35s. In legacy fighter cockpits there are often different and unique symbol sets. There's a lot of learning and a high potential for misunderstanding as pilots communicate. Whether pilots are flying an A, B, or C model, they use the exact same symbol set. With the F-35, pilots are speaking the same language – no matter their service or nation – and using the exact same terms to describe what they're seeing and how they're interacting with the display.

It's very graphical and very clear to the fleet. Its simplicity and standardization will enable ground commanders to easily use the pilot's picture above for an improved perspective on the battlefield.

This benefit will allow pilots to exchange data with command and control on the ground.

In an era where working with allies is a core requirement, the F-35 is a key coalition enabler, and the common cockpit will be a critical aspect of the integration process. With current fleets when pilots conduct Red Flag exercises with allies, when they participate in debriefings, they're all seeing a different picture in their displays. And with the F-35, that all changes. The F-35 allows pilots to see the same picture, ensuring they're on the same page.

The helmet is an extension of the panoramic cockpit display. The head up symbols are like those used head down. It blends seamlessly with what's head down and heads up. In addition to symbology, the pilot can select imagery from the distributed aperture system. This imagery is captured from sensors surrounding the aircraft, giving the pilot 360 degrees of situational awareness. Simply put, the pilot can use the helmet to look through the airplane and into the battlespace.

Currently, the helmet is working well but with any new technology there are developmental challenges. Mitigation pathways for the issues facing the helmet have been developed and are being implemented. The fact is that the helmet is already in use and the reviews from the pilots are overwhelmingly positive. One pilot went so far as to say, "I could fly the whole mission with a helmet bag over the top of my head and just look through the sensors and fly the airplane safely."

Another pilot recently stated, "I wouldn't go back to a fixed HUD (Head-Up Display). It is clear that the potential of the helmet and what it's going to be able to do for the war fighter is overwhelmingly positive and I would never want to go back."

Legacy aircraft have fixed HUDs, this is a combiner glass that sits on top of the glare shield onto which symbology is projected. All of that is gone from the F-35. Symbology is now projected on to the helmet's visor.

The step from a third generation fighter like the F-4 that did not have a HUD to the fourth generation fighter like the F-16, which did, was significant. No pilot would ever go back to not having a HUD.

In the same way, pilots experiencing the legacy HUD to the F-35 approach do not want to go back either.

In the F-35, the helmet gives you a HUD everywhere the pilot looks. The pilot can look straight up, straight down, left, right or even through the airplane's structure and get all the benefits of a HUD everywhere. It's a huge extension of technology that provides a significant combat capability. This capability alone will transform how pilots conduct close air support with Joint Tactical Air Controllers on the ground.

For further explanation of how the F-35 cockpit enables the pilot as a tactical decision maker see
http://www.sldinfo.com/whitepapers/the-f-35-cockpit-enabling-the-pilot-as-a-tactical-decision-maker/

The F-35 and Advanced Sensor Fusion

The F-35 cockpit displays the work of the onboard fusion engine as well as information provided by other members of the network.

But what is a fusion engine?

What combat systems are integrated onboard?

