Some F-35 Sensor Fusion Information with comments by some pilots & the main designer of the F-35 cockpit Michael Skaff

HMDS F-35 High Tech Helmet Pilot LtCol Lee 62FS CO 2019

https://www.youtube.com/watch?v=RVmLZekvdS4

http://www.airforcemag.com/MagazineArchive/Magazine%20Documents/2018/July%202018/Air%20Force%20Magazine%20July%202018%20Full%20Issue%202018.pdf

'Such A Capable Helmet'

by Frank Colucci
July 1, 2010

The Helmet Mounted Display System of the F-35 Lightning II provides the pilot with situational awareness from multiple sensors, slews weapons to head moves.

Stealthy, supersonic and sensor-rich, the Lockheed Martin F-35 Lightning II, or Joint Strike Fighter (JSF), will engage air and ground targets day or night. Key to using the F-35 in combat is a Helmet-Mounted Display System (HMDS) that superimposes flight and target symbology on the view seen through the pilot's helmet visor. This virtual Head-Up Display slews sensors and weapons to pilot head movements, and it enables the wearer to de-clutter the picture and zoom into targets with hands on sidestick and throttle.

A second-generation HMDS flew for the first time on a Marine Corps F-35B in March as part of program's System Development and Demonstration (SDD) phase. Manufacturer Vision Systems International (VSI), meanwhile, is building Low Rate Initial Production (LRIP) displays for the F-35 fleet.

By April, the LRIP display had been integrated with other pieces of the F-35 mission system on the Lockheed Martin Co-operative Avionics Test Bed (CATBird), a modified Boeing 737-330 designed to validate F-35 avionics.

"That's what makes this a very challenging program," acknowledged VSI President Drew Brugal. "SDD is going concurrent with the LRIP. The pilots are constantly evaluating the system, making recommendations."

The F-35 blends radar, electro-optical and datalinked intelligence with digital maps, threat warnings and systems data on a 20-by-8 inch L-3 Display Systems panoramic cockpit display.

"It's a fifth-generation airplane with fifth-generation sensors," noted Brugal. "The whole idea of this helmet is multi-sensor fusion.... You can bring several different images together in the pilot's field of view."

The HMDS shows imagery from the Northrop Grumman Electro-optical Distributed Aperture System (EO DAS) annotated with composite symbology from other sensors. The head-slaved display affords all-round situational awareness and enables the pilot to see "through" aircraft structure via remote apertures. "If you can show it on a screen in the cockpit, you can bring it up on the visor," Brugal said.

As currently integrated, the VSI helmet display does not now show the F-35 pilot magnified imagery from the aircraft's Lockheed Martin Electro-Optical Targeting System (EOTS) or Synthetic Aperture Radar pictures from the Northrop Grumman active electronically scanned array (AESA) radar. Target analysis and designation are done largely on the cockpit display.

HMDS symbology nevertheless

promises to reduce target location errors with the combined input of multiple sensors. Don Bolling, senior manager for business development with Lockheed Martin Missiles and Fire Control noted, "The thing that makes the F-35 very unique and powerful is that it has a fused architecture where all the sensors are working together. You don't necessarily know whether that information comes from DAS, the EOTS or the radar."

Clear View

VSI, based in San Jose, Calif., was formed by Elbit Systems Ltd., and Rockwell Collins to manufacture and market helmet displays for fixed-wing aircraft. The joint venture received an HMDS LRIP contract in 2009.

"The best way to think of it is anything that stays in the airplane is made by Elbit. Anything that is on the pilot is made by Rockwell Collins," Brugal explained. Cockpit transmitters for the electromagnetic head tracker, for example, come from Elbit while helmet receivers are supplied by Rockwell Collins.

The HMDS shell is made by Helmet Integrated Systems Ltd., in Stranraer, U.K., and personalized with a laser map of the pilot's head.

An Elbit display management computer interfaces the aircraft databus with the HMDS. A coaxial cable runs from the upper right side of the helmet down behind the pilot's neck through a plug by the ejection seat to carry power, video feed, data feed and head position data.

DAS imagery or the unenhanced view through the polycarbonate visor is annotated with green monochrome symbology at all times to provide airspeed, altitude, heading, velocity vector and other spatial references. VSI Chief Technology Officer Bob Foote noted that color symbology would be technically difficult and is not part of HMDS requirements. "Our requirement from the JSF community is resolution, resolution and resolution and brightness," Foote said.

Elbit provided HMDS software for the F-35 flight sciences test aircraft. In production fighters, the pilot will see symbology created by Lockheed Martin. "Those same symbols that he sees in the cockpit are replicated in front of his face," said Brugal.

Without the color cues available on head-down displays, Lockheed Martin engineers flag items with flashing, cross-hatching and other man-machine interface tricks. "We make the machine so powerful, they can do just about anything they want. Our job is to provide good resolution and good tracking to implement it." Foote said.

HMDS tracking accuracy is classified, but the head tracker from Elbit in Haifa, Israel, uses magnetic and optical references continuously to maintain confidence in the solution. "We have a requirement that there be no sort of alignment on-aircraft by the pilot," explained Foote. "The optical portion of the tracker system provides an accurate auto-boresight to achieve this capability."

VSI supplies the Joint Helmet Mounted Cuing System (JHMCS) on jet fighters around the world. The JHMCS uses a stroke display to put targeting symbology on a 20-degree circle over the pilot's right eye. The head-tracking display steers aircraft sensors and missile seekers in high off-boresight engagements. It does not show the pilot sensor video or flight symbology, and it needs a QuadEye replacement assembly at night.

In contrast to the monocular JHMCS, the binocular HMDS covers a 30 by 40 degree field of view and supplements projected day and night video with raster-like symbology. The field of view is determined by packaging tradeoffs. "You have a limited amount of space available on the pilot's head," Brugal said. "You can only displace those projectors so many degrees. Displace them farther, and the helmet gets very wide and causes interference."

The first-generation HMDS used a bifurcated visor to provide a 50-degree horizontal field of view. However, test pilots who flew the first helmet in U.K. Hawk trainers and the first F-35, AA-1, noted the witness line between the display segments. Raising the early visor also required the user to raise the entire optical unit. "You typically wouldn't be doing that in flight because there are a lot of moving parts." Brugal observed. The second-generation HMDS has a continuous-curve visor that slides up and down easily.

F-35 requirements say the ejection-safe HMDS can weigh no more than 4.5 pounds, slightly less than the JHMCS. VSI engineers leveraged flat-panel display technology to replace cathode ray tubes.

"That saved a considerable amount of weight," Foote said.

A partially mirrored coating on the see-through visor, meanwhile, eliminated the heavy optical combiner and supporting structures of past helmet displays. "We've made a fairly sophisticated train of optics that allows us to bring the display from the back of the guy's head to the visor," Foote said. The HMDS also benefitted from modern computer-aided design technology. According to Foote, "The CAD tools have gotten much, much better. We can design to closer tolerances."

Big Picture

The HMDS night imaging capability comes from sensors on the helmet and on the aircraft. On the helmet, an Electron Bombarded Active Pixel Sensor (EBAPS) from Intevac, Santa Clara, Calif., sends imagery directly to the visor. The camera works in the same wavelength as night vision goggles (NVG). "The sensitivity range is in the same range as image intensifier tubes," said Foote.

Though the 1280-by-1024 pixel camera does not have the acuity of the latest NVGs, it does provide the 700-line video required for F-35 pilots to land at night. According to Foote, "It's not really meant to be the main night sensor."

By day and night, the F-35 AN/AAQ-37 EO DAS (Avionics, August 2008, page 10) provides spherical coverage with near 20-20 visual acuity. Imagery from the half-dozen infrared sensors around the aircraft gives the HMDS a seamless picture anywhere in the EO DAS field of regard. The EO DAS also plays missile warning receiver to cue the F-35 pilot and weapons to threats on the ground. The pilot can turn EO DAS helmet imagery on or off and stabilize the image at a given point to look away, study targets on the head-down display and return to the head-up scene. The HMDS also cues the pilot to air and ground threats outside the immediate field of view.

In contrast to the fish-eyed EO DAS, the AN/AAQ-40 EOTS affords high magnification in a narrow field of view. EOTS packages a mid-wave forward looking infrared (FLIR) imager with a laser spot tracker and target marker. As an air-to-ground targeting sensor, the FLIR covers a 360-degree field of regard below the aircraft horizon. The F-35 pilot who spots an air defense or artillery site in the EO DAS helmet picture can slew and zoom the EOTS to the spot for closer study on the cockpit display. Air-to-air, the EOTS provides infrared search and track (IRST) symbology with target identification, azimuth, range and kinematics.

Like the EOTS, the Northrop Grumman AN/APG-81 radar generates HMDS cues for the pilot in combat. The high-resolution radar with Ground Moving Target Indicator functions zooms into ground targets or tracks and prioritizes targets in the air. “It’s really a target designator, whether it be an air-to-air target or a designated point on the ground. Any of that stuff can be put on that symbology on the HUD. You have an arrow pointing to that target in space,” said Peter Bartos, Northrop Grumman fifth-generation improvements and derivatives manager.

With all the sensors and symbology going to the helmet, HMDS engineers worked to traffic high-volume data without latency. Post-JHMCS processors gave them faster hardware, and some built-in prediction algorithms enhanced HMDS software. “Also, we very closely couple the head tracker and the image processing,” said Foote.

The same dedicated processor that tracks head orientation and position manages graphics. F-35 test pilots report the latency of early displays solved, but Foote acknowledges, “There’s going to be some lag; you can’t make it zero.”

The F-35 is due to achieve initial operational capability in 2012 with the U.S. Marine Corps, 2013 with the Air Force, and 2014 with the Navy. International operators will follow soon after, all using the HMDS. VSI has already received inquiries about HMDS for other platforms.

“There are helicopters who are considering this level of HMD. We are actively talking with the different services about applications on transports, gunships and other platforms,” Brugal said. “Obviously, we’re exploring those because the larger installed base, the lower the price point. The quality of the HMDS and its capabilities are very attractive on platforms you wouldn’t think would consider such a capable helmet.”

http://www.aviationtoday.com/av/issue/cover/Such-A-Capable-Helmet_68788.html

Shaping the F-35 Combat System Enterprise 22 Mar 2011 http://www.sldinfo.com/?p=16861

"...BARTOS:..."DAS is always tracking every aircraft nearby, in every direction, simultaneously, and looking for inbound missiles at the same time. F-35 mission fusion software keeps targets and IDs sorted out, even in a dynamic turning dogfight or when a target is directly behind you.

While flying an F-15 in a dogfight, I have to constantly swivel my head to manually detect and track adversaries and wingmen with my eyes. Situational awareness breaks down quickly, and I'm suddenly wondering if that distant object I'm looking at is an F-15 or an adversary aircraft. I've flown against MiG-29s, and it wasn't until I was up close and saw the paint job that I could be positive it wasn't an F-15. With your head and eyes shifting back and forth under high G loading in a turning fight, it is very easy to lose sight, get confused, and misidentify aircraft.

Data link update rates are too slow for ID purposes in a dogfight. ID correlations frequently are swapped from wingmen to bandits and vice versa as they streak past your jet and swap sides. The F-35 isn't going to lose those IDs; it isn't going to lose that situational awareness because there is always at least one sensor with high update rates tracking the various aircraft. In fact, you may even do better by just looking at your situational awareness displays or helmet symbology rather than at the confusing swirl of airplanes to visually sort out good from bad.

And if a missile is shot at you in the F-35, you'll see it coming whether it is smokeless or not. You can take the appropriate measures, or just let the aircraft automatically provide the countermeasures. In 95 percent of the air-to-air kills in history, the victim had no idea he was being shot at. Unless you're referring to the other guy's loss rate, that won't be the case with the F-35."

A White Paper By: Lockheed Martin – An Overview of The F-35 Cockpit

2.4Mb PDF: http://www.f-16.net/f-16_forum_download-id-15870.html

"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 off-board 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."

http://www.sldinfo.com/whitepapers/an-overview-of-the-f-35-cockpit-what-5th-generation-aircraft-are-all-about/

The F-35 Cockpit: Enabling the Pilot as a Tactical Decision Maker

"Dr. Michael L. Skaff created this briefing. Skaff described his background in a recent interview as follows: I was an F-16 pilot out of the Air Force Academy. I was prior enlisted, & 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. For a full discussion with Skaff regarding the baseline F-35 please see: http://www.sldinfo.com/understanding-the-basic-f-35-what-is-in-the-baseline-aircraft/

http://www.sldinfo.com/whitepapers/the-f-35-cockpit-enabling-the-pilot-as-a-tactical-decision-maker/

End of page quote below is about the last two graphics as seen above (13th & 14th slides).

"...The HMD with vHUD opens the view into over 41000 square degrees. This is the full sphere surrounding the aircraft. {Refer to next 2 vHUD graphics}

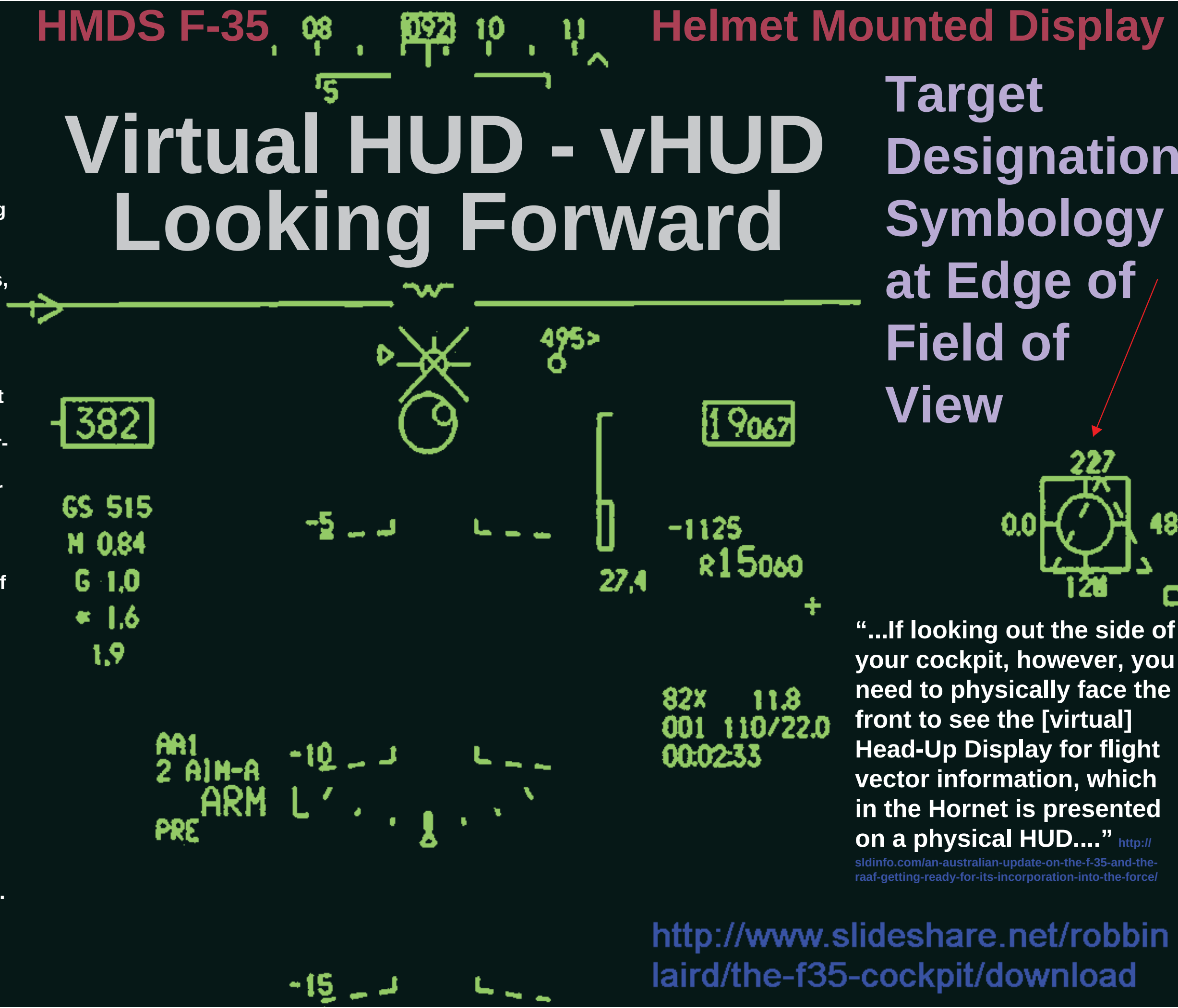
The thirteenth slide provides an example of the vHUD when the pilot looks directly forward where a physical HUD would be. F-35 pilots report that in about 10 minutes they become accustomed to the vHUD. The pilots recognize the potential improvements in lethality and survivability of the HMD. [vHUD=Virtual Head Up Display]

The final slide provides an example of off axis symbology. In general, Lockheed only take key flight parameters & tactical symbology off axis. In the future Lockheed will investigate off axis attitude awareness symbology. The mil standards don't yet address HMDs & off axis symbolgy. Lockheed will work with the Services to improve and update the standard as well as the HMD symbology."

HMDS F-35 Helmet Mounted Display

Virtual HUD - vHUD Looking Forward

Target Designation Symbology at Edge of Field of View



"ABSTRACT: Laboratory and flight test evaluations have consistently demonstrated the potential for helmet-mounted display (HMD) presented information to enhance air combat performance. The Air Force Research Laboratory's (AFRL's) Helmet-Mounted Sight Plus (HMS+) program seeks to provide further enhancement by enabling the presentation of multi-color symbology and sensor imagery. To take proper advantage of color-capable HMDs, systematic evaluations must be conducted to identify the best color-coding techniques. The experiment described here is the second we have conducted to address this need. The first experiment identified the better of two competing color coding strategies for air-to-air weapons symbology and indicated that pilots preferred the color codes over an otherwise equivalent monochrome baseline. The present experiment compared the "winning" color code to the monochrome baseline during trials of a complex multi-player air-to-air weapon delivery scenario. Twelve fighter pilots representing three different countries (U.S., U.K., and Sweden) flew simulator trials that included target identification, intercept, attack, missile launch, and defensive maneuvering tasks. Participants' subjective feedback and performance data indicated a preference for color coded symbology."

Helmet-Mounted Display Targeting Symbology Color Coding: An Air-to-Air Scenario Evaluation 1999 | Eric E. Geiselman and David L. Post, Air Force Research Laboratory, WPAFB OH 45433-7022:

http://www.dtic.mil/dtic/tr/fulltext/u2/a430137.pdf

"...If looking out the side of your cockpit, however, you need to physically face the front to see the [virtual] Head-Up Display for flight vector information, which in the Hornet is presented on a physical HUD...." http://sldinfo.com/an-australian-update-on-the-f-35-and-the-raaf-getting-ready-for-its-incorporation-into-the-force/

http://www.slideshare.net/robbinlaird/the-f35-cockpit/download

Helmet Mounted Display Looking Behind the Aircraft

Enemy Air Target Designator Symbols

F-35 EOTS Video

https://www.youtube.com/watch?v=L2q65qOl1tM

Video: F-35 Helmet Display System

https://www.youtube.com/watch?v=w0btzIvlScI

F-35 Helmet Mounted Display

Ownship Missile Inflight

http://www.slideshare.net/robbinlaird/the-f35-cockpit/download

THE F35B PILOT'S NEW HELMET AND DAS: A HUGE LEAP IN AIR-GROUND DECISION-MAKING SHARING - **Re-Shaping Tactical Capabilities**

http://www.sldinfo.com/?p=9192


Lieutenant-Colonel Dehner

The pilot on the F-35B is really a centerpiece of what we are calling the three-dimensional warrior. The new helmet and the interactions between the pilot and the systems on the new aircraft provide the hub for new operational capabilities.

In this interview, SLD talks with USMC aviator Lieutenant-Colonel Dehner from Headquarters Marine Corps, Aviation. Lieutenant-Colonel Dehner is involved in shaping how the new helmet will enhance the warfighting capability of the F-35B he is part of the JSF cell at HQMC and is currently the USMC test coordinator for F-35 and has flown with prototype test helmets in the F-35 concept of operations simulators.

SLD: You are involved with the program for the development and testing for the new helmet for the F-35B. Could you describe how the systems on the aircraft shape a new environment within which the helmet functions as well?