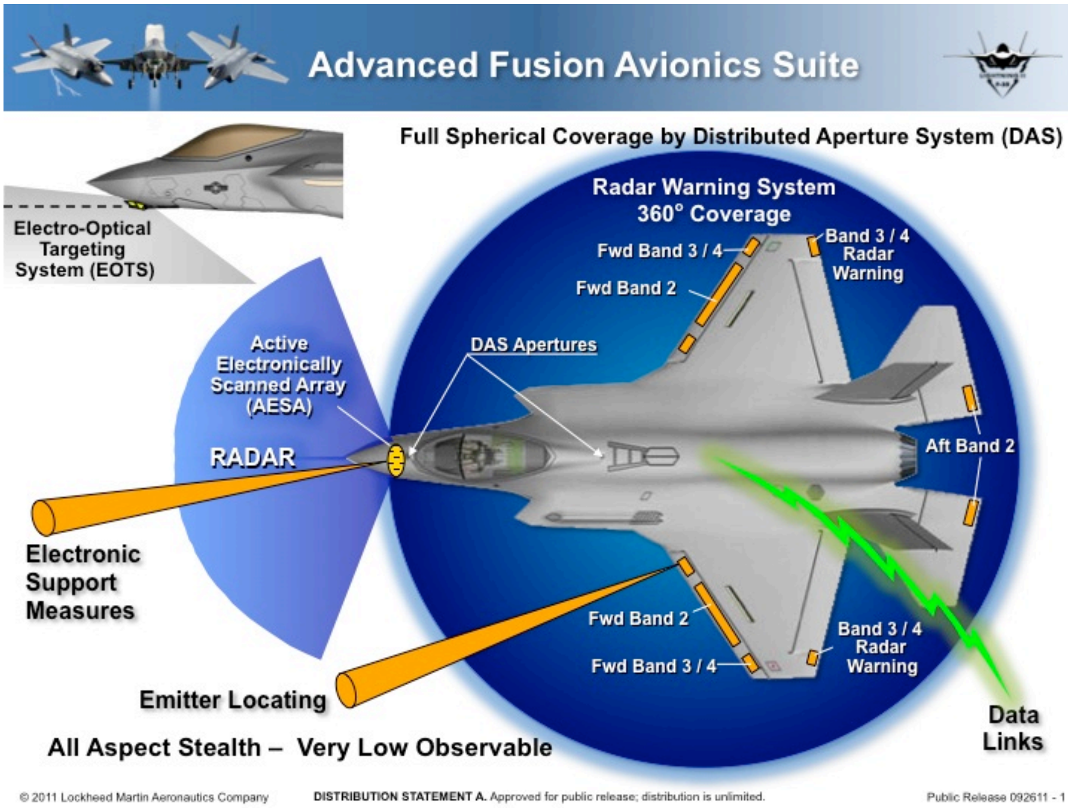
And what are the advantages of having multiple combat systems to provide the pilot with core combat capabilities?

The Advantages of Advanced Fusion

The system is so advanced and revolutionary in its design that there were concerns that test pilots would have difficulty isolating and testing a single sensor because the collective integrated suite would kick in.

Engineers deliberately put specific pilot vehicle interface into the airplane to allow the pilots to select a single sensor and tell the fusion engine to allow only that sensor's track to come through. This feature enables test pilots to verify individual sensors.

Now the enemy, instead of just working against the radar, is forced to fight an integrated and fused sensor suite.



The redundancy and comprehensive nature of the sensor suite gives the F-35 a tremendous advantage over legacy fighters. This is the huge advantage of advanced fusion.

The F-22 Raptor has this ability, so while it's not new, it's being perfected in the F-35, and is a key characteristic of 5th Generation fighters.

"We know how to do this; we've done it before," says Mike Skaff, principal engineer for the F-35's pilot vehicle interface."

"The airplanes that are coming off the line right now have this capability. Although it's not in its final form, it will get better and better with each block of the software."

We are getting closer to a software-defined airplane.

Advanced fusion does three things for the pilot.

First, it assembles a single integrated picture from all of the sensors.

Second,it tasks the sensors to fill in missing data

Third, it shares the information with everyone else on the network.

This is where fusion synergy really comes into play: all the F-35 pilots in the battlespace see the same picture.

Envision the following scenario.

An enemy pilot effectively neutralizes sensor A from one F-35 in a formation of several. The likelihood that enemy will be able to do the same to another F-35 in the same formation is slim to none.

It is extremely difficult for the enemy to defeat multiple sensors on multiple F-35s simultaneously.

Because the sensors between the F-35s are fused, the pilot in aircraft #1 can simply tap in to aircraft #2's sensor suite.

Let's look at the F-35's sensor suite in more detail and remember each sensor is connected and controlled by an advanced fusion software engine, which results in more than the sum of the parts.

The Radar

The radar, like all radars, transmits and receives energy. The F-35's active electronically scanned array (AESA) radar is built up of multiple transmit and receive modules, which can be thought of as individual miniature radars. They work together under a computer's control, which can steer beams through space almost instantly.

The AESA radar operates differently than a fourth generation fighter that has a mechanically scanned antenna that must be moved left, right, up and down.

Because an AESA scans electronically, we overcome the inertia of a physical antenna moving around and can build beams in space wherever we need. We steer these beams throughout the field of regard to perform numerous radar functions.
From the pilot's point of view, the radar seems to be doing air-to-air and air-to-surface simultaneously. It's really not. It's in very quick, serial fashion; but by the time the information gets to the displays, the pilot sees air and ground at the exact same time.

The radar does various functions such as: track while scanning, single target track and air combat mode. The modes aren't unique, but the AESA makes them even better.
Air combat mode allows the pilot to initialize a beam along the line of sight of the helmet mounted display. This capability is useful when the pilot wants to queue the radar along the helmet line of sight.

The result is an immediate lock as well as simultaneously generating a fire control solution for missiles and gun employment.

Prior to the helmet this could only be done through the head up display, which basically looks forward only. This advanced radar can also perform numerous air-to-surface functions such as ground-moving target indication and ground-moving target track. It can image the ground with high resolution.

The advantage of synthetic aperture radar is pilots get targeting imagery even through the clouds and light precipitation enabling them to see what's on the ground.

The F-35 also has color-weather radar. For the pilot who is trying to get through thunderstorms, squall lines, and fronts; the color-weather radar is important, and marks a first for fighters.

Most of the time fusion commands the radar to detect and track targets without much, if any, pilot involvement. Fusion uses the radar as one of its inputs and displays the result to the pilot and shares fused tracks with the other F-35s on the network.

The Distributed Aperture System

The Distributed Aperture System (DAS) is a new and unique sensor.

The DAS is comprised of six staring focal point arrays.

These are infrared cameras flush-mounted on the skin of the airplane, which detect the entire sphere around the airplane – that's 4 pi steradians for the mathematically inclined. The entire sphere is about 41,000 square degrees whereas the radar sees about 10,000 square degrees.
There is an intersection of the two sensors however. Where they're both looking through the same angular volume of space, fusion will work them synergistically, and they can queue each other.

Fusion really does the queuing. As soon as one sensor detects something, fusion then queues every other sensor to look along that line of sight and try to find information about the track.

The impressive thing is that this occurs without pilot involvement.

When fusion recognizes a DAS track is in the same angular space as the radar it will indicate to the Radar: “Radar, go look along this line of sight and get range on this track that DAS found.”

Or if the radar has a track and it gimbals, or in other words, the track goes beyond the radar’s field of regard, fusion will tell DAS, “You keep updating this and hold onto the track for the pilot until it comes back into the field of regard of the radar or comes back into the field of regard of some other sensor on the airplane,” according to Skaff.

It is this synergy of the sensors onboard the airplane and the fact that the fusion engine is doing this for the pilot which results in a manageable cockpit workload.

These things are laborious for the pilot to control manually, but are easy for a computer to control algorithmically.

The F-35 is returning the pilot to the role of tactician.

”The DAS performs a number of functions. It does short range situation awareness infrared search and track (IRST). For the pilot, the days of someone sneaking up on him are almost gone. In clear air, it can detect and track other airplanes by their thermal signature.It also does missile launch detection, which is its primary function. It’s tuned to a spectrum such that it can see rocket motors. If it detects a launch, it will say, “Launch, right 2:00 low,” according to Dr. Skaff.

(Note:the systems really do annunciate this message to the pilot).

In this instance, fusion will place a symbol on the helmet visor around the missile and the launch point. Pilots often say: “If I can see the missile, I can defeat it.” With a symbol in the helmet-mounted display the pilot will know there’s a missile inside the symbol even if he can’t see the missile with the naked eye.

The other function DAS performs is called GTL, ground target launch. This is the ability of fusion to extrapolate the DAS missile track back to the ground. Fusion places a symbol on the head down display at the point of origin.

This is a tremendous capability for the pilot and especially for other F-35 pilots in battlespace.

Fusion will automatically place the GTL symbol on all of our displays so that we can avoid the launch site.

The last function DAS does is imaging. This is a fall-out capability, which allows the pilot to look through the DAS cameras.