Lieutenant-Colonel Dehner: One of the new operational capabilities of the F-35B is its ability to sense the IR energy or the heat coming off the environment, a full 360 degrees around the aircraft. It's as if you are in the middle of a soccer ball : this is how I always picture it looking out through the facets. I have these IR sensors all around me. And then the aircraft also detects more of the electromagnetic spectrum similar to a Prowler. So, you do really have a lot more information that's coming in or is available to be understood.

This capability shapes the classic question of how does one put information in a way that a human being can understand and act upon it? Part of the answer is the way the information is displayed which enables the pilot to be a tactical decision-maker. You gain this God's eye perspective of the world. So, instead of being very mechanically-driven like we are in our current aircraft, in which I have to help move the radar around to make it do it's thing, I can pull back and allow the systems on the aircraft to do that on it's own.

Now, that's only part of the answer. The next piece is the Distributed Aperture Systems (DAS), that is sensing the IR world all around me. You have camera eyes staring at all times around you, and how do I get that information across to a person that, obviously, can only look in one direction at any given time.

So the system's interface, the DAS imagery, gets projected on a patch on your helmet, which is an improvement or a next a step from our current helmet. So now, I have a window into this other world and I can look at information in the IR. And as I turn my head I'm looking at the world surrounding me with the DAS information coming across.

SLD: So that the DAS system works closely with the helmet and it creates a new environment for the pilot to operate in. You also were alluding to something I find interesting, which is this whole relationship between the classic tactical fighter and a specialized war battle manager, who's on electronic warfare aircraft. In fact those specializations will be broken apart by the F-35.

Lieutenant-Colonel Dehner: Absolutely. The classic tactical fighter was defined by the strike package where I'm going to have aircraft that will deliver weapons; I'm going to have fighters that will either clear the way or protect them while they go in. And then I'm going to have electronic attack aircraft to provide another level of support. In contrast the F-35, by design, will be able to do all three of those things with either the same aircraft or the same little family of aircraft. So, you can prioritize different roles such as : the two on the front are the fighters today, the third is going to pick up electronic attack, and the fourth is going to do the strike. But depending on how we're configured, we can actually flex that real time. "Hey, looks like the fight is actually more on your side. So, we can actually shift that focus of effort to the other aircraft." So, it just allows us an extremely flexible platform.

But with all that increased capability, you still have the same human beings that are flying aircraft similar to what we did 50 years ago. Now, you just have to essentially build up those pilots a different way. You take all the very classic training techniques; teach them how to actually fly the aircraft, teach them how to use the aircraft as a weapon and then, you've got to go down a different route that's more or less teaching them to be an information manager, because this aircraft really is an information sponge. This aircraft just creates this little information hub in the sky. And the pilots, their job is to be effective for their primary mission, but then also decide how to get this information to other people, not just other pilots but also to the ground, because maybe they're in a better spot to be more effective?

> **« The classic tactical fighter was defined by the strike package where I'm going to have aircraft that will deliver weapons; I'm going to have fighters that will either clear the way or protect them while they go in. And then I'm going to have electronic attack aircraft to provide another level of support. In contrast the F-35, by design, will be able to do all three of those things with either the same aircraft or the same little family of aircraft. »**

SLD: Tell us a little bit about the role of the helmet in facilitating what you described?

Lieutenant-Colonel Dehner: The helmet in the F-35 will display fused data, and creates a picture so that, literally, when I look down through what would be the skin of the aircraft, I still get that projection of the ground underneath me. So, if I am trying to locate a target, the current helmets will give you a little box or a symbol to highlight that target. But as soon as the wing of the aircraft gets in the way then I would have had to move the airplane physically to clear it out of the way. So, now I can see through the wing with this new system.

An immediate benefit is I don't have to move my aircraft into a spot that I might not want. For example, when we set up an orbit for intel, surveillance, reconnaissance, that ISR mission which is a lot of what we spend time doing. There are better paths in the sky for us to just stay within a relative distance, and I want to get a really good picture, so I'm just going to set up an orbit. But that instantly can flex with, oh, my wing might be in my own way, so you're going to end up flying these non-optimal formations. I'm going to move the wing out of the way so I can get a better look. Oh, now, I've got to get back on profile. That's a lot of the work that the pilot is up to. Now, I don't have to do that with the DAS.

SLD: How would you describe the changes in pilot behavior you see from this synergy of the DAS and the helmet? Or what kinds of changes might you see?

Lieutenant-Colonel Dehner: One of the other significant changes is just the way we actually can fly our formations and getting more out of the handful of aircraft in an area where we operate. With traditional tactics, we're going to be tied relatively close to each other, because I'm going to be checking for anybody shooting at you from the ground. You're going to be checking me. So, we tend to fly together. We don't have to, but you take it at risk if you don't.

But, all right, to get more aircraft over a larger area, we're going to separate. And you can only do that when you have very fixed-wing tolerant conditions. I'm not going to be shot at a lot, because I'm either at a higher altitude or the threat is just not there.

With the DAS, the computer is working for me all the time looking all around, making sure that no one's taking a shot at me. So that instantly is going to free up the pilot and then the squadron to just spread out over more space. And we're not taking on risk, or adopting a different procedure, which is how we'd mitigate the risk today, because I have a system on board. So that's the initial basic pilot behavior change that you'll see right away.

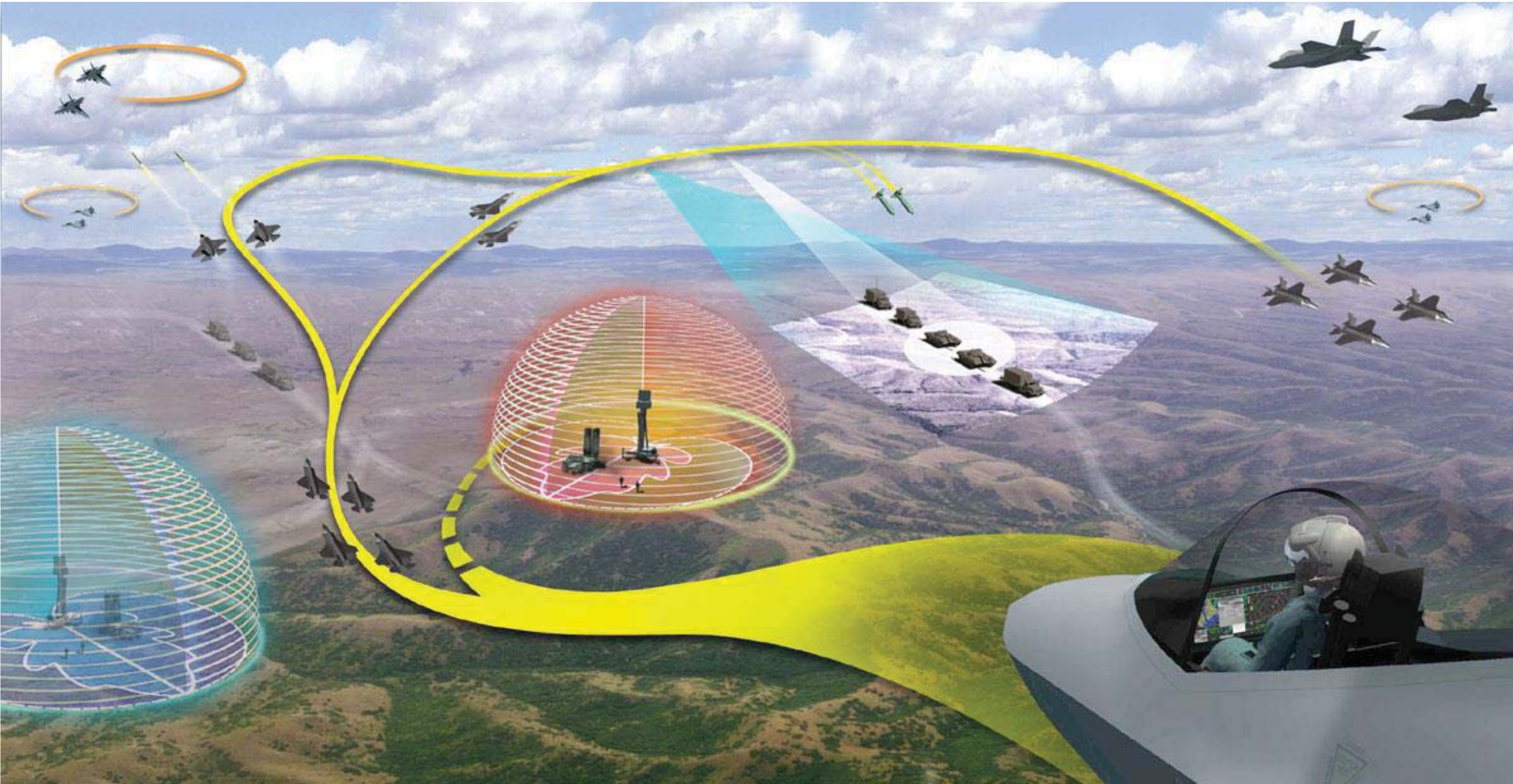
SLD: Final question: one of the controversies in Afghanistan has been control of collateral damage. It seems to me that this aircraft should help in this regard in a sense that by having a closer relationship enabled between the ground and the air element, the confidence level of using weapons in close support must clearly go up?

Lieutenant-Colonel Dehner: Precisely. The technology that we've enjoyed just in the last 10 years or so, has already improved that quite a bit. Now, this is going to be, again, that next huge step, because we're getting more information to the pilots, so that's going to make that pilot feel better about it. We've already started sending information down on our Legacy Aircraft. In the F-35, you're actually going to have more options of information to push down to those ground commanders for shared decision-making.

F-35 Mission Systems Design, Development, and Verification

Returning the pilot to the role of tactician

https://www.lockheedmartin.com/content/dam/lockheed-martin/eo/documents/webt/F-35_Air_Vehicle_Technology_Overview.pdf



The F-35 Cockpit: Enabling the Pilot as a Tactical Decision Maker

Dr. Michael L. Skaff created this briefing. Skaff described his background in a recent interview as follows: *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.* For a full discussion with Skaff regarding the baseline F-35

- **The second slide highlights the key elements of the basic F-35 cockpit.**

The highlights of the F-35 cockpit are:

1. **PCD -a large Panoramic Cockpit Display (PCD) which is a 20 x 8 inch contiguous piece of glass. The pilot interacts with this display through touch, cursor hooking, and voice recognition.**
2. **HMD - the pilot wears a Helmet Mounted Display (HMD) in lieu of a physical**
3. **Head-up Display (HUD). A virtual HUD (vHUD) is projected onto the visor. The vHUD is presented to each eye and is 40 deg wide by 30 degrees tall.**
4. **Audio & Voice – stereo wiring is used in the headset in order to facilitate full 3-D audio as a software upgrade. A Voice Recognition System (VRS) is used for "housekeeping" chores.**
5. **STOVL- the Short Takeoff and Vertical (STOVL) mode has been designed for safety and simplicity. The STOVL mode is extremely safe and easily trained to. In actual flight test non-STOVL pilots have been able to master it in solo on their first flight.**
6. **JPATS - the F-35 cockpit is designed to accommodate the full JPATS flying population from a 245lb man to a 104lb woman.**
7. **Escape- a Martin-Baker Mk-16 ejection seat provides for safe ejection. In the B-model, when in STOVL mode, the seat is automatically triggered to improve safety beyond the human's ability to react.**

- **The third slide focus upon the philosophy behind building the F-35 cockpit. The Pilot Vehicle Interface (PVI) design philosophy is "return the pilot to the role of tactician." Managing workload and providing the tools, which will build and maintain situation awareness, accomplish this.**

But more than that, information dominance is the design result. The F-35 is a complete weapon system and multiple F-35s are more than the sum of the air vehicles. When a flight or division of F-35s enters battlespace they become the dominant factor.

- **The fourth slide looks at the design philosophy for the controls and displays in the cockpit.The PVI was designed by pilot for pilots. This design approach views the pilot at the center of the of the air vehicle. From this point of view two control and feedback loops exist: 1) the internal loop and 2) the external loop. The external loop is the one featured in "Top Gun." This is the fly and fight loop, but the internal loop is equally important. The internal loop is all about getting the air vehicle safely into and out of battlespace. This is required in order to fly and fight.**

- **The fifth slide provides a visual of the F-35 cockpit display.The PCD is the first thing, which the casual observer notices about the F-35 cockpit.The PCD is a contiguous 20 x 8 inch surface which is composed of two physical 10 x 8 inch displays for redundancy. This display space may be configured based on pilot needs into 12 windows of various and content, location, and size. The larger windows are referred to as portals. There are four portals.**

The small windows at along the bottom are secondary windows and there are 8 of them. The entire surface may be controlled through touch, cursor hooking, or voice control. Upon closer inspection of the cockpit most recognize the paucity of switches and instruments. In fact, many pilots say this is the most naked cockpit in history (this is not true, the Wright flyer had fewer switches).During the initial design everything was removed from the cockpit volume and had to earn its way back into the cockpit based on "combat value added." Combat value means it must contribute directly to lethality, survivability, and be cost effective. Cost effective is "bang for the buck."

- **The sixth slide shows the JSF conceptual display. The initial implementation of the PCD was one physical display of 16 x 9 inches. This design had three portals and 6 secondary windows. The design worked, but pilots asked for another portal.**

- **The seventh and slides show the F-35 panoramic cockpit display. The current F-35 looks like this. In this example, the pilot has configured the PCD into 4 portals with 6 secondary windows. There are 5 portal configurations, which the pilot can program, prior during mission planning. Once airborne, it is extremely easy to use the touchscreen to re-configure PCD.**

- **For the eighth slide, we see three portals and 4 secondary windows.Portal one, on the left, is a large Tactical Situation Display (TSD). It is onto the format that fusion presents its view of battlespace. All F-35s share this view and contribute to its content. This is also the primary location that the pilot interactswith the air vehicle to sort and target. The two portals on the right are showing sensor data. In this case the Electro-optical Targeting System (EOTS) and the Synthetic Aperture Radar (SAR).**

- **The ninth and tenth slides focus upon the mission reconfigurable aspect of the cockpit. The Mission Reconfigurable Cockpit (MRC) was a Contract Research and Development (CRaD) program, which Lockheed had, back in the early 90's. During this program Lockheed explored advanced fighter cockpit concepts.**

Among these were vHUD, touch, voice recognition, and accommodation. The results of this research became the foundation of the F-35 cockpit 10 years later. The MRC contract allowed Lockheed Martin to explore the under pinnings of information dominance.The greatest challenge is how to bridge the gulf between information overload and information dominance.

Think of it this way: when you look at a populated spreadsheet you see data. Data is important, but it is extremely difficult to understand by just looking at it. If you graph the data the meaning and importance becomes obvious. We'll call this information. We can act on information unless there is too much of it. We need to cull out which information is of most importance for the immediate task at hand. We call this INFORMATION DOMINANCE. Information dominance is what makes the F-35 unlike any other weapon system.

- **The eleventh slide highlights the joint attack strike technology. The follow on contract to the MRC CRaD was called Joint Attack Strike Technology Onboard/offboard (J/OBOB). This research assumed that the 5th generation tactical fighters would be connected. They could literally have an IP address and receive intelligence feeds while airborne. This really complicated the issue of information dominance. It's like a Google search which returns ten thousand results. You suspect the desired result is out there, but how do you get to it.**

The remaining slides look at the role of the helmet within the cockpit system.

- **The twelfth slide shows the Helmet Mounted Display. The vHUD being projected onto the visor is new technology and will change tactical employment. The jump from 3rd gen fighters to 4th gen brought a full head-up display.**

The HUD was a paradigm shift, which dramatically improved lethality and survivability. In similar fashion the jump to 5th gen with a vHUD is a paradigm shift and has the potential to revolutionize employment. A physical HUD projects into about 1200 square degrees of battlespace directly in front of the aircraft. The HMD with vHUD opens the view into over 41000 square degrees. This is the full sphere surrounding the aircraft.

- **The thirteenth slide provides an example of the vHUD when the pilot looks directly forward where a physical HUD would be. F-35 pilots report that in about 10 minutes they become accustomed to the vHUD. The pilots recognize the potential improvements in lethality and survivability of the HMD.**

- **The final slide provides an example of off axis symbology. In general, Lockheed only take key flight parameters and tactical symbology off axis. In the future Lockheed will investigate off axis attitude awareness symbology. The mil standards don't yet address HMDs and off axis symbolgy. Lockheed will work with the Services to improve and update The standard as well as the HMD symbology.**

http://www.special-ops.org/wp-content/uploads/2014/12/maxresdefault3.jpg

View can be ‘decluttered’

What The F-35 Pilot Sees Through His Helmet Display

http://www.special-ops.org/video-what-the-f-35-pilot-sees-through-his-helmet-display/

CODE ONE

LOCKHEED MARTIN

The New Front Office

By John Kent Posted 15 June 2006

With stealth, fully integrated avionics, advanced sensor fusion, and a dizzying array of interoperability and data-exchange requirements, the F-35 Joint Strike Fighter represents more revolution than evolution. Nowhere are the advances in this multirole combat fighter more starkly illustrated than in the cockpit.

What is *not* there is what is most evident to pilots the first time they see the F-35 cockpit. Gone are the analog steam gauge dials that populated the control panels of previous generations of fighter aircraft. In their place are large liquid-crystal touch-screen displays featuring color-coded symbology, pictographs, and digital information.

Changing the displays is only a matter of pressing a finger on different parts of the screen of the multi-function display, or MFD, to reconfigure or prioritize information or activate systems. The forest of toggle switches in previous fighter cockpits has been wiped clean from the F-35's interior landscape, with most of their functions moved to the touch screen. A few switches still sprout here and there, but the overall cockpit ambience is one of simplicity and calm, almost to the point of aeronautical *feng shui*.

Similarly, the cockpit of the F-22 Raptor offers a trio of glass displays. "Those displays represent a significant step toward the F-35 cockpit's spare ambience and a departure from its steam-gauge predecessors," notes Jon Beesley, the chief test pilot for the F-35. Beesley should know. As a veteran of advanced aircraft development programs, he served as a US Air Force test pilot on the F-117 stealth fighter and as a General Dynamics test pilot for the YF-22. Beesley was the fourth pilot to fly the YF-22 and second pilot to fly the F-22. "The F-22 prototype, the YF-22, had finger-on-glass controls as well," Beesley notes. "We learned a lot from the experience with this technology on the prototype, which was not implemented in the production F-22."

The F-22 Raptor is equipped with four reconfigurable liquid crystal displays — three 6.5 by 6.5 inches and one eight by eight inches — along with two non reconfigurable three- by four-inch up front displays. "They are a real advance from the past," Beesley explains. "But the F-35 is the ultimate expression of the less-is-more sensibility."

Beesley's initial reaction to the F-35 cockpit is shared by many other seasoned pilots who see the cockpit for the first time. "Pilots are most impressed by the minimal number of hard switches in the F-35 cockpit," he explains. "The most prominent portion of the cockpit is the eight- by twenty-inch LCD controlled primarily using finger-on-glass technology that has matured tremendously over the last several years. In the pursuit of easing pilot workload, advanced technology takes care of what pilots refer to as housekeeping chores."

For example, finger-on-glass controls replace cockpit switches for selecting such functions as air refueling mode and flight control system tests. All radio, mission systems computers, and identification and navigation controls are on glass.

Beesley notes that the large eight- by twenty-inch multifunction display (created by combining two eight- by ten-inch displays) can be customized and divided into many different-sized screens through what he describes as an "elegant pilot-vehicle interface design." By touching the screen, the pilot can select a pair of eight- by ten-inch window displays, or four five- by eight-inch windows, or any combination of window sizes to project information based on its importance at any given moment.

"This ability to control formats eases the interpretation of complex data," adds Beesley. "The flexibility in display size and the diversity of data are not available in any other fighter aircraft."

If one of the eight- by ten-inch screens fails, all information is automatically transferred to the other eight- by ten-inch screen. At the same time, this second screen remains fully customizable. "The missions for the F-35 can be some of the most complex fighter missions conceivable, varying from air superiority to close air support, to the destruction of enemy defense systems," Beesley explains. "Well-thought-through pilot-vehicle interface makes the transition from one type of cockpit mission to another type of cockpit mission very natural, effectively reconfiguring the cockpit at the same time. Pilots adapt to the concept quickly."

Rather than evolving the F-35 cockpit from previous designs, engineers decided to start with a clean sheet and base the cockpit's architecture solely on the needs of the 21st-century fighter pilot. Instead of presenting the pilot with acres of gauges representing all systems and situations all the time, engineers gave priority to situational awareness and to ensuring the information — not just raw data—the pilot receives is the most pertinent for any given moment.

"The F-35 cockpit design is driven by the desire to return the pilot to the role of tactician," says Mike Skaff, a former US Air Force F-16 pilot who serves as senior manager of the team designing the F-35 pilot-vehicle interface. "Modern fighters are amazingly complex. Monitoring the status of aircraft systems can divert a pilot's attention from information more critical to the mission. The F-35 cockpit is designed to ensure that the pilot can focus on getting the job done without having to worry too much about other tasks."

Beesley, whose résumé includes more than 5,000 hours of flying time in twenty different fighters, has already logged hundreds of hours in F-35 cockpit simulators. More recently, he is spending more time in the actual first F-35A test aircraft, known as AA-1, as its first flight approaches. The cockpit appearance of AA-1 is essentially the same as that of all subsequent F-35s. The handful of AA-1 features that won't make it to production include a pair of electrical system emergency switches, an instrumentation control panel mounted in the center pedestal, and a small digital readout of tactical air navigation information required for AA-1's unique communications, navigation, and IFF equipment.

"In past programs, controls unique to flight test, such as flutter excitation, control change evaluation, and flight test maneuvers, were selected through panels and switches," continues Beesley. "On the F-35, these controls have all been incorporated into a display format that can be brought up on any of the LCD screens. We've incorporated numerous lessons learned from previous programs on the layout of these displays and on the operation of these flight test critical controls. We engage and terminate various modes using the controls on the hands-on throttle and stick, or HOTAS."

The three F-35 variants share identical cockpits but with one functional difference. The conventional and carrier variants provide a button to drop and raise the arresting hook for carrier and emergency landings. The STOVL variant commands conversion into and out of the STOVL propulsion mode.

The engine throttle on the pilot's left and the side stick on the pilot's right are positioned to be compatible with the widest possible range of pilot shapes and sizes. The throttle is designed to give pilots the capability to vary the detents. It is also an active throttle, which means it provides feedback to the pilot as a function of flight envelope and flight mode. The side stick is also an active controller.

"Stick forces and deflections can be programmed in an active stick to allow either a slight increase or decrease in stick force while pulling g's," Beesley explains. "The real driver for an active stick was for vertical flying conditions on the F-35B, or

STOVL, variant where we thought we would need light stick forces. In fact, we haven't needed the feature so far. We have put detents in the STOVL stick. We use a soft stop detent to indicate the desired touchdown sink rate in the STOVL mode.

"The throttle uses the active controls to a greater degree," Beesley continues. "The internal motors allow the throttle to be moved back automatically when the pilot has an auto throttle connected or in some of the STOVL modes allows the option to input soft stop detents and afterburner detents at will."

One unique feature of this active throttle is that it does not have an engine cutoff position. It has, instead, a single toggle switch to cut the engine. The use of the active stick and throttle and a cutoff switch was introduced on the JSF demonstrator, the X-35.

Pilots have guided the F-35 cockpit design process from the very beginning to ensure the fighter's front office is an efficient workspace that liberates the operator from unwanted distractions. "The design has been driven entirely by current and former military pilots from the US Air Force, Navy, and Marines as well as current and former military pilots from the United Kingdom, Canada, Denmark, Norway, the Netherlands, Italy, Turkey, and Australia," Skaff says.

One of those military pilots providing direction is Lt. Col. Jeff Karnes, a Harrier pilot who is currently flying the F/A-18 Hornet for the US Marine Corps. He is a member of the exclusive fraternity that is both shaping and testing the F-35 cockpit. "The twenty- by eight-inch display provides expansive tactical workspace for manipulating the system and for segmenting down to twelve individual displays," he says. "It places navigation, threat warning, target designation, and ordnance displays together for quick reference. The Joint Strike Fighter has been specifically designed to reduce pilot workload by minimizing cockpit switches, increasing system automation, and reducing displayed information to only critical items the pilot requires to complete current tasks. The active stick and throttle allows realtime control shaping to optimize feel and aircraft response as a function of current flight envelope and mode."

Text and symbology on the MFD are color-coded to contrast clearly and sharply with the absolute black of the display screen background. Bob Russell, who manages simulations for the team integrating F-35 pilot systems, simplifies the significance of the colors. "In general, green indicates good or safe conditions, yellow indicates potential problems requiring pilot attention, and red indicates serious conditions demanding immediate pilot attention," he says. "For example, text for advisories appears in green, cautions appear in yellow, and warnings appear in red."

The same color codes apply to exterior objects, other aircraft, and phenomena detected by the F-35's sensors. Symbols on the tactical display appear green if the aircraft's sensors or off-board assets determine these objects are friendly. If unknown to the sensors, objects appear yellow. If identified as potential adversaries, objects appear red. "We also use blue and magenta, but sparingly," adds Russell. "We use shades of gray to outline maps and to outline the aircraft planform shown on various subsystem formats, such as fuel, flight controls, and weapons. The symbols representing air and ground threats appear in different shapes that, along with the colors, enhance the pilot's comprehension and situational awareness."

Among the other cockpit features is voice activation of certain aircraft functions. "In the movie *Firefox*, thought or voice control is used to command weapons," Beesley says. "Finger activation, however, is much quicker than voice activation. Consequently, we do not use voice activation for tasks that demand split-second decisions. We use voice commands to take care of duties that normally require numerous inputs on a keypad, such as punching in navigation coordinates and changing radio frequencies and bingo fuel amounts. Voice is very effective for housekeeping chores."

The F-35 cockpit also includes a simplified control system for the short takeoff/vertical landing variant and the ability to accommodate a spectrum of pilot physiques ranging from the light and short (about 100 pounds and four feet eleven inches tall) to heavy and tall (about 250 pounds and six feet five inches tall).

The F-35 cockpit is also the first in a production fighter to use a virtual head-up display that projects information onto the pilot's helmet visor. The new system, called a helmet-mounted display, or HMD, was switched on in March for the first time in F-35 laboratories where it projected symbology onto the visor by way of the actual F-35 vehicle-management and display-management computers. The HMD provides HUD information as though pilots are looking through an actual HUD no matter in what direction they turn their heads.

"We have flown in the past with helmet-mounted sights, such as Joint Helmet-Mounted Cueing System, or JHMCS," explains Beesley. "This system is used for off-axis symbology for tactical maneuvering. But because of higher latency, or lag times, these systems cannot be used to fly the airplane. This latency issue has been solved thanks to improvements in computer technology that allow very quick update rates needed for information associated with flying the airplane."

With the virtual HUD, pilots can look in different directions to find key tactical and flight information in their line of sight. This off-axis capability, as it is called, increases lethality and survivability by allowing the pilot to target threats with head instead of aircraft motions. The HMD eliminates the cost and weight associated with traditional head-up displays and simplifies cockpit design.

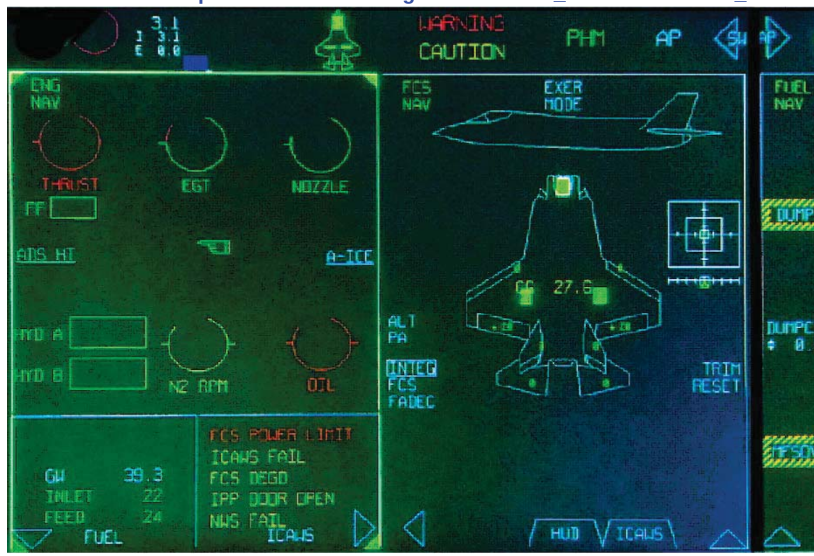
"HMD advancements will improve both weapons' aiming and target information that flows to the pilot," Beesley says. "In the past, forward-looking infrared, or FLIR, imagery used for targeting was restricted to the narrow field of view of the head-up display or to the restrictions of a head-down display. With HMD, pilots can view the FLIR imagery in its true location, thereby greatly enhancing their awareness of the immediate environment."

In addition to these advancements, the HMD allows night vision display capability both on-axis and off-axis using the F-35's 360-degree array of infrared sensors, which is called a distributed aperture system. The sensors work in combination with night-camera technology.

While the F-35 cockpit has undergone evolution and iterative change during its development — including a switch from digital light projection technology to advanced liquid crystal displays — the baseline design is now essentially fixed. It is unlikely to undergo any further significant modifications. "The design will continue to be refined throughout the life of the F-35," Skaff says, "but the actual layout and hardware will probably not change appreciably."

"Any changes will lie primarily in pilot-vehicle interface improvements and in additional aircraft capabilities," Beesley says. "One of the great areas for development is the use and operation of the HMD, because we are doing things with the helmet that have never been done before."

Overall, the F-35 cockpit environment is a generation beyond those aircraft preceding it, with changes made not for technology's sake but purely for the sake of mission success. "The significant difference is the F-35 cockpit's flexibility," says Beesley. "Complexity of missions, sensors used, weapons employed, and technology available have made this cockpit both necessary and possible." **http://www.codeonemagazine.com/f35_article.html?item_id=35**



"The Plane is a Broker of Information": A Conversation with Mike Skaff

25 Feb 2015 Robbin Laird

…**[Laird]** For Skaff, it is very rewarding to be getting this kind of feedback from the F-35 pilot community and also the formation of an initial users group shaping demand for changes in the way the cockpit and its integrated systems operate. In other words, he is learning what the pilots like and what they don't; what works the way it was designed and what needs to be improved or changed.

[Skaff] When we approached the design of the F-35 cockpit, we actually thought of dividing the two screens into an air-to-air screen and an air-to-ground screen. But the pilots did not want us to do that, for they wanted much greater flexibility to reshape to their operational demands and needs of the moment.

Now, the pilot can program what he wants to see on the tactical situation display. He has the air picture, the ground picture, or both pictures; a navigation picture or whatever he believes is most crucial to his mission success at that time. And so what you described was what we had anticipated that each pilot would have a different technique, a different way to employ the jet. And so I'm glad to hear you say that.

I think though the technology is moving so fast and so now we see the commercial world it's outpacing us. And we say, oh, I wish we had that in the cockpit. Now we're not yet ready for a technology refresh because there's enough hardware robustness that we can just change the software. And we've talked before about a software-defined jet. And so that's good news. We can do a lot of upgrades and alterations using the software.

Question: Clearly, one change is in display area where change will come over time. What is your thinking about this challenge?

Skaff: It is. With regard to the sensors, there is a lot of trade space. But in the displays where I work it is tighter. We are getting closer to the limits in graphics processing technology. What you see on commercial displays may appear in the future on the airplane, but not right away.

When we talk to the manufactures of new gaming display technologies they make it clear that the virtual reality machines are using something called texture as opposed to vectors. And so when sensors report battle space we typically portray that to the pilot in vector form, circles, squares, triangles, radar dishes, etc. And so these chip makers told us their chips don't do that. We're not quite there yet, but we're almost there.

But we're going to have to rethink how we portray information for the pilot. And that's always the trick. Because we know that we're deep in the information age and information dominance is what makes us lethal. The person that can garner and use information the quickest and the best is going to be victorious. And so the more I know and the better I can act on that.

And so in this information age we realize that that airplane is just a broker for information. So the smart person can use gray matter to decide how to act upon that information and then dominate in battle space. That really is the key. And we've talked about how do you dominate?

Do you interconnect the vehicles? Do you dominate that way? And so if somebody knows something that I don't know I may want to know it, but I don't know until you show me what you have. And so we're to the point where you do a search on Google you get back too much information. You've got 10,000 hits on this search word, well, which one is the one you want? Haven't you done that before? And you keep going next page, next page, next page, and five pages in was what you were really thinking about and going for. And you wonder how come the machine couldn't have put that on the first page? What caused it to do that? And so that's what we're wrestling with now.

Trying to figure out what the war fighter needs and when she needs it and determining the best way to present that information on those big displays is crucial for information dominance.

Question: Clearly, with a growing number of pilots flying the airplane, they will be key factors in shaping your thinking about the way ahead in engineering terms. How do you see that process?

Skaff: When I worked on the F-16, many of the changes came from input from the pilots. How are you using our product? Where are the problems? Where does it let you down? What didn't we think of that you want on the airplane? We will do the same with the F-35.

And there is a new technological aspect which will shape the way ahead as well, namely the new helmet technology. With pilots using both the screen and helmet technologies over time, they will determine how they use these integrated but different systems.

The helmet is working really well. Remember we talked about that as being risky, and we've mitigated all the risk and we're very pleased, have high expectations that it's working better than anticipated.

And so there are things in there that we have not even dreamt of using that for. And looking through the airplane with DAS, that's neat. But it's way more than that. That sensor has tremendous potential. The hardware is installed, there's plenty of trade space to change the software. What else can those cameras detect?

And we are now reaching the point where we will shape military standards for the new helmet, and as we do so, provide baselines for moving ahead and future modernization. Much of this will be determined by pilot use and re-engineering to deal with design shortfalls or simply desires by the operators to do it differently from how we initially designed the system to work...."

http://www.sldinfo.com/the-plane-is-a-broker-of-information-a-conversation-with-mike-skaff/

F-35 Simulator - AA and AG Modes / Avionics

DailyAirForce 12 Nov 2010 “10 Minutes long video shows F-35s' AA & AG modes”

https://www.youtube.com/watch?v=5lPZDc8mzsY

http://www.defence-today.com.au/f-35a-greatest-evolutionary-change

SECOND LINE OF DEFENSE
Delivering Capabilities to the Warfighter

http://www.sldinfo.com/discussing-fifth-generation-aircraft-with-the-usmc-pilot-of-the-f-22/

When you consider the fused cockpit of a JSF, you begin to understand just why all those descriptors are really accurate. It's an evolutionary leap. It's a paradigm shift. It's a game changer!

**** Posted On 13 Sep 2010*

WHAT IS THE FIFTH GENERATION AIRCRAFT ALL ABOUT? THE VIEW FROM THE COCKPIT

Discussing Fifth Generation Aircraft with the USMC Pilot of the F-22

In a recent discussion with Lieutenant-Colonel Berke who is based at Nellis AFB, the only USMC pilot of the F-22, the role of fifth generation fighters and how they are being used was discussed with Second Line of Defense.

Lieutenant-Colonel Berke has been an F-18 pilot, an F-16 pilot, a TOPGUN instructor and served as ground Forward Air Controller with the US Army for a year. He gained his Viper experience in an F-16A–flying aggressor tactics at TOPGUN; so you have a Marine Hornet Driver flying "foreign tactics" in a Navy training squadron in an AF Fighter. He is currently flying the Raptor and shaping tactics for the plane in its joint force role. He will become the second squadron commander at Eglin for the USMC version of the F-35.

SLD: Could you explain why a USMC pilot is flying the Raptor?

Lieutenant-Colonel Berke: The decision was made a few years ago to put joint pilots into the Raptor. The Navy did it in 2006 and the Marine Corps wanted to as well. For the USMC, the transition to the JSF is a critical issue. We can learn from the operational experiences of the Air Force F-22 transition. So an exchange billet with the Air Force at Nellis was created in the Operational Test squadron to give a Marine exposure to the process. The intent was to get someone into the fifth-gen world; to see what the Air Force has done with the F-22 for the last few years and thereby get some fifth-gen perspective. Then that pilot would hopefully be value-added to the Transition Task Force and the JSF team at Headquarters, Marine Corps. Also, it's important to get some perspective on what the Air Force lessons learned have been with the introduction of the Raptor and to learn some of their roadblocks in moving from legacy to fifth gen. We (USMC) are the lead for the IOC for the JSF and have a lot to gain from that experience. I have been selected to Command our JSF Squadron, VMFAT-501 at Eglin AFB. I will replace the first Marine JSF Skipper who is there now.

SLD: Obviously there are two advantages to this. I mean first of all the one mentioned, which is to begin to understand what the fused sensor experience is all about and the whole capability of an aircraft is not really an F series but a flying combat system. And second you get operational experience working the fifth generation capability with legacy aircraft.

Lieutenant-Colonel Berke: I think you're hitting the nail on the head with what the JSF is going to do, but it's also what the Raptor mission have already morphed into. The concept of Raptor employment covers two basic concepts. You've got an anti-access/global strike mission; and you have the integration mission as well. And the bottom line is that integration mission is our bread and butter. When I say "us," I'm talking about the Air Force and the F-22. Most of our expected operating environments are going to be integrated and success depends on how we play with other four-gen assets.

The joint operational role for the Raptor is significant. I'd say 80% of our funded testing since I've been here in the last two years in some way, shape, or form involves integration; whether it's integration with other airplanes like F-18s, F-15s and 16s, or integration with Aegis. Maritime Interdiction Integration is a key element of what we're doing. Virtually all of our tests are about how to make the airplane value-added to the conventional fleet, and that's pretty much all we've done recently.

SLD: But let me just puzzle over something for a moment, which is the whole experience of flying an F/A-18 and shifting to an F-22. Just what's that whole experience for you?

Lieutenant-Colonel Berke: It's a major evolution. There's no question about it. My career has been in F-18s, but I also flew F-16s for three years. I was dual operational in the Hornet and the Viper when I was a TOPGUN instructor. I am now coming up on three years flying Raptors. I was also on carriers for four years, so I've done a lot of integration with the Navy and a lot of integration with the Air Force. Three years flying with the Air Force has been pretty broadening.

For me, it's a great experience to see the similarities and difference between the services. Navy and Marine aviation is very similar. USAF aviation is very different in some ways. I actually was with the Army for a year as FAC in Iraq as well. So from a tactical level, I've got a lot of tactical operator experience with all three services – Navy, Army, and the Air Force. This has been really illuminating for me having the experience with all of the services in tactical operations. Obviously I will draw upon that experience when I fully engage with the JSF. But flying a Raptor, the left, right, up, down, is just flying; flying is flying. So getting in an airplane and flying around really is not that cosmic no matter what type of airplane you're sitting in.

But the difference between a Hornet or a Viper and the Raptor isn't just the way you turn or which way you move the jet or what is the best way to attack a particular problem. The difference is how you think. You work totally differently to garner situational awareness and make decisions; it's all different in the F-22. With the F-22 and certainly it will be the case with the F-35, you're operating at a level where you perform several functions of classic air battle management and that's a whole different experience and a different kind of training.

SLD: When you're in a classic tactical aircraft, basically somebody else is doing the battle management in an AWACS or CAOC or somewhere. With this aircraft, with the F-22 and certainly the F-35, you're really moving from a classic air battle management approach and that's got to be a whole different experience and require a different kind of training.

Lieutenant-Colonel Berke:It absolutely is. The irony is that when you talk about distributed battle management it is based on how the F-22 and F-35 provide for situational awareness. With an F-18 or F-16, you have federated sensor systems; the information is stovepiped and the pilot must fuse the information in his own mind.

You basically receive a lot of data and you're trying to shape that data into usable information. In the Raptor, the data is already fused into information thereby providing the situational awareness (SA). SA is extremely high in the F-22 and obviously will be in the JSF; and it's very easy for the pilot to process the SA.

Indeed, the processing of data is the key to having high SA and the key to making smart decisions. There's virtually no data in the F-22 that you have to process; it's almost all information. There's a small amount, but it is presented to you clearly and it takes very little effort to process what's going on. The fused data is so easy to absorb and it's so easy to use. A huge amount of brain cells, a huge amount of pilot effort is necessary to do that in the Hornet. You just don't have to do it anymore in the Raptor and the JSF. Ironically, that takes some getting used to. The SA in a fused cockpit is so incredible that it takes time to adjust from a legacy mindset, but once you do, the payback is exponential. The best SA I ever had in the Hornet pales in comparison to what the JSF will do for me.