Each of the cameras is seamlessly stitched together to present the full sphere of imagery for pilot use. The pilot can look straight down through the airplane or look anywhere throughout this sphere even on the darkest of nights.

EOTS

The electrical optical targeting system is called TFLIR on the cockpit displays. The targeting forward-looking infrared (TFLIR), is a familiar term that's been used in other airplanes. The F-35's TFLIR is very similar to the SNIPER targeting pod and can do most of what SNIPER does.

It is a high magnification thermal imager which looks along a line of sight and performs tracking and imaging functions.

Here is the most important feature: it's mounted inside the airplane.

If you look at an F-16, F-15 or even a B-1, the TFLIR pod is big and hangs outside in the airstream. Consequently, it results in a lot of radar cross-section and a lot of aerodynamic drag.

To have this pod reengineered small enough to fit up inside the airplane is a key enabler. It looks out through a window under the radome.

The TFIR's line of sight may be controlled manually by the pilot or automatically by fusion. Fusion does an extremely good job, which means the pilot has one less thing to manage.

The Electronic Warfare Suite

The plane has an electronic warfare suite. It has multiple functions and performs in an integrated manner with fusion.

Some of these functions include radar warning receiver (RWR), electronic support measures (ESM), and electronic countermeasure (ECM). These are functions that are federated on most 4th generation fighters.

In the F-35, the electronic warfare suite has all of these functions built into it, and it's able to use the antennas all around the airplane, including the multi-function array, all under fusion control and with minimal pilot involvement.

As the airplane flies through battlespace, the EWS is tasked by fusion to build a picture of the electronic order of battle. It identifies emitters, locates them, classifies them and then reports to the pilot what it detects in battlespace.

CNI

The Communications, Navigation, and Identification (CNI) suite is a software-defined radio.

This means that there really aren't radios in the traditional sense in an F-35. There is one real physical radio in the airplane hooked to the battery for emergencies, but other than that, everything else is a software radio.

Radios don't exist until the pilot instantiates them with software.

The CNI system actually builds the radio in software once the computers initialize and run their programs.

Radio frequency (RF) waveforms such as Link 16, multi-function data link, instrument landing system, and voice get defined and built in software rather than being fixed in hardware. This scheme allows for tremendous growth and opportunity for change.

New data links and new waveforms are created in software, which, in many cases, means no new hardware to buy and install.

The Implications for Combat Learning and Evolution of the F-35

The F-35 was designed based on lessons learned.

The most salient lessons learned were from the world's only other 5th generation fighter. The F-22 was developed more than a decade ago, and engineers now have the benefit of newer technology and lessons learned.

The F-35 is the next step in the line of 5th generation fighters.

One of Col. John Boyd's legacies is the famous OODA loop: observe, orient, decide, and act. He said that to be decisive in combat the fighter pilot must run through his OODA loop faster the enemy can run through his.

Advanced fusion is the key enabler which allows a 5th gen fighter to do just that.

Advanced fusion is at the heart of the 5th generation. We are closing in on a software-defined airplane.

While the F-35 isn't quite there it is the closest to achieving that vision than any aircraft yet.

See also the slide show on the fusion engine and the text of that slide show contained within it

http://www.sldinfo.com/whitepapers/the-f-35-combat-systems-fusion-engine/

Shaping a Manageable Workload for the Pilot

The cockpit, the helmet, the fusion engine were synergistically designed with manageable workload in mind.

At the beginning of the program, 15 years ago, our design goal was "low workload." We came to understand that low workload might not be possible during all phases of the mission. In a dense target area with modern air and surface threats low workload is not realistic.

We changed our approach and now we say "manageable single seat" workload which is a realistic objective.

The software is designed to provide situation awareness, manageable workload, and usability.

The approach is pilot friendly and designed around enhancing his or her combat effectiveness. It corrects many issues found in fourth generation airplanes that relied on simply bolting on new sensors and displays.
New hardware and better capabilities are good, but there is a point of diminished returns as we add workload and contribute to information overload.