SLD: And what is the impact of being able to share that fused data with other assets?

Lieutenant-Colonel Berke:The impacts of sharing data will be profound with JSF using MADL (Multifunctional Advanced Data Link) as a gateway; currently the Raptor requires an offboard gateway, but will eventually get MADL as well. As a matter of fact, we just completed a test on IFDL (Intra-flight Data Link) distribution through to BACN (Battlefield Airborne Communications Nodes) to get Raptor data into Marine F-18's with great success.

The F-22, especially when we get that data off board, gives tremendous SA to legacy assets. Eventually when we can pipe the data either through a gateway or when we get MADL, those methodologies once they're resolved will make the aircraft a fused sensor for 4th gen fighters. Or put in other words, the beauty of the F-22 is it's basically a big flying sensor providing info to our integrated assets.

And the way we perceive our role as a big flying sensor allows us to be a facilitator for another force to execute their mission more effectively, more efficiently and with less risk. We quantify everything with the metrics of survivability and lethality. Obviously the goal is simply to increase survivability and increase lethality, so we want to be more deadly while take less risk doing it.

SLD: Could you discuss further the interaction between the Raptor and the legacy aircraft?

Lieutenant-Colonel Berke: The Raptor can facilitate the Hornet's mission whether it's by providing SA, meaning giving him sensor pictures that shows him where the highest threats may be. Or by injecting a kinetic attack to let that Hornet pilot to get to a release point without having to deal with a particular threat. I can make the Hornet more survivable. I can facilitate him getting to a point where he optimizes his sensor footprint or optimizes his kinetic release and I can increase his survivability by handling a particular threat.

I might not affect his ability to be more lethal in the sense that I can't help him guide his weapons or maybe I'm not finding the target for him because I don't have those type of sensors. But the result is a significant force multiplier that's really hard to quantify because it makes everybody more survivable and hopefully by definition it makes the force more lethal.

SLD: So the F-22 underwrites the overall capability of the joint force?

Lieutenant-Colonel Berke: Exactly. Our perception of what we do in the joint force is to enhance the entire joint force's survivability. If we can keep somebody alive for longer or keep somebody alive closer to the threat, that makes them more lethal and then in turn makes us, and everyone, more survivable. So there's a lot of synergy back and forth, there's nothing more lethal than four Hornets and two Raptors.

We're a lot more lethal with four Hornets and we're more survivable with four Hornets . That's something that's often overlooked; how much less of an opportunity the threat has to kill a Raptor because there are Hornets flying with us. It will be even more true with the JSFs operating; two JSF will be a lot more survivable with four Hornets than they are by themselves. And everyone becomes more lethal as a result.

SLD: I think of the Raptor as the tip of a three-dimensional grid and the fact that you're flying 60,000 feet or more in a maritime environment, and the F-18 certainly flies much lower, that extra 20,000 feet that I'm carrying up at the top of the grid and looking at the nap of the earth in a maritime environment is very significant, it seems to me, in terms of your CONOPs. You want to leverage the assets we've got now. But over time as you essentially ferret these things out and replace them with F-35s and F-22s and add other unmanned or whatever other assets, the capability that you're seeing now for distributed operations will be really a sea change in terms of the ability of the fleet, both airborne and surface. And the fleet I'm referring to not just the surface ships and the airplanes to work together to expand their survivability and their lethality, to use your terms?

Lieutenant-Colonel Berke: Yes absolutely. The idea that we're going to attack a cruise missile problem without the use of tactical aircraft surprises me from an analytical perspective, especially considering how often we do it and how much we consider it. It's hard to train to counter-missile operations, but it's certainly a mission set that we investigate routinely. The Raptor and JSF and their expanded sensor sets will play a key role. Working the relationship between Aegis and 5th Gen is central to the capability to kill missiles attacking the fleet or in dealing with longer-range targets.

SLD: Could you highlight the changing role of the combat pilot in the fifth generation aircraft?

Lieutenant-Colonel Berke: In the sensor fused cockpit of the Raptor, two things result. It simplifies the information and presents it more accurately and more quickly. It also provides such performance in a full 360-degree sphere. That allows a Raptor pilot almost 100% of the time to just make decisions. So he can essentially spend none of his time interpreting and spend all of his time deciding the best way to attack a problem.

That allows the pilot to decide what's best for him and for all the airborne forces whether it's other Raptors or F-18 strikers that you're supporting or F15's Eagles on a sweep, or any integrated mission. You don't have the luxury of doing that in a legacy airplane. The fused sensors enable all of this. The JSF will only expand this capability with its newer and expanded sensor array.

As a flying sensor, you can accurately decide the best way to attack a particular problem for everybody else that is flying. A Raptor flight lead (and a 5th Gen fighter is far more effective than a flight leader in another airplane) with the amount of SA that he has can help guide the other aircraft that don't have that level of SA.

SLD: So from this point of view, the new role for the combat pilot, with new fused sensors and related capabilities, the new aircraft are game changers?

Lieutenant-Colonel Berke: People throw out those terms all the time, "the paradigm shift", "a game changer", "an evolutionary leap", all those things, but it's all true. It's all accurate. And I can tell you from the perspective of a guy who has flown over 2,000 hours in a Hornet. I was a TOPGUN instructor. I was really at the top of my game. I was as competent as the Marine Corps could've taught me to be.

In spite of this background, it was a challenge and a major mental leap for me to go to the F-22. It takes time to turn the corner with 5th Gen thinking. But once you do, there's no going back. Your SA and your ability increase dramatically. Truth be told, you're always going to have limits in any legacy platform, for many reasons. There's not a pilot in the Air Force that's flying Raptors right now that will not tell you the exact same thing.

But what they'll also tell you is that the first class that flew the Raptor straight from flight school was exceptional. They were surprised at how good they were at optimizing the airplane as a sensor. The guys with no experience did extremely well; and I think a huge part of that has to do with them not bringing old habits or a lifetime of thinking a certain way.

Changing the way you physically move is one thing, but changing the way you mentally think is very difficult to do and it takes time. When the concepts just don't apply anymore and you've leveraged those concepts for 15 years, it's not an easy thing. This will be a challenge for all pilots transitioning to the JSF because it's going to force them to think differently than they ever thought before. But doing so is crucial to the shift in air operations. Once the mindset shift occurs, the true capability will be understood.

As I said before, once that happens the results are exponential. In just a few years, we're going to have STOVL JSF operating from forward bases. Aside from all the operational and strategic implications, the tactical significance is huge. A single F-35B pilot will have more SA than anyone flying a Marine aircraft ever has. And he's going to be directly connected to the entire supported force.

When you consider the fused cockpit of a JSF, you begin to understand just why all those descriptors are really accurate. It's an evolutionary leap. It's a paradigm shift. It's a game changer!

[RAAF] Air Combat Operations 2025 and Beyond SEMINAR EXECUTIVE SUMMARY

Andrew McLaughlin April 2014

"...STEP CHANGE

The step change in capability the F-35 will bring was a recurring theme throughout the seminar presentations. Speakers consistently pointed to the aircraft's advanced sensors, LPI communications, low observability, improved situational awareness, and other advanced systems as the key attributes that differentiate the F-35 from its predecessors.

To emphasise the advances in sensors and other systems, AIRMSHL Brown explained how the classic Hornet which was developed in the 1970s is a very different aircraft today to the one the RAAF initially acquired. In the last decade the Hornet has undergone a massive mid-life upgrade program which has seen it equipped with a more capable APG-73 radar, Link 16 and ARC-210 comms suite, enhanced cockpit displays, an advanced electronic warfare suite, a helmet mounted cueing system with new high PK active and high off-bore sight air-to-air missiles, and precision-guided and stand-off air-to-surface weapons.

He related a recent experience he had when flying an upgraded Hornet in a training mission. Despite being in a dominant position against a relatively new Hornet pilot, he was 'killed' by an over the shoulder ASRAAM missile shot which had been 'spiked' and uncaged by the pilot's helmet mounted cueing system. He remembers that event as a "technological development that had fundamentally changed my mind as to what was offensive and what was defensive."

SQNLDR Matthew Harper offered a clear insight by comparing his experiences in flying the 4th generation classic Hornet and the 4.5 generation Super Hornet in the RAAF, and the 5th generation F-22 Raptor while on exchange with the USAF.

He told the audience that, despite the advances which have made the classic Hornet "one of the best 4th generation aircraft out there", the aircraft is still very limited. He spoke of the mechanically scanned radar which needs to be "driven by the pilot" and which is restricted in the number of targets it can see and track, and of the limitations of the Link 16 network and the compromises that need to be made when "everyone wants to use it".

He also explained that the Hornet is "not low-observable in any way", that its mission computers are at 100 per cent capacity, and that sensor performance is very sensitive to the operator's skill levels. Sensor fusion for a Hornet pilot essentially means looking at multiple displays, each one displaying a different sensor picture which may not be up-to-date due to Link 16 limitations, and often means having to make a best-guess decision based on poor situational awareness. He said with the Hornet, in the decade ahead "it's increasingly obvious we don't have the systems capability to offer a meaningful contribution to the fight."

With the Super Hornet, SQNLDR Harper said the improvements brought by the AESA radar, integrated electronic warfare features, some low observable enhancements, the advanced mission computer, and better sensor fusion which provides greater ability to manage complex EW & targeting, have made a "fantastic jet" even better. He said the improvements were "designed to a sensible point which made financial sense", and would mean the Super Hornet is survivable and upgradeable into the 2020s.

But he said the Super Hornet was still limited by being confined to a Link 16 network which isn't LPI, and despite the better sensors the lack of real sensor fusion "adds a layer of complexity" which can result in task saturation. "It's still very challenging to determine what the best way is to track an adversary and maintain SA against advanced threats," he said.

By comparison, SQNLDR Harper said the 5th generation F-22 was built from the ground up to optimise its capabilities, and that there is a real impression that the platform was "built in collaboration with engineers, scientists, fighter pilots, and warriors."

He said the most important feature of 5th generation is its integrated avionics, and that "all the sensors are built into the jet" and are all controlled by a central core processor, which means the pilot doesn't need to manipulate them. He explained that the cockpit displays promote an "evolved level of pilot interaction with the platform," and that the HMI is "incredibly intuitive – It wasn't long at all to go from the previous mindset, to looking at the displays and working with the picture to set up a work flow."

SQNLDR Harper said the fusion is the "key enabler" for 5th gen. He said because the sensors require little or no manipulation means it "frees up huge amount of brain space for the pilot." He said all the relevant information is presented in sync "not just your own aircraft, but with the entire formation."

LtCol Berke described the fusion offered by 5th gen platforms as "an overwhelming advancement in breadth and depth in terms of the spectrum in which it operates." He said it's unlikely we fully understand what that breadth and depth will allow pilots to do yet due to the vast differences to the capabilities offered by legacy platforms. "It's not just a matter of being able to function in a wide array of information – if we can't fight in a particular spectrum, whether it's RF, IR, laser, EO, the F-35 has the ability with the agility on the platform to live in whatever spectrum it thinks it needs to be in."..."

http://www.sldinfo.com/wp-content/uploads/2014/05/Air-Combat-Seminar-summary-AndrewMcL.pdf

The Joint Strike Fighter: Driven by data

Vanguard Magazine Apr / May 2014 by Chris Thatcher

Talking in detail about the F-35 Joint Strike Fighter requires verbal dexterity. Many of the aircraft's features are classified, so inadvertently revealing a number or the full capabilities of a sensor carry a heavy price.

"Leavenworth [prison] is such a terrible place to be," Stephen O'Bryan says with a rueful smile as he pauses yet again at the description of a sensor system.

The vice president of F-35 Program Integration and Business Development for Lockheed Martin Aeronautics is treading carefully for good reason. He needs to continue selling the virtues of the aircraft to Canadians, especially Cabinet members who now hold the fate of Canada's CF-18 fighter replacement program in their hands following the delivery of an options analysis report by the National Fighter Procurement Secretariat in April. But he wants them to understand the generational leap in technology he believes the F-35 represents without revealing the full extent of its capability.

A former U.S. Navy fighter pilot with years of experience in F-18s, O'Bryan knows the limitations of so-called fourth generation fighter jets. Where survival was once about the skill of a pilot, it will now be about the strength of the data. "We used to say speed is life; it's now, information is life," he says.

Rather than a technician in the cockpit, O'Bryan envisions a tactician making rapid decisions based on the automatic fusion of data from thousands of sensors. "Fourth generation flying was hard. The best fighter pilots I knew where the ones who [could process what they heard over their radios] and meld it with what they were looking at in their displays. That made it more art than science.

"With the F-35, the pilot is a user of information. The idea is to give you near-perfect information from a variety of sources, including your wingmen, and fuse it into one picture. [And] everybody has the same accurate picture."

He equates the introduction of the F-35 to the arrival of the aircraft carrier and its impact on the notion of close engagement in naval warfare. The fighter jet's array of sensors, database and processor allow it to operate from distance to degrade and then attack an opponent's capability.

To demonstrate why the F-35 is a self-sufficient gamechanger, able to operate without the support of electronic attack, airborne warning and control, or joint surveillance and target attack aircraft, he points to the AESA (active electronically scanned array) radar.

For starters, the F-35's APG 81 radar is no longer just a radar. "It's a multi-functional array" that automatically fuses information from "thousands of radars" in the aircraft, O'Bryan explains. And rather than the familiar sweeping cone, the F-35's beam is more like a laser, able to focus on a specific target or on multiple targets (the exact number is classified) with ten times the power of an EA 6B Prowler, he says.

Furthermore, a formation of four F-35s can alternate transmission of the jamming signal among themselves, again automatically. And with stealth capability, one or all four of the aircraft can operate from inside the target's firing range.

"You start with 10 times more power, and if you are much closer and you are alternating signals between four airplanes with a stealth data link between them, you can do that jamming in a coherent, cooperative manner. The signal, the technique, everything is done for [the pilot]."

Equally important, where fourth generation radar are able to detect the arrival of a threat with plus or minus 30 degrees accuracy, the F-35 can pinpoint the threat to within plus or minus one degree, an advantage that is narrowed further with the assistance of a formation of four aircraft sharing that threat trajectory, he says.

When combined with the F-35's equally accurate ranging and its ability to build a common ground picture from a "tactically significant range" (the resolution is classified) that enables auto target correlation and recognition, "[the F-35] has the ability to take the pictures, through the weather, classify the [targets], and give mensurated coordinates."

It's a bit like being in a boxing match with an opponent who is blindfolded and with his ears covered, O'Bryan explains. "You've got great situational awareness, but you've also degraded his situational awareness with stealth, electronic attack, other sensors and techniques."

The rest of the electronic warfare (EW) systems, the distributed aperture system (DAS) and the electro-optical targeting system (EOTS) are equally impressive.

The six cameras that make up the DAS provide 360-degree situational awareness and missile detection and tracking that is able to identify which aircraft in a formation has been targeted and then triangulate the location from where the missile was fired. "DAS is turning out to be better than we thought," O' Bryan says.

And the EOTS underneath the nose of the aircraft provides laser guided bomb targeting, including locking onto moving targets, infrared search and track (IRST), blue-force interrogation, non-cooperative target recognition (CTR) and radar frequency counter measures (RFCM), which allow the F-35 to identify an adversary by the return of its engines and emissions.

"It has the best combat ID suite of any fighter I have ever come across," he says. "And it has the most advanced suite of countermeasures of any fighter airplane." In addition, he points out that the F-35 carries 18,500 pounds of onboard fuel, meaning it can stay in the fight longer than its fourth generation counterparts.

That range of capability – operating at distance, onboard electronic warfare, target identification, common situational awareness, and the ability to engage for longer duration – suggests a change in tactics.

O'Bryan says young pilots entering the F-35 program are already starting to think of new ways of operating. "They are getting very innovative. I have seen them in the simulator do things that I have learned from, things to create deception and surprise." But that, too, will remain classified.

http://vanguardcanada.uberflip.com/i/304887/

JSF: http://www.aviationtoday.com/2003/09/01/jsf-integrated-avionics-par-excellence/

Integrated Avionics Par Excellence

Charlotte Adams
01 Sep 2003

What must a 21st century tactical aircraft incorporate to satisfy the needs of the U.S. Air Force, Navy and Marine Corps and international customers seeking a multi-mission air vehicle? The short answer is plenty of onboard and off-board data collection, processing and fusion. The long answer emerges from a close look at the Joint Strike Fighter's (JSF's) design.

The stealthy, supersonic fighter, designated the F-35, is expected to replace U.S. F-16s, A-10s, F/A-18/A/B/C/Ds, F-14s, and AV-8Bs, as well as UK GR7s and Sea Harriers. The U.S. Air Force wants to buy 1,763 Joint Strike Fighters; the U.S. Navy and Marines, 680; the Royal Air Force, 90; and the Royal Navy, 60. First flight of the conventional takeoff/landing (CTOL) version is expected in 2005. CTOL, short takeoff/vertical landing (STOVL), and carrier-capable versions will feature "high 90 percent" avionics commonality.

The affordability, size and mission goals for an aircraft developed with funding from eight countries, as well as the United States, have dictated unprecedented sensor overlap and processing centralization. The electronically scanned radar array, under the control of mission systems software, will be able to perform electronic warfare (EW) functions, and the EW system will share some com/nav/identification (CNI) apertures. The JSF's infrared (IR) sensors will use detector/cooling assemblies of a common design. Integration also means the use of common modules wherever possible, both in the integrated core processor (ICP) and in other key systems, as well as the use of a 2-gigabit/sec Fibre Channel backbone for instant communications between the ICP and the sensors, CNI system and displays.

Designers intend integration and cooperation to drive breakthrough situational awareness. Data from radar, electro-optical, EW and CNI sensors–not to mention offboard systems–will be fused by mission systems software and presented to the pilot as an intuitive tactical picture on a panel-wide head-down display. A helmet-mounted display system (HMDS) will project the IR picture and urgent tactical, flight and safety symbology onto the pilot's visor and provide high-angle, off-boresight targeting.

Inputs from six common, distributed aperture system (DAS) sensors are designed to create a 360-degree protective IR sphere around the airplane, providing the pilot approximately 20/40 vision acuity and allowing airplanes to fly in closely spaced nighttime combat spreads. The pilot will be able to look down to "see" the scene below the aircraft, through darkness, smoke and dust, projected on the helmet visor. DAS, the latest in IR-based missile warning and situational awareness tools, is complemented by EOTS, the internally mounted electro-optical targeting system. EOTS provides a smaller field of view but longer-range targeting. Under the command of the mission software, EOTS could provide range to a target without turning on the radar.

Fourth-Generation Radar

The F-35's fourth-generation active electronically scanned array (AESA) radar is designed to reduce by half the cost and weight of third-generation technology, deployed in emerging platforms such as the F/A-22. The JSF radar, for example, uses "twinpack" T/R modules, consolidating two into one package. The AESA system's lifespan is projected to be "well over" 8,000 hours, the typical life of a fighter aircraft, says Robert Thompson, director of JSF combat avionics for radar developerï¿½ Northrop Grumman Electronic Systems.

In air-to-surface operations the radar will support functions such as synthetic aperture radar (SAR) ground mapping and inverse SAR for ship classification. In air-to-air operations, the sensor will support features such as cued search, passive search and multitarget, beyond-visual-range tracking and targeting. Because the beam can move from point to point in millionths of a second, a single target can be viewed as many as 15 times a second.

JSF's powerful sensor suite will allow the aircraft to assume an active role in the tactical "infosphere," company officials assert. "The tactical fighter used to be at the end of the food chain," receiving information from special-purpose sensor aircraft, Thompson says. But it became obvious, from the quality of JSF sensor data and the number of planes to be fielded, that they will be "a major feed of tactical information."

The sensors have gone through preliminary design review (PDR) and are heading toward critical design review (CDR) over the next six months. Critical design work, on the hardware side, emphasizes areas such as component reliability, cost and ruggedness, and final board layouts.

Wrapping Sensors Up

Mission systems software, still in early development, will be key to the F-35's success, sifting, fusing and presenting sensor data "so that it is inherently obvious to the pilot what the course of action should be," asserts Jon Waldrop, director of international programs for prime contractor Lockheed Martin. The software "wraps [the sensors] up into a functional architecture that allows them to smartly work together, cross-cue and take advantage of fused information to help the pilot," Thompson explains.