Fifth generation hardware and software integration is done with the core purpose of freeing the pilot to become a better tactical operator and to re-shape how the aircraft can contribute to air, ground, and surface operations in a joint or coalition fleet.

It is about enabling a different concept of operations for the future.

Fourth generation aircraft have added disparate technological capabilities, which can lead to information overload.

For instance, datalinks; datalinks are great tools and nobody wants to do without it them, but if it's not fully integrated with an advanced fusion architecture it may result in information overload for the pilot.

The F-35 is not just a stealthy F-16. Credit Photo: Lockheed Martin

The needed information is there – somewhere – it's just hard to find it, to mentally correlate it, and then to act on it.

Information overload leads to pilot task saturation and channelized attention, which has a negative impact on survival. Pilots may become preoccupied trying to interpret information when they need to be focused elsewhere.

Here's an example to which we can all relate: Imagine your driving a car while studying the GPS or talking on the phone. Your safety is decreasing and your performance is suffering. It's an example of misdirected focus and channelized attention.

The same holds true in the cockpit. Displays with information overload are focus magnets. It drains more and more of the pilot's processing capacity as it takes an increasing amount of his attention to interpret data.

Consequently, safety and performance are compromised.

During those periods of channelized attention pilots become vulnerable. They may no longer be lethal. They're certainly less survivable, and safety has been negatively impacted, even in the peacetime environment.

From the beginning of the program, we set out to design a fully integrated sensor suite coupled to an advanced fusion engine shared by other F-35s in the formation.

Next, we had to provide an easy to understand picture of battlespace in order to facilitate making tactical decisions based on that Common Operating Picture.
Instead of being buried by technological innovation, the pilot is now in a position to master it; adding technology in an integrated fashion doesn't make the situation worse, it enhances it.

The 5th generation design approach starts at the beginning.

You've got to plan for:

- Internal fuel
- Internal weapons
- Agility
- Stealth
- Autonomic logistics
- Fully integrated sensor suite
- Advanced sensor fusion
- Network enabled.

We're getting more than the sum of the parts because everything is designed to be integrated in, not bolted on.

We must also design for change – primarily software change, but also tech refreshes which upgrade the internal processors. This means a block upgrade approach is part of the design process. We are getting closer to a software-defined airplane.

Managing workload and then providing tools that build and maintain situational awareness pursuant to information dominance is the goal. It's more than just delivering a weapon system to the users. It's a paradigm shift.

The F-35 is not just a stealthy F-16. The F-35 shifts how pilots operate by returning them to the role of tacticians in battlespace.

The focus is on multiplying performance by using the synergy available through the fusion engine, which assembles and displays the Common Operating Picture.

Rather than information overload we jump the gap to information dominance, which enhances lethality and survivability of each pilot by providing a fleet wide integrative capability.

Flying with the Common Operational Picture (COP)

The advanced fusion engine enables connected F-35s in battlespace to share the COP. Each plane is synergy enabled.

The shift from radio to a visual COP is a key definer in the shift from legacy aircraft to 5th generation fighters.

20 years ago radio was the tool for pilots to create synergy.

A good flight lead was able to describe battlespace to his wingmen, and that was the key. If you couldn't describe battlespace and build a picture inside everyone's mind, then it was difficult to maintain mutual support let alone combat synergy.

Now modern 4th generation fighters employ datalinks which have improved information sharing. Most have some type of datalink, which begins to give them synergy, but it's not the same as designing a weapon system from the beginning to be synergy enabled.

With the COP (generated by fusion from all of the sensors in my airplane and yours, presented in an easy-to-understand graphical view of battlespace) the pilots can now share common situational awareness.

Every connected F-35 sees the same thing.

The synergy we possess does not depend on the pilot's ability to mentally fuse and correlate multiple sensors into a picture, and then communicate it verbally. We share the picture automatically which means Blue-4, a brand-new F-35 pilot, sees the same picture that Blue 1 is seeing who has 1,000 hours in the jet.

Not only that, the lead pilot can see what I'm doing and may be able to catch minor mistakes that I'm making, or he can direct me if he sees ways that I'm not using the airplane as we briefed.