The crucial data fusion function has been identified as a program-level risk, which means that senior officials will track its progress, says Air Force Lt. Col. Jim Baker, F-35 mission systems lead. A risk-reduction effort is under way. Flight testing was scheduled to commence in August or September, using current versions of the radar and EOTS system on Northrop Grumman's BAC-111 test aircraft, according to Steve Foley, tactical information systems lead with the JSF program office.

"The government pushed on Lockheed to start fusion flying early," Thompson says. The idea is to look at baseline algorithms, prove out algorithm development and simulation tools, and confirm basic architectural concepts, explains John Harrell, Lockheed Martin's tactical information systems lead. The risk reduction flight program is expected to run about six months, with analysis of the results feeding into on-going fusion algorithm studies.

The approximately 4.5 million lines of mission systems code will be developed in block upgrades. Early versions of data fusion algorithms will be examined in the risk reduction program. "Fusion really starts hitting in 2007, when we start doing fusion of all onboard sensors," Harrell says. Fusion capabilities will continue to increase with the Block 3 mission software release to flight test in mid-2010, adding information from offboard sources.

Mission systems functions are organized around the concept of a continuous "OODA loop," which stands for observe, orient, decide and act. Sensors and data links will acquire data, which will be fused in the ICP, activating tactical decision aids–or "planners." Search, attack, avoidance and denial planner modules would work simultaneously on the fused data, producing action plans for the pilot.

The search planner is intended to help pilots locate targets. This software application would look, for example, at all the possible places where a column of tanks could be, based on factors such as the last siting, the road network, terrain and the speed of the vehicles.

Although the details of pilot/software interaction are far from mature this early in the program, Baker describes one search planner scenario. The software module would ask the group leader–digitally or audibly–how many F-35s are on the mission? If the lead says, or indicates, "four," a grid would pop up to show where each wingman should be for optimal searching. Similarly, the search planner would overlay the possible locations of the tank column on a map for the pilots in the JSF formation.

After the tanks have been located, the attack planner could plan the ingress route, assess the vulnerability of the tanks, and indicate where the wingmen should be. While these tasks are proceeding, a "fast track" process would send any high-priority threat information directly to the pilot, who would determine, with the help of an "avoid planner," the evasion route. Although still a long way from realization, these processes would execute in fractions of a second, permitting pilots in a multiship formation to counter or avoid multiple threats and at the same time attack multiple targets.

Lockheed plans to hold several "pilot simulation events" to evaluate the mechanization and utility of these functions, i.e., what the pilot can do well and what is best handled by onboard computers.

A portable memory device from Smiths Aerospace–designed to provide hundreds of gigabytes of nonvolatile storage–will help the pilot load mission plan data and record video and other information in flight. Smiths also will provide a second, permanently installed mass memory device and an airborne file server.

Core Processor

Hosting the mission systems software is the JSF's electronic brain, the ICP. Packaged in two racks, with 23 and eight slots, respectively, this computer consolidates functions previously managed by separate mission and weapons computers, and dedicated signal processors. At initial operational capability, the ICP data processors will crunch data at 40.8 billion operations/sec (giga operations, or GOPS); the signal processors, at 75.6 billion floating point operations (gigaflops, or GFLOPS); and the image processors at 225.6 billion multiply/accumulate operations, or GMACS, a specialized signal processing measure, reports Chuck Wilcox, Lockheed's ICP team lead. The design includes 22 modules of seven types:

- Four general-purpose (GP) processing modules,
- Two GPIO (input/output) modules,
- Two signal processing (SP) modules,
- Five SPIO modules,
- Two image processor modules,
- Two switch modules, and
- Five power supply modules.

The ICP also will haveï¿½ "pluggable growth" for eight more digital processing modules and an additional power supply, Wilcox adds. It uses commercial off-the-shelf (COTS) components, standardizing at this stage on Motorola G4 PowerPC microprocessors, which incorporate 128-bit AltiVec technology. The image processor uses commercial field programmable gate arrays (FPGAs) and the VHDL hardware description language to form a very specialized processing engine.The ICP employs the Green Hills Software Integrity commercial real-time operating system (RTOS) for data processing and Mercury Computer Systems' commercial Multi-computing OS (MCOS) for signal processing. Depending on processing trades still to be made in the program, the JSF also could use commercial RTOSs in sensor front ends to perform digital preprocessing, according to Baker. The display management computer and the CNI system also use the Integrity RTOS. COTS reduces development risk andï¿½ ensures an upgrade path, according to Ralph Lachenmaier, the program office's ICP and common components lead.

Tying the ICP modules together like a backplane bus and connecting the sensors, CNI and the displays to the ICP is the optical Fibre Channel network. Key to this interconnect are the two 32-port ICP switch modules. The 400-megabit/sec IEEE 1394B (Firewire) interconnect is used externally to link the ICP, display management computer and the CNI system to the vehicle management system.

Low-level processing will occur in the sensor systems, but most digital processing will occur in the ICP. The radar, for example, will have the smarts to generate waveforms and do analog-to-digital conversion. But the radar will send target range and bearing data to the ICP signal processor, which will generate a report for the data processor, responsible for data fusion. Radar data, fused with data from other onboard and offboard systems, then will be sent from the ICP to the display processor for presentation on the head-down and helmet-mounted displays.

EW System

The electronic warfare suite, integrated by BAE Systems, includes:

- All-aspect radar warning capability, supporting analysis, identification, tracking, mode determination and angle of arrival (AOA) of mainbeam emissions, plus automatic direction finding for correlation with other sensors, threat avoidance and targeting information;

- Defensive threat awareness and offensive targeting support–acquisition and tracking ofï¿½ main beam and side lobe emissions, beyond-visual-range emitter location and ranging, emitter ID and signal parameter measurement;
- A multispectral countermeasures suite with countermeasures response manager function, standard chaff and flare rounds; and
- Passive EW apertures.

The EW suite complements the field-of-view and frequency coverage of the radar by providing complete coverage around the aircraft at a wider frequency range. Passive radar warning system apertures–at three different frequency ranges – are embedded in the skin of leading and trailing wing edges and horizontal tail surfaces. The EW system also can use the radar antenna for electronic support measures (ESM). Expected mean time between failure (MTBF) is 440 hours.

The radar warning system is active all of the time, providing both air and surface coverage. Packaged in two electronics racks, it includes cards for radar warning, direction finding and ESM. The system uses DAS inputs directly, as well as fused inputs from the ICP. Digital processing allows reprogramming and increases reliability.

Vehicle Management System

One of the most important non-ICP processing functions is the vehicle management system, which handles flight control and utility systems such as fuel management and electrical and hydraulic system controls. BAE Systems designed the vehicle management computer (VMC), three of which are connected together via an IEEE 1394B bus. About the size of a shoe box, each computer contains a processor card, I/O card and power supply card.

All three VMCs process data simultaneously, constantly comparing results across channels to assure data integrity. In the case of divergent data, two processors can "vote" one processor or signal out, explains Bill Dawson, JSF program manager for BAE Systems Aerospace Controls.

Interfacing to the VMCs are remote I/O units provided by Smiths. These devices–10 per aircraft–are an integral part of the vehicle management network, receiving flight control and other inputs from hundreds of digital, analog and discrete sources, processingï¿½ the data and outputting the results to the VMCs over the 1394 bus.

Head-Down and Helmet Displays

The Joint Strike Fighter's flight deck display moves beyond the F/A-22's multifunction display-type layout to a single, panoramic, 8-by-20-inchï¿½ viewing area, the largest ever in a fighter aircraft. Developed by Rockwell Collins (Kaiser Electronics), the multifunction display system (MFDS) comprises two adjacent 8-by-10-inch projection displays, each with a resolution of 1280-by-1024 pixels. Each half is fully functional, so the system can continue to operate if one half fails.

The MFDS will present sensor, weapons and aircraft status data, plus tactical and safety information. The viewing area can be presented as a large tactical horizontal situation display or be divided into multiple windows.

Functions are accessed and activated by touch–the first touch screen on a large-format display–or by hands-on-throttle-and stick (HOTAS) commands. Each 8-by-10-inch area has an integrated display processor for low-level data crunching and a "projection engine" to cast the image onto the screen. The MFDS uses micro-active matrix liquid crystal display (LCD) image sources–three per projection engine–illuminated by arc lamps. Collins will provide the display drivers and the first layer of services software, which Lockheed Martin will use to implement display applications.

Collins will procure glass commercially, tempering it with proprietary chemical processes. The Collins display processor _circuit card assembly design also is used for the display management computer-helmet (DMC-H). The assembly uses Collins application-specific integrated circuits (ASICs), as well as commercial processors, memory and graphics chips. Flight qualification and safety testing will begin once initial display systems are delivered in the second quarter of 2004. Standby 3-by-3-inch active matrix LCD flight displays are provided by Smiths Aerospace.ï¿½

The F-35's helmet-mounted display system (HMDS) will replace the traditional head-up display (HUD), "allowing for a tremendous cost savings and, more importantly, weight reduction," asserts Louis Taddeo, director of business development with HMDS designer, Vision Systems International (VSI). VSI is a joint venture partnership between Collins and EFW Inc., an Elbit Systems Ltd. subsidiary.

The HMDS uses a combination of electro-optics and head position and orientation tracking software algorithms to present critical flight, mission, threat and safety symbology on the pilot's visor. The system allows the pilot to direct aircraft weapons and sensors to an area of interest or issues visual cues to direct the pilot's attention, Taddeo explains. The HMDS comprises the helmet-mounted display, DMC-H, and helmet tracking system. VSI also supplies the joint helmet-mounted cueing systems used on the F-15 and F/A-18E/F aircraft.

Fundamental requirements for the HMDS include visor-projected, binocular, wide field-of-view, high-resolution, near real-time imagery and symbology; equivalent accuracy to head-up display systems; 24-hour usability; and fit, comfort and safety during ejection. Proper weight and balance are crucial in minimizing pilot fatigue resulting from high-g maneuvers and reducing head and neck loads in ejections, Taddeo stresses. The F-35 helmet is expected to weigh 4.2 pounds (1.9 kg).

The F-35's HMDS employs a flat panel, active matrix LCD, coupled with a high-intensity back light, as its image source. The partially overlapped display provides a binocular image 50 degrees wide by 30 degrees high.

The digital image source provides both symbol writing and video capability. The system includes a clear, optically coated visor for night operations and a shaded visor for daylight operations. Imagery is provided via the distributed aperture system (DAS) or a helmet-mounted day/night camera. F-35 pilots can select imagery and symbology via HOTAS commands.

F-35's CNI System

The two-rack communications, navigation and identification (CNI) system processes waveforms internally, sending high-level status data to the core processor. The CNI system is designed to provide functions such as beyond-visual-range identification friend-or-foe (IFF); secure, multichannel, multiband voice communications; and intraflight data link (IFDL) exchanges, synchronizing the displays of multiple aircraft. The CNI suite will support 35 different com, nav and identification waveforms–about 5 pounds (2.26 kg) per waveform function, compared with the legacy black box approach of 10 to 30 pounds (4.54 to 13.6 kg), or more, per waveform, according to Frank Flores, JSF program director for Northrop Grumman Radio Systems.

Software-defined radio technology means that the suite can provide numerous radio functions–ranging in frequency from VHF to K band–from a set of more general-purpose module types, including:

- Wideband RF module, performing analog-to-digital conversion, waveform processing and digital signal processing.
- Dual-channel transceiver module, which can receive and digitize waveforms over a wide frequency band and generateï¿½ waveforms for transmission, driving ï¿½ï¿½ï¿½ power amplifiers. This module supports most of the 35 waveforms.
- Frequency-dependent power amplifiers, including L-band, VHF/UHF, and higher-frequency units.
- Power supply module.
- CNI processor module, which performs signal processing, data processing and comsec processing.
- And an interface module.

Northrop Grumman developed middleware, located between the operating system and the applications. This layer of software is designed to allow smooth system growth and compatibility with Joint Tactical Radio System (JTRS) waveforms.

The CNI suite uses Green Hills Software's Integrity commercial real-time operating system, PowerPC processors, field programmable gate arrays and digital signal processors. Radio Systems is streamlining the design to minimize footprint.

Some of the suite's baseline functions include: VHF/UHF voice, HaveQuick I/II, Saturn (HQ IIA), satcom T/R, IFF/SIF (selective ID feature) transponder, IFF Mode IV interrogator, ILS/MLS/MLS/Tacan, IFDL, Link 16 T/R, Link 4A, tactical data information link (TADIL-K), 3-D audio, TACFIRE/Air Force applications program development (AFAPD), and ADS-B.

F-35 Electronic Warfare Suite: More Than Self-Protection

Ron Sherman | April 1, **2006**

http://www.aviationtoday.com/2006/04/01/f-35-electronic-warfare-suite-more-than-self-protection/

At A Glance:

Integration is at the heart of the F-35's electronic warfare (EW) capability. This article discusses:

- General capabilities of the EW system, including its radar warning, electronic support measures and countermeasures functions, as well as the corresponding equipage;
- Integration synergies both internal to the EW system and in the context of the other mission systems; and
- Highlights of the EW system's ground test and flight test schedules.

Electronic warfare (EW) systems allow modern combat aircraft to use the electromagnetic spectrum against the enemy. EW includes the ability to collect, identify and locate signals, detect hostile radars and missile attacks, and activate countermeasures to disrupt or degrade enemy offenses and defenses. While some aircraft remain dedicated to the EW mission, the F-35 is designed to accomplish a wide range of electronic warfare tasks simultaneously with air-to-air and air-to-ground functions in support of its overall mission. Taken together, the Joint Strike Fighter's (JSF's) electronic warfare system is designed to extend the pilot's situational awareness and to identify, locate, track and defeat enemy defenses both in the air and on the ground.

JSF designers are attempting an unprecedented level of integration--between elements of the electronic warfare suite and within aircraft mission systems. Older fighters like the F-14 had federated EW systems, explains Mark Drake, F-35 business development manager with BAE Systems, the designer of the F-35's EW suite. There was a box for the radar warning receiver (RWR) and a box for dispensing chaff and flares. The pilot would see a missile launch on one display and detect other signals in the environment through another system. The pilot was the ultimate information integrator.

The F-35's EW system, by contrast, would lessen that workload. JSF is designed from the ground up to be an integrated system that would incorporate all the different aspects of survivability and mission accomplishment, Drake says.

While the JSF package is not the first integrated EW system--the F-22 does the same--it is the "first real improvement on fighter-based EW systems that is clearly linked from the beginning to do a combination of jobs," he says. "The novelty of the JSF is its ability to draw together an abundance of data and formulate it into actionable knowledge for the pilots," permitting them to focus on tactics and strategies for overall dominance, says Eric Branyan, vice president of JSF mission systems for Lockheed Martin, the F-35 prime contractor.

Deep Integration

Integration of EW sensors with the F-35's AN/APG 81 active electronically scanned array (AESA), communications and electro-optical distributed aperture systems puts offensive, defensive, coms and data-gathering sensors at the service of the pilot to process onboard and offboard data. The EW system employs a range of dedicated antennas and shares the AESA antenna for tasks such as electronic support measures or signals collection and analysis. The F-35's high-gain, electronically steered radar array provides jamming support under the control of the EW system. Because the AESA array provides very directional radio frequency (RF) output, the JSF could target a very small area and selectively jam it, which enhances survivability by reducing electronic emissions.

Integration of the EW system's elements is intended to reduce system volume and power requirements and increase affordability. But it also can aid survivability, compared with federated systems. Integrating the radar warning and countermeasures functions, for example, shortens response time. "The [systems'] handshake is intimate," Branyan says.

At a deeper level of integration, EW and other mission sensors are connected via a common, large-scale computing resource--the F-35's integrated core processor, or ICP. Integration at this level, for example, enables the electro-optical distributed aperture system (EODAS) sensor to support the deployment of countermeasures. Although the RF-based EW system and infrared (IR) -based EODAS system are built to run separately in different frequency domains, they are tied together at the ICP level. Instead of having the pilot operate EW and IR displays separately to detect threats with the individual sensors, "the airplane can deploy the optimal countermeasures with or without pilot action," Branyan says. This level of automation and improved situational awareness shortens the timeline of detection and response.

The integrated core processor aggregates and correlates multisource data and formulates solutions for presentation to the pilot, mixing the best data from each sensor. This maximizes detection ranges and provides the pilot options to evade, engage, counter or jam threats.

"The end result will be maximum situational awareness within individual cockpits and throughout strike packages, linked to command and control nodes, to ensure the battlespace is fully detected, understood and exploited," asserts Jon Waldrop, Lockheed Martin's director of international programs. At the EW system level, the F-35 will about equal the F-22 in performance, Branyan predicts. But because the newer aircraft's EW suite was developed from the start for reliability and affordability, it promises twice the reliability at half the cost, compared with legacy aircraft.

The F-35's EW system is all-digital, which translates to reduced size, weight and power requirements, as well as greater speed and accuracy. The ICP will process data at up to 1 trillion operations per second, and that capacity could double before the F-35 becomes operational, says Waldrop. Lockheed Martin selected a commercial-based ICP, which costs considerably less than its mil-spec predecessors and promises orders of magnitude more power.

Always active, the EW system would provide all-aspect, broadband protection. "If you were to put a ... circle around an aircraft, there would be no one quadrant, degree or section that is not covered instantaneously, all the time," Drake asserts. Six low-observable EW apertures are distributed around the aircraft--two embedded inside the leading edge of each wing and one in the trailing edge of each horizontal tail. Located inside the aerodynamic mold line of the aircraft, the EW apertures are designed to allow the aircraft to perform missions without altering its radar cross-section. One aperture can be used to identify the mode of a hostile radar, and two or more apertures can be used to determine the direction of enemy emissions. There are three, four-channel wideband EW receivers.

Of the various mission sensors, the EW elements, aided by the AESA antenna, probably would detect the enemy first, after which the aircraft's electro-optical system could scan it. The radar and EW apertures cooperate closely in the RF domain. The F-35's AESA antenna and the EW receivers are connected to support quick, long-range searches throughout the AESA antenna's bandwidth.

The radar warning function includes analysis, identification and tracking of hostile radars, as well as mode detection and monopulse, angle-of-arrival direction finding. The EW system discriminates one emitter from another by determining signal characteristics such as frequency, pulse width and pulse repetition frequency. Mode determination includes defining the operating function of an emitter at a given time, e.g., search, acquisition, tracking, based on known characteristics.

The self-protection system includes a response manager and RF/IR countermeasures. Two countermeasure dispensers are located in the aft area of the aircraft, carrying IR flares and chaff. The IR flares are relatively small, allowing more to be carried than was possible in predecessor aircraft. The EW system claims a 440-hour mean time between failures. An onboard diagnostics and fault isolation system, which automatically downlinks data to maintainers, allows line replaceable modules to be ready when the aircraft returns to base. This should simplify logistics and increase combat sortie rates.

EW Testing

Six years ago Lockheed Martin selected BAE Systems as the F-35's EW supplier. Now about 50 months into the F-35's 10-year development cycle, the company has completed proof-of-design work and met the form, fit, functionality and maturity goals established for this initial phase of development, Branyan says.

The F-35's flight test program is slated to commence in the fourth quarter of 2006, using the first seven aircraft. But these are "flight sciences" aircraft, fitted with only the basic avionics infrastructure to support coms and navigation functions. They will be used to evaluate flying qualities, stability, envelope expansion and weapons release.

Last July BAE Systems flight tested the EW system built to the proof-of-design maturity level. The company used a leased T-39, the military version of the Sabreliner business jet. This internally funded risk reduction effort conducted at the Naval Air Weapons Station, China Lake, Calif., "proved the system worked and exceeded all predicted performance parameters," Drake asserts. According to the company's announcement at the time, the EW sensors collected simulated RF threat data from ground emitters, using the system's digital receivers.

Block 0.5 Suite

The China Lake test provided airborne evidence of early system maturation and fed into the proof-of-manufacturing phase. BAE Systems is testing the proof-of-manufacturing-level electronic warfare system at its Nashua, N.H., facility.

Lockheed Martin expects to receive the equipment later this month in Fort Worth, Texas. With the initial Block 0.5 configuration, BAE Systems will deliver the processing architecture, apertures and about 35 percent of the software. These elements will be enough to start evaluating the basic functionality. In 2007 BAE will start delivering more capable, Block 1.0 software and the final countermeasures suite. The Block 1.0 EW version will be evaluated on system development and demonstration (SDD) jets. Block 1.0 also provides the initial operational capability (IOC) that will be installed on the low-rate initial production jets to be used in operational test and development.

When the Block 0.5 equipment arrives, Lockheed will perform testing in a simulation and stimulation environment. The EW system can be exercised from a flight simulator, which is "flown" to an area with simulated threats that test whether the EW system correctly identifies, tracks and engages the hostile emitters. Stimulation refers to the input of RF signal simulation in order to evaluate EW functions against simulated threats. Lockheed also will use an open air, full-scale F-35 model, mounted on a pole outside the facility, to further verify EW capabilities. The apertures can be installed on this open air model, so other aircraft can be put up to test the EW system and essentially "fly against it," Branyan says. Airborne testing of the integrated sensor suite is set to begin in the first quarter of 2007 on Lockheed's F-35 Cooperative Avionics Testbed, a modified Boeing 737, [CATBIRD] shown at end of this article.

Flight testing of the EW system on the F-35A is planned to begin in the fourth quarter of 2008 with the first flight of a fully integrated "avionics aircraft." This aircraft will include the first full-production EW suite, slated for delivery in the first three months of 2007. The suite will be identical in all U.S. and international F-35 variants.

Producibility Focus

According to Dan Gobel, BAE Systems' vice president of F-35 programs, the development program is unique in using performance-based specifications instead of the traditional military specifications. "Performance" in this context refers to aircraft performance and supportability. Performance-based specs have been a major factor in meeting cost and reliability goals. "We set defined goals very early in development," says Gobel. "In the critical design review, we were 10 percent below our weight goal and below the target for recurring fly-away costs." Last year BAE Systems quoted EW system weight as 185 pounds (84 kg).

Leveraging legacy technology and past problem-solving techniques helped solve early issues. BAE Systems' team, for example, used lessons learned from the F-22's AN/ALR-94 RF warning and countermeasures subsystem, which the company developed. "We made a point to involve the average guy on the line, all the way up to a vice president, from day one, as we designed the system," Drake says.

"Every element of the [F-22] team was interviewed at length, and the [design] problem was examined from every possible angle and from every level of seniority, expertise and function. They were asked what they would do differently if they had to do it all over again."

As a result, JSF's EW system--both the architecture and the manufacturing and assembly methodology--avoided processes, materials or techniques that would have increased cost or weight, or adversely affected supportability, Drake says. The design of the aircraft's low-observable antenna arrays, for example, benefited, as these elements "were a follow-on to a previous design," he says. By introducing producibility considerations at the beginning of development engineering, BAE asserts it was able to reduce production risk and increase system reliability and affordability. "It was a very good strategic decision," Drake says.

Also important is the use of spiral development practices to leverage the commonalities between the F-35 and F-22A. Waldrop says: "Every time the F-22A flies we learn more. We can now spiral advanced technology developed for the F-35 back into the Raptor." The similarities between both sensor suites allow for an unprecedented degree of technical cross-fertilization. The F-35's iterative flight test program will contribute significantly to JSF maturation, as well. The flight test schedule is built around a series of periodic block releases, allowing content and function to be influenced by test results.

JSF's EW suite uses an open architecture to simplify integration and future evolution. It uses industry-standard components, including software written in the C++ programming language, field programmable gate arrays (FPGAs), 6U circuit cards in the VME format, and PowerPC microprocessors. F-35 mission systems designers aim to avoid the rigidities of firmware "burned into" hardware devices to provide the flexibility for spiral updates.

Total Integration

Within the JSF's overall mission systems package there is considerable overlap between the sensors. The best example is the aircraft's electro-optical distributed aperture system. While not part of the EW suite, EODAS has six strategically placed, embedded sensors, providing a fully spherical, continuously operating IR shield that can identify and track threats such as missiles, vastly increasing pilot situational awareness, says Branyan. Operating in the midwave-IR range, EODAS can provide warning at "tactically significant ranges," he says. EW and EODAS are two elements of an integrated sensor suite designed to detect and identify the full spectrum of air- and ground-based threats. EW, coupled with EODAS, provides integrated RF-IR domain coverage, Branyan says.

"Within the battlespace, pilots must be continually aware of both threats and friendly assets," Waldrop says. "While integrated systems like EW and DAS significantly ease pilot workload, it's ultimately up to the pilot to prioritize threats to ensure mission success." In the case of long-range detection, he says, the pilot has more time to detect and assess the threat. The ability to find and analyze a threat well before it detects the F-35 maximizes both offensive lethality and survivability. But it's a definite advantage to know that the integrated EW suite continues to operate in the background.

"It is important to note that as F-35 pilots fly a mission, the integrated sensor suite provides full situational awareness," says Waldrop. Sensor information includes not only onboard radar, EODAS and EW, but also offboard information. This could involve data from E-3 airborne warning and control system (AWACS) aircraft, Joint STARS (E-8C ground surveillance) aircraft, data-linked air and ground intelligence, other combat aircraft, and both space- and sea-based elements. All the tactical/defensive information, both on board and off board, is fed to the pilot through the F-35's integrated core processor.

The JSF team has overcome some big systems integration challenges, including "the ability to provide the pilot with incredible amounts of information in a very intuitive way," enabling the pilot to maintain the tactical advantage over any adversary, asserts Waldrop. The aircraft's open architecture design and use of commercial off-the-shelf components, furthermore, should improve sustainment and allow efficient upgrades.

The overarching challenge, Waldrop says, is to detect and assess relevant events in the battlespace, drawing from and publishing critical data into the "infosphere." In the final analysis, he concludes, the ultimate goal of the pilot-JSF integrated sensor interface is to achieve "a maximum level of actionable situational awareness."

Comprehensive CATBIRD CATB Article at CODE ONE magazine: http://www.codeonemagazine.com/article.html?item_id=50

The Difference Between 4th and 5th Gen EW

http://intercepts.defensenews.com/2014/10/the-difference-between-4th-and-5th-gen-ew/

"...fusion is going to take place in the pilot or electronic warfare officer's brain in a 4th gen aircraft..." Aaron Mehta / October 13, 2014

The Association of Old Crows (AoC) annual conference in Washington is the arguably the largest gathering of electronic warfare experts in the world. For three days, the basement of the Marriott Wardman Park in Northwest DC becomes the center of the EW-community, a mecca of sorts for those who gets down with wavelengths, sensors and receivers.

Unsurprisingly, experts from the Pentagon are well represented, both on the show floor and in the conference halls. Among those speaking Oct. 8 was Air Force Lt. Col. Gene "Joker" McFalls, F-35 Enterprise Lead with the 53rd Electronic Warfare Group.

McFalls was speaking as part of an Air Force panel on electronic warfare, but specifically was there to talk about the difference between 4th-gen fighters — legacy systems such as the F-15 or F-16 — and 5th gen fighters, such as the F-22 and McFalls' focus, the F-35 Joint Strike Fighter.

Defenders of the F-35 claim the jet will be the world's most advanced fighter. Where the plane will really shine is in the sensor fusion, McFalls said, taking the information from the plethora of sensors on the plane and taking the various data streams, combining them and spitting out easy to understand information.

Right now, pilots have to look at a number of different information streams, then mentally make decisions on how to react. The F-35 will do all those mental calculations for the pilot, McFalls said, freeing them up to focus on the operation unfolding around them.

"So what's the big difference in 4th gen vs 5th gen?," McFalls asked the audience. "Basically.. fusion is going to take place in the pilot or electronic warfare officer's brain in a 4th gen aircraft. This is probably oversimplifying it, but 'fighter pilot see bad guy, club bad guy with stick.' It's Og the Caveman, right?"

"Whereas with 5th gen, it's 'Dave, there is a MiG-100 out there. Would you like to kill him now? Check yes or no.'"

His disturbingly excellent HAL-voice aside, McFalls continued to lay out the case for 5th gen technology and how it might play out during a run-in with another fighter:

> "So you're going to take all of those sensor inputs — your radar, your electric-optical, your comm, your distributed aperture system and your radar warning, and it's going to fuse them all together to give the pilot a more accurate picture of what's going on for situational awareness and how he's going to engage that. And that's the big advantage you get with including all these sensors, because you're reducing the ambiguity down and enabling them to deploy the aircraft more effectively…
>
> With a 5th gen display, it's going to tell you pretty much what aircraft it is and what level of confidence it has determined that, and what the different sensors on the aircraft are predicting that threat to be. So what happens if we don't get this mission data program done effectively? With your legacy EW, the pilot has to do the fusion in his brain…
>
> With 5th gen, you start with the [electronic warfare database] data, going into the fusion engine, and then you can start eliminating things. So we get the characteristics and performance. We know it's flying, so it can't be a ground based threat. We have airspeed, we have altitude, that kind of thing. We add IR signatures. Ok, now we have mission data that lets us know whatever the threat is, it's a [radar cross section] of X and its size is Y, so we know it's probably not that first aircraft.
>
> Then we take the order of battle data and the [geospatial intelligence] data, and we know where we're flying, what the country has in their inventory. So we can eliminate it down, reduce the ambiguities so the pilot gets a representation of what the sensor fusion actually thinks the threat is. It takes all that data, fuses it together into that unique platform identification.

"Take away that data," McFalls said, and all that's left is "a stealthy F-16."

It's a continuation of a theme seen with the F-22 Raptor, the first 5th-gen fighter that is finally being used in action over Syria. Experts have highlighted the Raptor's advanced suite of ISR sensors as being just as key to allies as its air-to-air capabilities or the ability to strike targets on the ground.

McFalls admitted a lot of work remains to make sure the full capabilities of the jet are unlocked, and that's part of what his team is working on. But if the system works the way he told the audience to envision it, the F-35 is going to be very popular among pilots of the future.

Elite Engineering: The Brain of the F-35

April 14, 2015 https://www.f35.com/in-depth/detail/elite-engineering-the-brain-of-the-f-35

The human brain relies on five senses: sight, smell, taste, touch and hearing. It takes information from each of these sources and analyzes the data to understand our surrounding environment.

Similarly, the F-35 relies on five sensors: Electronic Warfare (EW), radar, Communication, Navigation and Identification (CNI), Electro-Optical Targeting System (EOTS) and the Distributed Aperture System (DAS). The
F-35 "brain"—the process that combines this stunning amount of information into an integrated picture of the environment —is known as sensor fusion.

LM Senior Fellow Tom Frey and Research Scientist Kent Engebretson are part of the world-class Lockheed Martin team of experts who have made sensor fusion a reality on the F-35.

Defining "Fusion"

At any given moment, a huge influx of data flows into fusion from sensors around the aircraft—plus additional information from datalinks with other in-air F-35s. Fusion takes all information from those various sources and combines it into a centralized view of activity in the jet's environment.

Many 4 generation aircraft were designed for a crew of two. The pilot flew, and the "back-seater" analyzed data displayed on various screens. For a single-seat jet like the F-35, the system must gather relevant data automatically and display it in a way that allows the pilot to fully concentrate on flying the mission ahead.

While the pilot flies, fusion actively interprets real-time sensor data to give him or her perhaps the most valuable advantage of all: reliable situational awareness.

Pieces of the Puzzle

F-35 fusion has the ability to take partial data from each sensor and combine it to make an accurate assessment. It not only combines data, but figures out what additional information is needed and automatically tasks sensors to gather it—without the pilot ever having to ask.

Given this unique capability, the way F-35 sensors had to adjust how they "think about" and report incoming data to take full advantage of the fusion system.

"Fusion is the core of our 5th Generation system," Kent remarks. "We're asking the sensors to send us not only their answer, but we want to know the reasoning and details behind that answer. That is what we combine during fusion to give us the whole picture."

The F-35 changes the way data is displayed for pilots. The full Panoramic Cockpit Display (PCD) enables data from all sensors to be shown on one screen in simplified form, instead of multiple. It even allows each pilot to customize the size and layout of displays. This makes it much easier for the pilot to assess the situation and make smarter decisions in the battle space.

It's All About Math

So, what is this entity that works so tirelessly to "fuse" all the information together?

The answer: math equations.
That's right, thousands of algorithms encoded onto a standard processing chip simultaneously fuse the staggering amount of data. And what's more: they are constantly changing.

Kent, Tom and their counterparts can take the software code they write, test it in simulators and make adjustments based on the lessons learned. This enables them to rapidly mature the fusion software along with the capabilities of the F-35.

"Fusion is easy when all the data agrees—but every now and then, there are discrepancies," Tom reveals. "It makes it harder when sensors give misinformation or are in conflict."

It's math that figures out what data to believe, when to believe and how much to believe. No one knows this better than Kent, who has been the Target Identification (ID) expert in F-35 fusion for the last 13 years following his time in the U.S. Air Force.

"For ID fusion, it's a lot of probability theory," he shares.
While there are many standard equations at the base of F-35 fusion, the team creates faster or more efficient implementations to handle all of the aircraft's fusion needs.

The Fusion Evolution

While the concept for fusion was first conceived in the 1970s on the F-15 program, no one ever fully succeeded in standing it up in an aircraft system until the F-22.

With 18 years spent as a representative on the F-22 fusion team, Tom is one of only a handful of people who have intimate knowledge of both the F-35 and F-22 fusion systems.

"Some innovations had to happen mathematically to deal with data the way they were sharing it before the F-22" he says. "By the time the F-22 came along, the computers and technology finally caught up, and we launched the first real 5th Generation fusion on an aircraft."

That was "Fusion 1.0." The F-35 takes it one step further.

"The F-35 not only has the ability to proactively collect and analyze data, but it adds the ability to share it amongst the fleet and work as a pack," he explains. "That's 'Fusion 2.0.'"

When asked about what's ahead for sensor fusion, both Tom and Kent see it continuing to evolve.
"We do things with fusion now that a decade ago, we said were impossible," Tom elaborates.

"When you have capability that no one ever dreamed of when it all seemed to be 'too hard'—and it all of a sudden becomes available—it changes the way we operate and fight."

Kent adds that, "I am very excited looking to the future, because there's this influx of additional technology that will surely enable us to do even more."

The Impact of Advanced Fusion in 5th Generation Fighters on Combat Capability

http://www.sldinfo.com/wp-content/uploads/2013/10/The-Impact-of-Advanced-Fusion.pdf

by Michael Skaff, Lockheed Martin Aeronautics Company

When Col John Boyd documented the concept of the Observe-Orient-Decide-Act (OODA) loop as it pertains to tactical aviation and the energy maneuverability egg it was in an era when fighter physical performance was the dominant factor.

Although there were simple fire control radars and missiles, his analysis pertained primarily to the visual encounter and energy maneuverability.

His bottom line: the pilot who runs through his OODA loop fastest stands a far greater chance of victory than his slower opponent who is constantly reacting to an ever changing situation.

This assertion stands today, but fighter performance is no longer the primary factor.

it is information, and the dominance thereof, that determines victory in the information age of tactical aviation.

Information Versus Data

In the early 21st century, more than any previous, we understand what information is and the manipulation thereof.

We are the information generation. The personal computer ushered in the world of information manipulation. We are bombarded with information from e-mail, RSS feeds, blogs, and social networking sites.

The Internet and associated browsers are our "go to" information brokers.

What would have taken a week of library research time is now accomplished in an hour of Internet search time. We hear the idiom "Google it" and know exactly what is meant: have you used a search engine to find information about an associated topic?

We even expect our personal telephones to do the same for us wherever and whenever.

But how does this apply to tactical aviation and just what is meant by the term "information dominance?"

When I type the word "information" into Google I get 6.9 million hits in less than a quarter of a second.

The problem is now I have too much information on information. I don't have time to sift through hundreds let alone millions of hits looking for the exact information I need so I narrow the search to "information dominance" and get 144 thousand returns.

I then spend the next 5 minutes trying to find a definition and perhaps an apropos example, but alas none is entirely satisfying (although the US Navy has quite a bit on the topic).

Let me now deal with the difference between data and information which is the nub of understanding the problem.

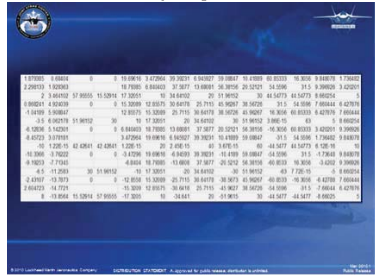


Figure 1

Figure 1 shows the cells of a spreadsheet.

In this form it is obvious that data is present.

It certainly adheres to the definition of "information in numerical form that can be transmitted or processed."

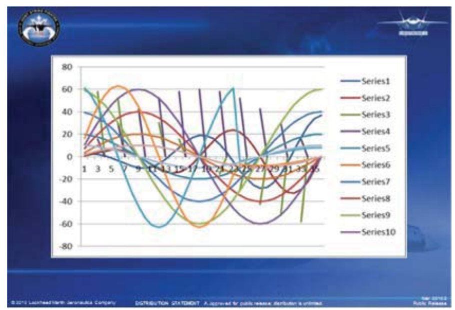
It is not immediately apparent what this data represents or how we'd make any real decisions based on it.

Now to a way to think about information as opposed to data.

Figure 2 is a graphical representation of the data from Figure 1.

When shown in this form it is far easier to visually communicate the data.

If you're a mathematician or a radio frequency engineer you probably recognize Bessel curves. The Bessel curves look like decreasing sinusoids. The highest amplitude curve is the orange one that peaks at 60 on the vertical axis and coincides with 6 along the X-axis.



This is a good example of information: "the communication or reception of knowledge."

By graphing the data it became information and we are able to gain knowledge of what the data represents.

We still do not know how to act based on this information. That comes next.

Figure 2. Graphical Representation of Spreadsheet Data.

Information dominance can be understood as flowing from the significant difference between data and information.

http://www.sldinfo.com/the-impact-of-advanced-fusion-in-5th-generation-fighters-on-combat-capability/

Here is a simple task: find the peak amplitude of the red curve before your opponent who doesn't have a graph. You can do that visually in just a moment – it's 40.

In this exercise your task was to find the peak value of the red curve in order to win. This became a trivial task because the data was transformed into graphical information and you were told how to act upon it.

Dominance is the goal in tactical aviation. Being second best in a combat situation is not a path to survival.

The "dominant must exert control and influence over the adversary" in order to prevail.

Information dominance determines winners and losers in the information age.

Sensors and datalinks have progressed to the point that we have a glut of data in the cockpit.

This glut quickly becomes information overload rather information dominance if not dealt with properly.

This is the decision making challenge: how to turn information overload into information dominance.

Enter advanced sensor fusion … one of the hallmarks of the 5^{th} generation fighter.

Let's look at the processing models that have lead up to advanced sensor fusion and provide an effective pathway from information overload a decision atrophy to information dominance and effective combat decision making.

Sensor Fusion as a Tool for Information Dominance

In this section, I am going to look at *three variant approaches* to putting the data together to ensure that I have the information to conduct combat operations.

Each of these approaches provides a way to deal with the problem, but only advanced fusion, the third model enables one to move ahead towards information dominance.

The Additive Approach

In the first processing model or approach (figure 3) is built around an additive process, whereby sensors are added to the airplane, but left up to the pilot's brain and experience to do the fusion.

As each new sensor or datalink was added the pilot was tasked with individual controls and displays. Each sensor had its own display and control panel. There were segregated paths from sensor through processor to display.

We then tasked the pilot to manage the bevy of disparate sensors all the while flying an extremely complex aircraft.

The information from these sensors was good and no pilot would think of going into battle without them, but there was a problem: information overload. The pilot was relegated to the role of sensor manager and that left little time to be a tactician. To complicate the situation sensor correlation and fusion was accomplished within the pilot's mind.

A Strike Eagle weapon systems operator (WSO) told me that he had a display for radar, a display for electronic warfare, and another display for datalink. It was his task to scan the three displays, make control inputs, and then build a mental picture of battlespace for the pilot and then communicate this picture to the other members of the flight.

The four WSOs in the flight verbally exchanged what they were seeing on their displays in order to build a consolidated picture of battlespace.

Experienced WSOs did this extremely well, but it takes hundreds of hours to become an experienced WSO and even more to get really good working as an integrated team.