It is almost like having an instructor with you all the time. Nobody wants to fly with an instructor full time… except in war. It's good to have somebody who's better than you are because the stakes are high.

Fourth generation datalinks are important and nobody would give them up, but they are not typically well integrated into the weapon system. They are an add-on, much like a new sensor or new pod and must be managed and correlated which can cause information overload.

The COP gives us a visual vice verbal approach to generating synergy.

It's synergy in a picture rather than words.

Of course, looking at the COP for a pilot with 1,000 hours of experience is going to be different than a newbie on his or her first mission. You can't teach judgment and experience, but we can begin to bring the valleys of inexperience up quickly and in such a matter that we have a positive effect on lethality and survivability.

The focus is on time – which is a precious commodity in tactical employment.

Rather than pilots spending time constructing a mental picture of the battlespace, the F-35 constructs this picture for them and presents it graphically.

Remember the core philosophy: return the pilot to the role of tactician by managing workload and providing situational awareness that leads to information dominance. One great way to do this is by returning time to the pilot. This is time needed to evaluate the battlespace and to be a tactician.

Picture: "Squirt" Kelly, Test Pilot of the Year, is shown with his F-35 Helmet. Credit Photo: F-35 Joint Program Office

The COP approach is symmetrical with the generational transition. The visual world is where the next generation of fighter pilots will live and operate.

The next generation LIVES in a graphical world, and they tend to process tasks graphically.

Legacy 4th generation aircraft were forged in the MS-DOS world, which was textual rather than graphical. Apple came on the scene and caused a paradigm shift. The shift was to interacting with technology through graphics.

That same shift has finally made it to the tactical cockpit.

The generation to which we're referring is the millennials. We built the F-35 weapon system for them, and we've had to remind ourselves that we are not building the F-35 for current 4th generation pilots. We're building it for the future ones.

"I admit the paradigm shift in the cockpit is challenging with an HMD in lieu of a HUD, voice control, touch, and the PCD. We introduced risk into the cockpit, but it will pay huge dividends in lethality and survivability for the next generation of pilots." says Michael Skaff, principal engineer for the F-35's pilot vehicle interface.

If we're going to defeat the enemy, then we have got to cycle through our Observe-Orient-Decide-Act (OODA) loop faster and better at every level, including the graphical level.

We built a fighter, which is targeted toward a new generation of pilots. The men and women who are in their first year at the academies right now will probably hit the fighter pipeline just about right to be the first Lightning II pilots right out of flight school. These folks are millennials.

Between F-35s we build synergy, which is greater than the sum of the parts.

The synergy extends to sensor control. This means that in your cockpit you can actually use my sensors. You don't really take control of my radar or my EW, but as you interact graphically with your display my sensor suite may get tasked to help with your solution.

The COP has impacts on the flight debriefing and the entire learning process as well.

The COP has merit beyond real time use. It has value before the mission. Before we fly into battlespace I would like the benefit of someone who was just there. In the past this was done verbally. F-35 pilots just returning from a mission have the most recent and relevant view of battlespace. I would like to speak with them about what they encountered and better yet… I'd like to see the COP from the target area.

We aren't quite there, but in the near future, the airplanes that took off this morning and flew through the battlespace and gathered essential elements of information will come back with a digital representation of what they encountered. Then, we'll download that information into my jet prior to takeoff. This means as we mission plan, we won't start from a blank slate. We'll start from their slate.

The COP and the fusion "engine" set in motion a whole new combat learning process.

There are datalinks on 4th generation fighters such as Link 16 and others; and to some degree Airborne Warning and Control System (AWACS) can put a picture into an F-16. That's helpful, and it's worth having.

But, the problem with this approach is twofold: the link waveform is observable and it's not well integrated into the sensor suite.

The first issue means the enemy may be able to detect the datalink and track the users and ultimately target them.

The second issue, although contributing to situation awareness, greatly increases workload. Fourth generation datalinks do not get us to information dominance.

We need a private data link, which is fully integrated into the advanced fusion architecture. This is Multifunctional Advanced Datalink (MADL) on the F-35.
Advanced fusion and a private datalink are the key enablers.

We are seeing the evolution from voice, to datalink, to a private data link, which is fully integrated into the weapon system.

We also recognize that we need to put more and more of our assets on this private data link. MADL has a bright future.

Software Upgradeability Built In

The F-35 is built upon a 21st century foundation in many ways.

One of the most crucial is the computer, chips and software foundation. The chips in the central onboard computer are designed to be swapped out every few years, as technology progresses. The software is upgraded over time, through a block process.

But each block represents the most mature capability for the aircraft at the time the block is released.

And the aircraft is fully functional from Block 2 onwards.

In a real sense, the software will never be finished for the F-35.

It will evolve over time as new code is written and technological refreshes are done to further enable the performance of each block of software.

The airplane was designed with technical refreshes built in, knowing that we would want to change hardware and software on the way, even in the SDD phase of the program. Initially, we designed for two technical refreshes.

We call them "Tech Refresh One" and Tech Refresh Two".

In the case right now between Block 2 and Block 3, there's a tech refresh. The software remains but it just runs better. It's very much like going to the store, buying a new computer, and running your existing software but it runs better.

With each Block, we add more and more capability, but we can leave much of the existing software in place as a foundation that we're going to build on.

For example, Block 2 introduces all of the data links-- the link 16, the Multifunction Advanced Data Link, the variable message format, etc. are included in Block 2 which is the USMC initial aircraft.

Also included in Block 2 are some of the core weapons to be used by the aircraft.

Block 3 will include a full up of additional weapons integrated within the aircraft, and includes the strafe and air-to-air gun as well.

Block 2 is the first time that the airplane would be ready to go to war because now it can use weapons. The sensors are integrated; fusion is working; the data links work. You could take that to war and you could do better than any fourth gen airplane.

With Block 3, at the end of SDD, the plane is fully capable with everything that we were put on contract for and then beyond this phase, Block 4.

Each block builds on the foundation of the previous blocks.

There's no throwaway code inside the blocks. With tech refreshes, we can change the hardware associated with the computer and systems between Blocks 2 and Blocks 3 to make that code run faster and better. The cards and the chips are replaced in the upgrade to Block 3.

You're really not changing the airplane. You're not buying a new pod or a new sensor.

All of those sensors are installed in Block 1; they're in the current airplanes right now, rolling off the assembly line. You're putting in a new graphics card, a new central processor, so that that the hardware and sensors work even better.

It is analogous to what one does at home when one uses new software and finds that software constrained by the hardware necessary to run the software. Your computer has become bogged down because you've put such a software burden on it. It has gotten slow and clunky and so you go to the store and you buy a new chip set, a new motherboard, a new graphics card, and you install that and suddenly the software that was slow and clunky yesterday has become smooth and fast.

When we say, "A hardware upgrade," often folks are thinking we are talking about new things to put onto the aircraft. Well, there aren't new things.

All of the things are already in the airplane at Block 1, so the airplane's currently coming off the line. Everything is already in there: the radar, the electro-optical targeting system, the distributed aperture system, they are all in there.

What we're doing is upgrading the computers that work the systems, and the computers are working just fine. They were designed to handle the entire Block 2 load, but they will be at their limit for Block 3 and beyond.

So the tech refresh, will put in new computing power because we're looking to the future, and let's pay for that in this phase of the program and not five or ten years from now. Let's get it done early while it's available and relatively inexpensive compared to five years from now.

Another example would be how one might approach buying a laptop. When you want to buy a new laptop and you go to Best Buy, you know the moment you buy that laptop, in six months; there'll be something better that's a little bit cheaper.

So what if Best Buy said, "In order to entice you to buy," they said, "You buy this laptop today from me, and I guarantee that in three months, we will swap out the chips or the motherboard for free, that we'll make it as good as the one we're going to sell in six months."

You would say, "Yeah, I'll take that deal in a heartbeat," because otherwise, as a consumer, we'd keep waiting and waiting because knowing in six months there'll be something better for a little bit less.

Built into the program, we did that.

"Buy now and we will swap out the guts of this airplane, the processing power, between Blocks 2 and 3 for you."