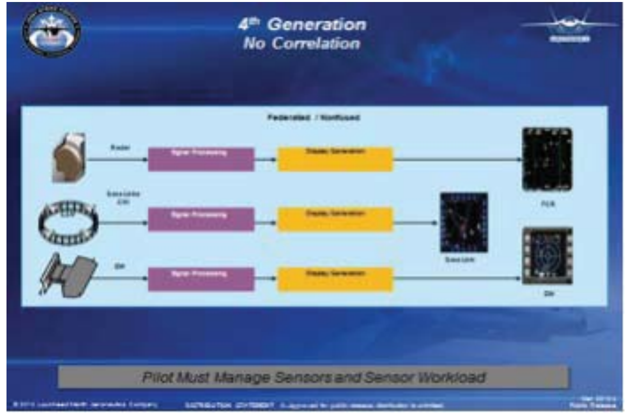


Figure 3: Processing Model 1

Correlation Sensor Suite Approach

The second model built out from the first. The correlation sensor suit was built upon simple correlation between sensors and datalinks.

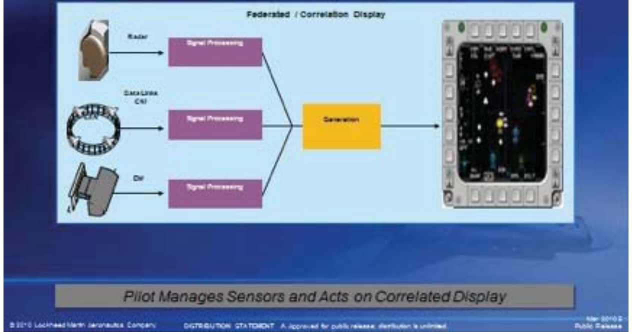
This is an important step toward sensor fusion.

Many later fourth generation fighters now incorporate some level sensor correlation.

Correlation can be accomplished at many levels, but the easiest is at the display level.

Display correlation combines the various sensor and datalink information onto a single display. This has the advantage of "one stop shopping" for the view of battlespace.

The disadvantage is track clutter.



Each sensor and datalink shows all of its information at the same time on the same display. What is needed is a means of combining tracks and fusing their identities in order to declutter the picture.

Figure 4. Simple correlation of sensors with datalinks.

The Fusion Engine Approach

The third model is what characterizes fifth generation fighters.

This is too often confused with stealth, but really as about stealth enablement for a flying fusion engine.

Advanced sensor fusion in 5th generation fighters performs three distinct functions: build the picture, task the sensors, then communicate the result.

Notice there is an extremely tight control and performance feedback loop being executed by the advanced sensor fusion engine.

This loop essentially isolates the pilot from the drudgery of controlling and monitoring the individual sensors.

The output from the advanced fusion engine is a picture of battlespace. It is designed to be easily interpreted by the pilot so that he can act quickly and decisively.

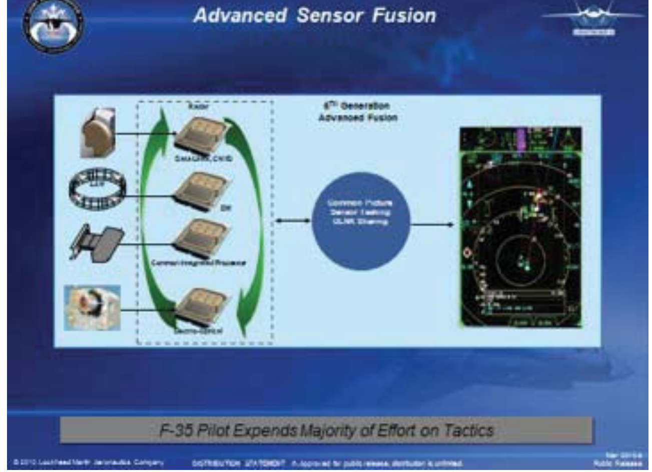
Remember, the dominant will exercise his OODA loop more quickly than his opponent.

The picture is the most visible part, but there is much going on behind the scene.

Automatic sensor control is giving time back to the pilot and the system is automatically communicating results with the other aircraft on the link.

This is time needed to make decisions and act upon the situation.

The F-35 and Advanced Sensor Fusion



The following sections highlight the major functions of advanced sensor fusion as it exists in the F-35 Lightning II.

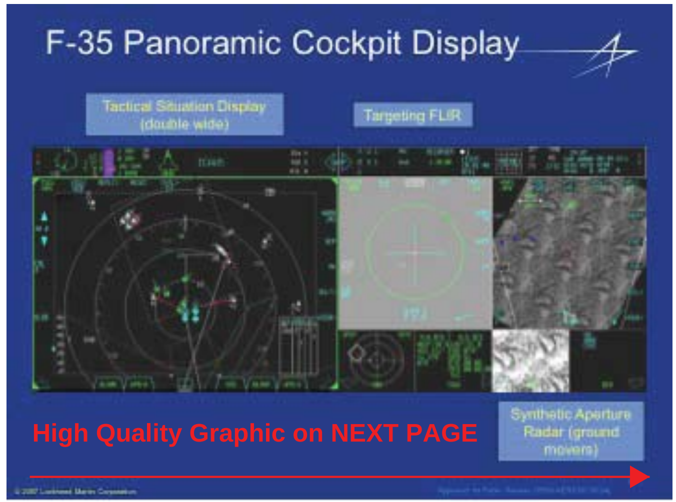
Figure 5. Advanced sensor fusion.

The picture is a fused and correlated view of battlespace.

The Tactical Situation Display

The Tactical Situation Display (TSD) is where the fusion engine's picture is displayed.

The TSD is the largest window in Figure 6.



Now, instead of the pilot monitoring a separate display per sensor, fusion presents a single integrated common operational picture (COP) on the TSD. The picture is an easy to interpret graphical representation of what surrounds ownship. It is color coded such that red diamonds, green circles, and yellow squares correspond to foe, friend, and suspect.

The differing geometric shapes are used for redundant coding so that color alone is not relied upon for identification.

F-35 Panoramic Cockpit Display

Tactical Situation Display (double wide)

Targeting FLIR

Synthetic Aperture Radar (ground movers)

Combat identification (CID) is performed automatically by using all of the information from each onboard sensor as well as offboard datalinks.

Another key aspect that enhances situation awareness is the use of common symbols across the services and international fleet of F-35s.

In legacy fighter cockpits there are differing symbol sets.

There is a lot of learning and a high potential for misunderstanding as pilots communicate. Whether pilots are flying an F-35A, 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 one day enable ground commanders to easily use the pilot's picture for an improved perspective on the battlefield.

Providing for Decision-Making Tools

5th generation advanced sensor fusion is more than a fused and correlated picture of battlespace.

The fusion engine controls the sensors and tasks them automatically to fill in data and combat identification holes. As each sensor reports kinematic and identification data, the fusion engine notes the data that is missing or data that would be better reported from a different sensor.

For example, a high resolution scanning infrared search and track system may report extremely accurate azimuth and elevation data, but poor or no range data. The radar, on the other hand, may report fair angles and very accurate range. Fusion will task the radar to stare along the IRST line of sight to measure the range.

Fusion then combines these two sensors into a "best features" kinematic solution. Fusion does this for every track and every sensor, as appropriate. Automatic sensor tasking occurs in the background and without pilot involvement.

Advanced sensor fusion goes beyond the ownership of a single cockpit. It is part of a fleet.

It connects in order to communicate with the other fusion engines through a high speed network.

This affords tremendous synergy as 5th generation fighters operate together in a connected OODA loop sharing sensor information. The pilots all see the same picture on their tactical situation displays.

As an individual airplane builds the picture, it is shared with the other fighters on the network.

Don't misunderstand, we don't share the graphical picture – we share the fusion contents in such a manner that each participating fusion engine can build its own graphical depiction for the pilot. In similar fashion to how fusion uses the best data from each sensor to build a better kinematic and ID solution it also uses every other fusion engine's contribution to do the same thing.

Why is this important?

Here is a simple example.

Suppose the enemy is able to attack and defeat a sensor on one aircraft. Fusion will exclude data from that sensor and use another sensor or even another aircraft's fusion results. The chances of the enemy being able to attack and defeat every sensor on every connected 5th gen fighter at the same time are almost impossible.

The synergy of connected fusion engines is one of the hallmarks of the 5th generation.

In the 5th generation the Common Operational Picture or COP is assembled and shared by each aircraft.

The shift from radio to a visual COP is a key definer in the shift from legacy aircraft to 5th generation fighters. With the COP (generated by fusion from all of the sensors and then presented in an easy-to-understand graphical view of battlespace) the pilots now share common situational awareness.

This is a multiplier in terms of lethality and survivability, but perhaps most importantly – it doesn't increase workload.

The pilot is returned to the role of tactician.

Twenty years ago radio was the tool used by pilots to create synergy. A good flight lead had to describe battlespace to his wingmen. If you couldn't describe battlespace and build a picture inside everyone's mind, then it was difficult to maintain mutual support and to generate combat synergy.

Modern 4th generation fighters with datalinks have improved information sharing, 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 mentally correlated.

Fifth generation advanced sensor fusion does not depend on the pilot's ability to mentally fuse and correlate multiple sensors into a picture and then communicate it verbally.

The planes share the picture automatically which means Blue 4, a brand-new 5th gen pilot, sees the same picture as Blue 1 is seeing who has 1,000 hours in the jet.

The shared COP is the key enabler for combat synergy.

It is 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 for a new pilot on his or her first mission. You can't teach airmanship, but we can bring the valleys of inexperience up quickly and in such a manner that we have a positive effect on lethality and survivability.

Mitigating Information Overload

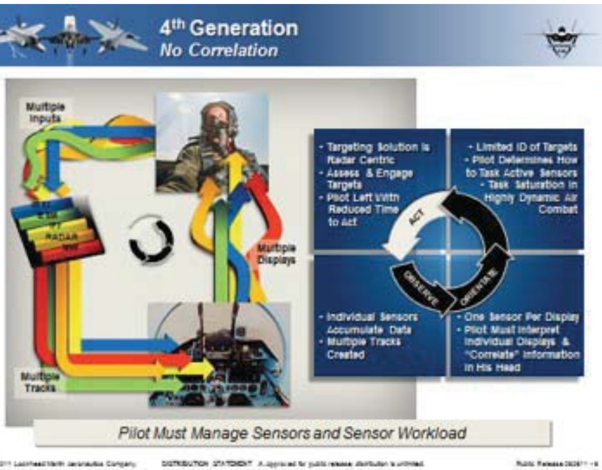
Let's go back to Col Boyd's OODA loop.

Figure 7 depicts an early 4th generation fighter with disparate sensors, datalinks, and displays. In this situation the pilot is controlling multiple sensors whose data is being shown on multiple displays.

This requires the pilot to build a mental picture of battlespace.

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 when not fully integrated into an advanced fusion architecture they contribute to information overload for the pilot.



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

Figure 7. Early 4th generation OODA Loop.

Information overload leads to pilot task saturation and channelized attention which is deleterious to survival. Pilots may become preoccupied trying to interpret information when they need to be focused elsewhere.

Here's an example to which we can relate: you're driving while studying the GPS and making a simple control input. Your driving performance is affected and your safety is being compromised because of misdirected focus and channelized attention.

The same holds true in the cockpit.

Displays are focus magnets.

They drain more and more of the pilot's mental processing capacity as it takes an increasing amount of attention to interpret the data. Consequently, performance and safety are compromised.

In tactical fighters this equates to impaired lethality and survivability.

Figure 8. Correlation Only OODA Loop.

The ability to turn situation awareness into dominance is the hallmark of 5th generation advanced sensor fusion.

The pilot requires information that is presented in an easy to consume format.

Another example to consider: when I was a new F-16 pilot we were tasked to fly against some fighters that had just gotten JTIDS installed. The JTIDS network gave them tremendous situation awareness of the battlespace. Every track, friend or foe, velocity, altitude, and aspect was displayed on top of the radar display – it was a cacophony of information and very cluttered.

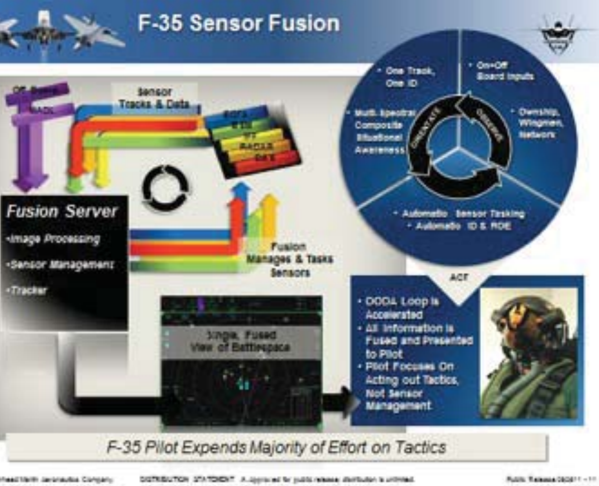
Information overload does not equate to information dominance.

We joked in the debrief: "they died with more SA than anyone."

It wasn't that we were extremely good and they extremely bad, but their information display was not being presented in an easy to consume format.

They became glued to the head down display and completely forgot about the visual fight that was ensuing out the canopy.

Most 4th generation fighters have now integrated sensor correlation as depicted in figure 8.



This is a significant step that places information from multiple sensors onto a single display and in some cases correlates the tracks. Sensor correlation works to provide a decluttered picture of battlespace.

A correlated sensor picture is important, but it is only one third of the equation. The pilot is still tasked with controlling the sensor suite and then communicating the picture with the others members in the flight.

Figure 9. Advanced Sensor Fusion OODA Loop.

Figure 9 depicts the 5th generation advanced sensor fusion suite in OODA loop form.

This design is fully integrated with the sensor control and display suite in order to provide the picture, perform automatic sensor tasking, and connectivity with the other fusion engines on the datalink.

In the 5th generation the advanced sensor suite is planned and built in from the inception of the weapon system.

Advanced sensor fusion is one of the hallmarks of the 5th generation.

Its contribution is far more than situation awareness and manageable workload. It provides information dominance.

Information dominance determines winners and losers in tactical aviation.

Addendum: Definitions

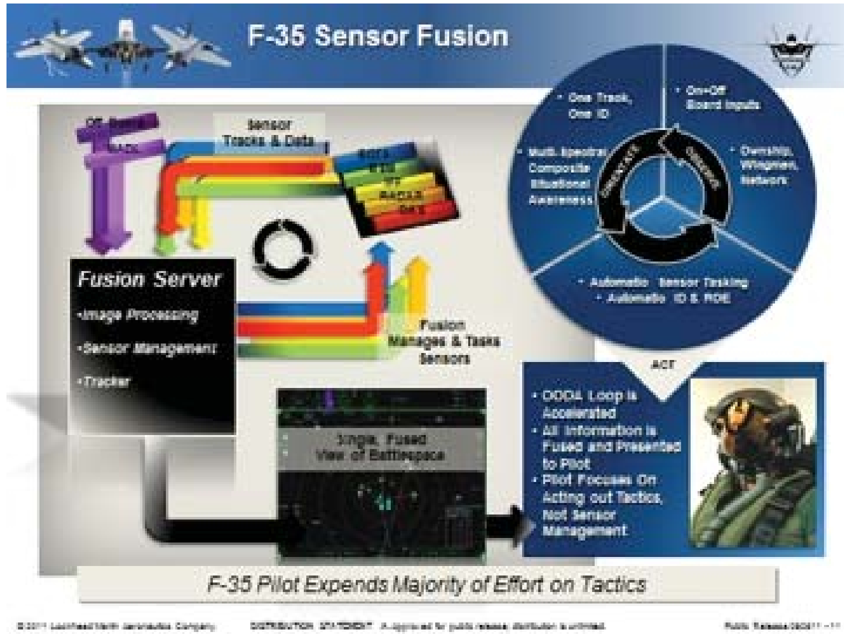
- Data – information in numerical form that can be digitally transmitted and processed (Merriam-Webster)
- Information – the communication or reception of knowledge or intelligence (Merriam-Webster)

- Dominance – the influence or control […] exerted by the dominant (Merriam-Webster)
- Information Dominance – the ability to use information in such a manner that you dominate over an opponent.

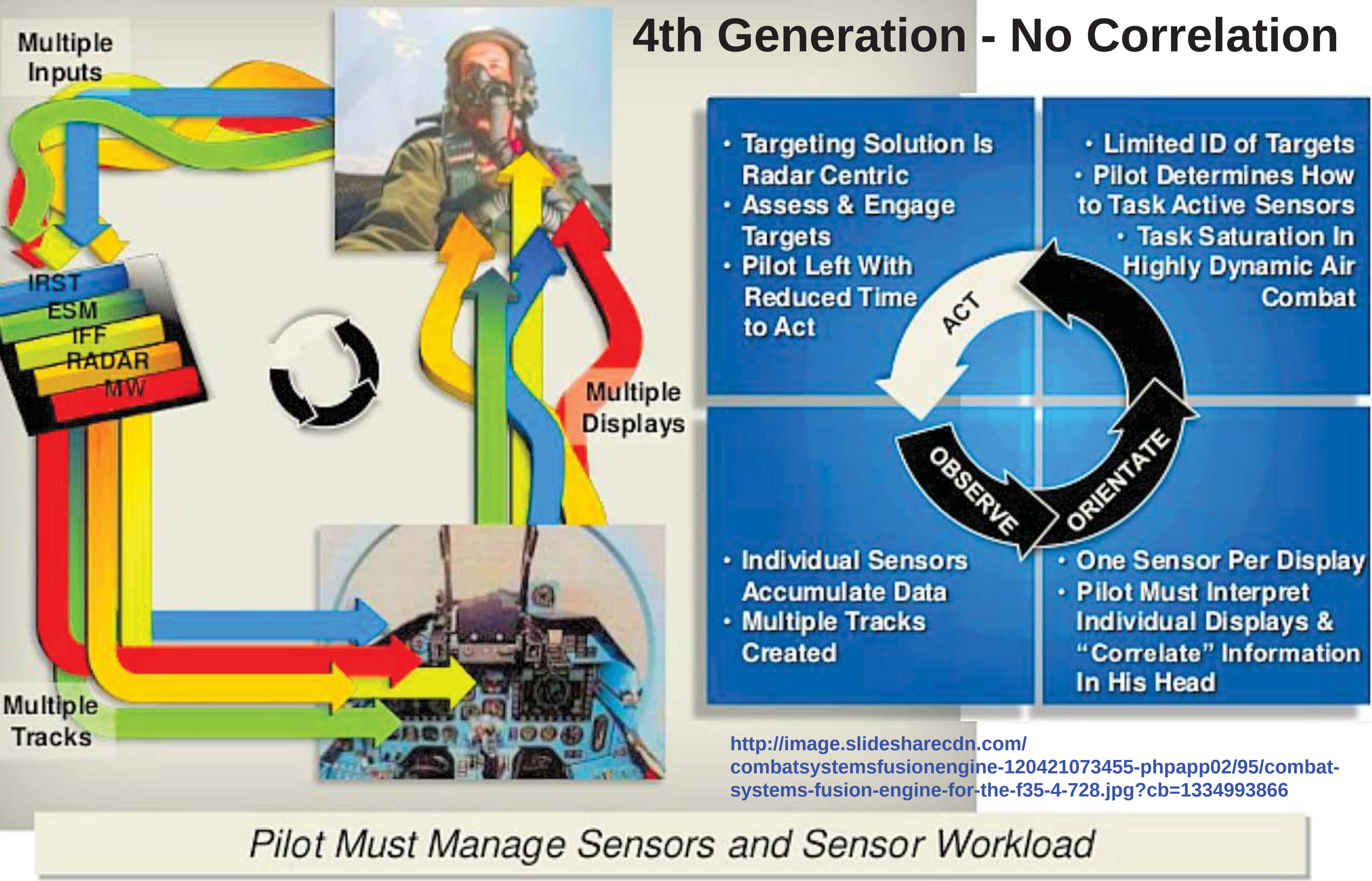
Mike Skaff has worked on the evolution of pilot cockpits and the processing of information for those cockpits for many years. He was a major contributor to the success of the F-16 cockpit and is the Principal Engineer for the F-35's pilot vehicle interface .

We published earlier a discussion between Ed Timperlake and Mike Skaff on how the fusion engine is an input to a new approach for pilot learning as well.

http://www.sldinfo.com/shaping-a-new-approach-to-combat-learning-the-role-of-the-f-35/



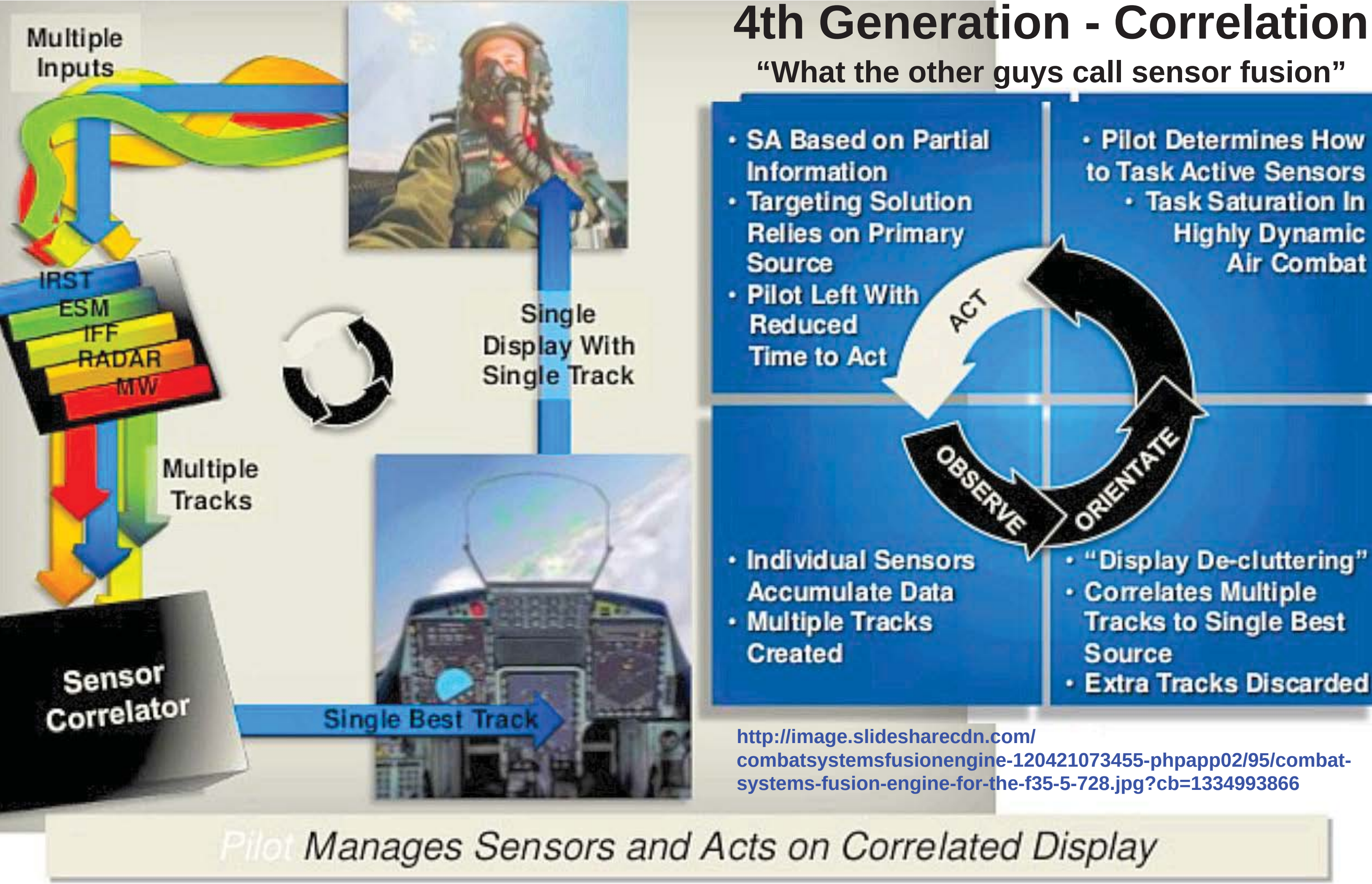
4th Generation - No Correlation



http://image.slidesharecdn.com/combatsystemsfusionengine-120421073455-phpapp02/95/combat-systems-fusion-engine-for-the-f35-4-728.jpg?cb=1334993866

4th Generation - Correlation

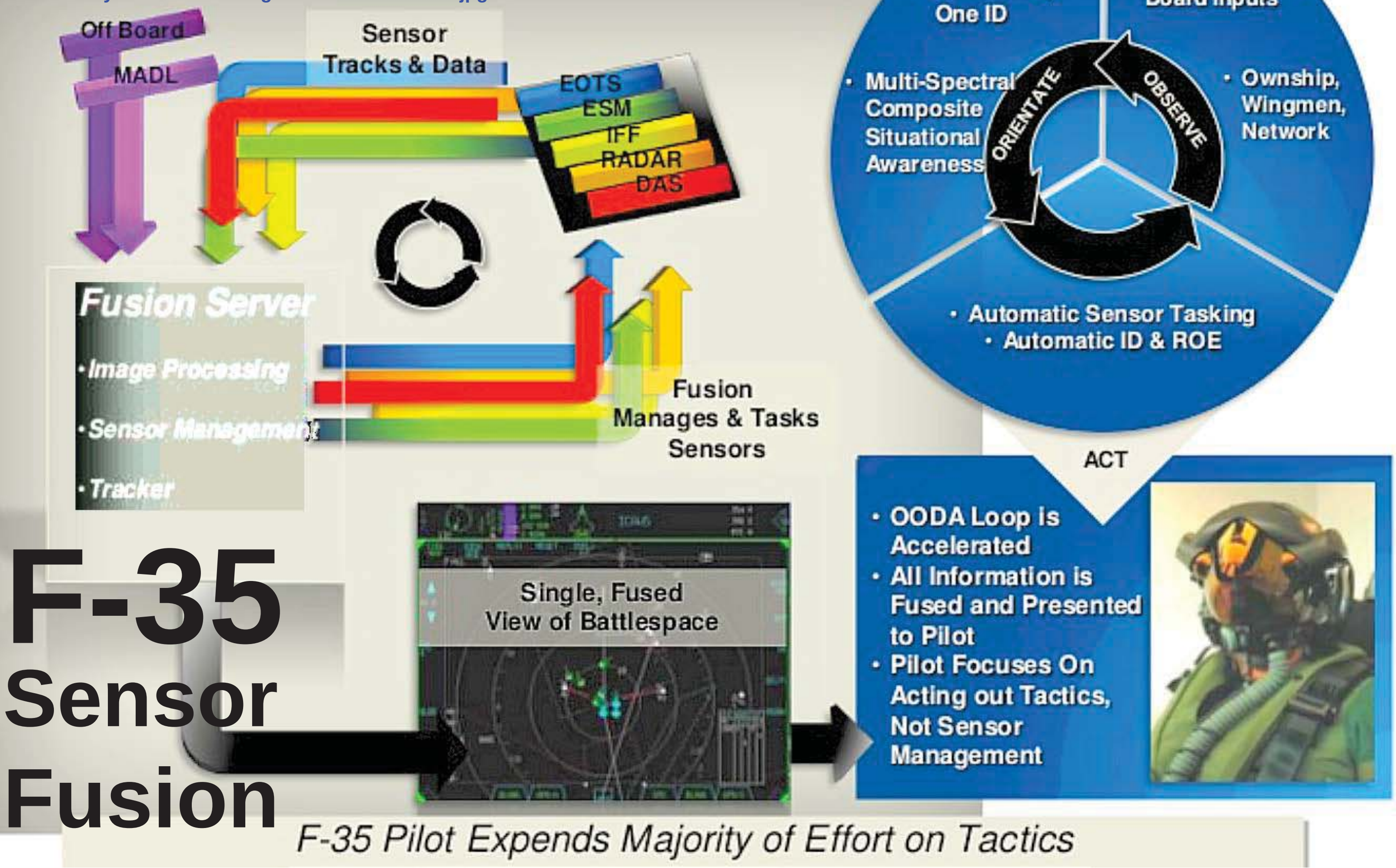
“What the other guys call sensor fusion”



http://image.slidesharecdn.com/combatsystemsfusionengine-120421073455-phpapp02/95/combat-systems-fusion-engine-for-the-f35-5-728.jpg?cb=1334993866

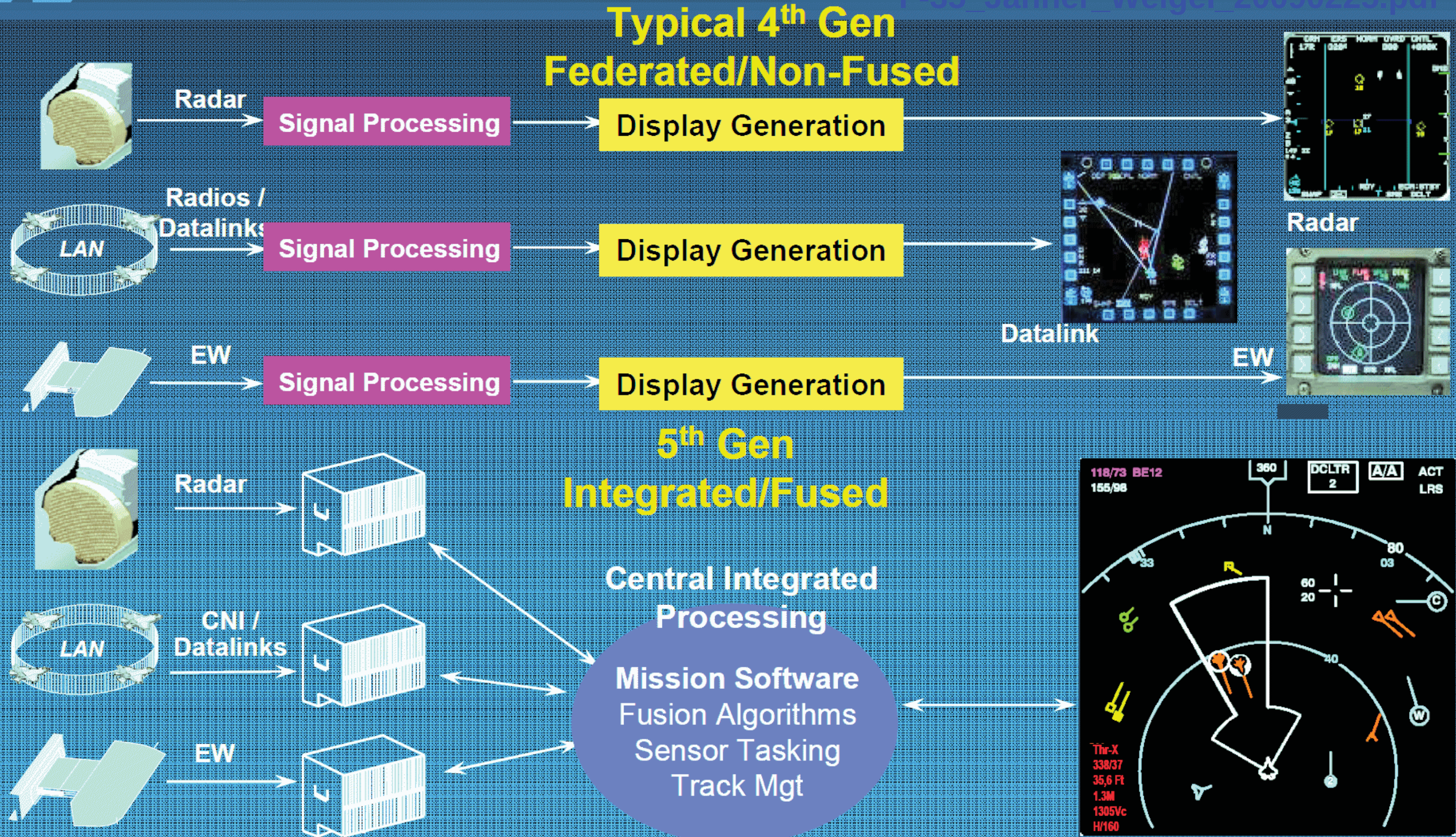
http://image.slidesharecdn.com/combatsystemsfusionengine-120421073455-phpapp02/95/combat-systems-fusion-engine-for-the-f35-6-728.jpg?cb=1334993866

F-35 Sensor Fusion



Integrated vs Federated System Architecture

https://www.ncoic.org/apps/group public/download.php/11779/ F-35_Jahner_Weigel_20090225.pdf



SAE International™

F-35 Lightning II Cockpit Vision

2010-01-2330

Published 10/19/2010

Michael Skaff

Lockheed Martin Aeronautics Company

ABSTRACT

A brief explanation of the design iterations and philosophy used to integrate the pilot into the F-35 Lightning II cockpit to achieve optimum Pilot Vehicle Interface (PVI), manageable single seat workload, and superior situation awareness.

INTRODUCTION

The design philosophy of the F-35 Lightning II cockpit is to *"return the pilot to the role of tactician."* This is accomplished by allowing computers to do what computers do best and allowing pilots to do what pilots do best. Computers do not, per se, make decisions, but merely organize, prioritize, and present data. They do this extremely well. With the proper algorithmic processing data becomes useful information. The pilot, on the other hand, does not process data in an algorithmic fashion, but is able to make heuristic decisions which only he or she can do based on experience and understanding. The role of the cockpit designer is to recognize these two fundamental differences in handling data and to rightly divide the tasks between man and machine. This paper describes the cockpit design approach and how the design team integrated the pilot into the F-35.

F-35 PROGRAM OVERVIEW

The F-35 is the world's second 5th generation tactical fighter. It is being produced by a team comprising Lockheed Martin, Northrop Grumman, and BAE Systems. Lockheed Martin Aeronautics Company is the prime contractor. Four contractual pillars underlie the program: lethality, survivability, supportability, and affordability. The F-35 must do better in these four areas than the fighters it replaces - a tall order.

Figure 1 lists some of the important program highlights. The aircraft is designed to meet the needs of the USAF, USMC, and USN in three variants the F-35A, F-35B, and F-35C respectively. In addition, 8 partner nations are participating in design and development of the aircraft.

The three variants are nearly identical and differ mainly in their ability to takeoff or land in unique fashion. The A-model is a conventional takeoff and landing (CTOL) aircraft and will be used predominantly by traditional air forces from long runways. The B-model has short takeoff and vertical landing (STOVL) capability and will be used by the Marines and some partner nations. The C-model has a slightly larger folding wing with beefed up landing gear designed for aircraft carrier (CV) launch and recovery. This model is designed exclusively for the US Navy.

The F-35 is the second 5th generation fighter to be produced. Figure 2 lists the characteristics which define fighter generations and gives examples of typical fighters from those generations. The 4th generation is marked by an increase in advanced avionics and sensors. Unfortunately, in fourth generation fighters the pilot was relegated to the role of sensor and systems manager. There was hardly time left to "fly and fight."

The key attributes of the 5th generation are: very low observable (VLO) stealth, fighter performance, integrated sensor fusion, network enabled operations, and advanced supportability. The F-22 Raptor was the first and is currently the only operational 5th generation fighter in service today. The F-35 is scheduled to go operational with the US Marine Corps in 2012, the US Air Force in 2015 and US Navy in 2016.

The F-35 will replace multiple 4th generation fighters including the F-16 Falcon, F-18 Hornet, A-10 Thunderbolt, and the AV-8 Harrier. It will also replace numerous 4th generation aircraft for our international partners.

Figure 1. Program Highlights

COCKPIT OVERVIEW

The cockpit was designed by pilots for pilots and is the culmination of a 15 year effort which started in 1995. A small team of former and current military fighter pilots assembled to design the cockpit. This multi-service team had over 150 years of tactical aviation experience in 7 different fighters including the 4th generation fighters the F-35 is designed to replace.

Figure 3 shows the final result. The cockpit is dominated by a large 20 inch by 8 inch Panoramic Cockpit Display (PCD) which incorporates an integral touchscreen. The fly by wire system is controlled via an active sidestick on the right and an active throttle on the left. Active means these inceptors are under complete computer control and can be programmed as to gradient, force feedback, and stops - all on the fly. There are 10 switches on the sidestick and 12 on the throttle. The Hands-on Throttle and Stick (HOTAS) are mapped to the most used tactical and subsystem time critical functions.

Notably absent is a physical combining glass for the Head Up Display (HUD). In lieu of a HUD the pilot wears a Helmet Mounted Display (HMD). Much more about the HMD will be described later in the paper. The HMD will be as revolutionary to tactics as was the HUD.

Most pilots who look into the cockpit for the first time are struck by the lack console switches and physical instruments. The design team decided early to start with a clean sheet/ cockpit and then to add mass based on value added functionality. This decision worked well to control cost and weight in the cockpit. As many functions as possible were mapped to virtual switches. These functions are controlled through cursor hooking, touch, and voice recognition.

The few remaining physical switches control safety critical functions such as landing gear, engine start/stop, and electrical reset. These functions work regardless of software in an emergency.

COCKPIT DESIGN METHODOLOGY

The cockpit consists of software and hardware. Two distinct disciplines can be applied: Pilot Vehicle Interface (PVI) and Human Factors Engineering (HFE). The PVI is akin to the graphical user interface and the HFE are the things which the pilot can physically touch and feel.

Pilot Vehicle Interface Design

The Pilot Vehicle Interface is implemented in software and is the graphical user interface. The interface incorporates a windowing scheme and multiple individual formats which dictate content and control interaction. Example formats are fuel, engine, and weapons. The windowing interface is not as flexible as the ones found on desktops, but it does allow the pilot to arrange and resize the windows. ***The PVI is the heart of the cockpit.***

Figure 2. Fighter Generations

Figure 3. F-35 Lightning II Cockpit

The PVI process is the pragmatic application of human factors done by subject matter experts. It is sometimes referred to as a BOGSAT (bunch of guys sitting around a table). The key is that these are all extremely experienced and astute military aviators who have "been there - done that" and, in general, know what they need to be lethal and survivable in tactical aviation warfare. What, from the outside, appears to be a swirling dervish of opinions, ideas, and pride; will in fact result in a good design and effective operator interface.

The most challenging part of PVI is not the paper design, but the implementation on target hardware. The pilots, more times than not, can design PVI which is well beyond the hardware state of the art in graphical processing power. Because of this a number of technology refreshes were designed into the program. Even with the refreshes the hardware is taxed to present the PVI.

Human Factors Engineering Design

None of the pilots on the design team were trained in formal human factors and man-machine interface which makes them poorly suited to scientifically integrate the human into the cockpit. For this task human system / human factors engineers are called into the process. Their task is to properly engineer the accommodations, escape, life support, personal flight equipment, HOTAS, and displays. These tasks are done through full scale mockups, engineering trade studies, and anthropometric modeling. ***The human factors engineering is the backbone of the cockpit.***

Special design consideration and attention to hand size is needed for the stick and throttle. The sheer number of buttons on theses controls can make the pilot feel like she is "playing the piccolo." Most of these switches are important enough to warrant double or triple redundancy which affects the grip's volume. The HOTAS are carefully mapped to time critical functions which must be accessed in maneuvering flight at G-loadings from +9 to −4. The grips themselves must be comfortable and useable while wearing chemical-biological protection gloves.

The cockpit is designed to accommodate an extremely wide range of pilots from a petite 103 lb. female to a large 245 lb. male. This range of anthropometry must allow every pilot to reach all of the controls in all flight conditions and to be safely ejected in the event of an emergency.

The ejection seat must accommodate the full range of pilots comfortably for 6 hour or longer missions. It is impossible to get up and move around. The seat must also extract the pilot under conditions from motionless on the ground to near supersonic velocities and high altitude.

Head-down Display

The cockpit environment is particularly harsh and requires unique display capabilities. Within the cockpit are extremes of pressure, temperature, and G-loading; but the greatest challenge is operation under a bubble canopy. The displays must be legible and of sufficient brightness, contrast, and color saturation to compete with the noon day sun at 50,000 feet. The Panoramic Cockpit Display (PCD) utilizes liquid crystal displays which are backlit with high intensity light emitting diodes (LED). The LEDs have sufficient dynamic range to be used at noon as well as midnight or with night vision intensification. The displays must also fit within the allotted volume and for this a detailed trade study had to be conducted.

The aerodynamicists dictated the cockpit volume and outer mold lines within which the displays must fit. Figure 4 shows four options which met the volume and mass requirements and were top candidates in the display trade study. Note that three of the configurations do not depict a Head-up Display (HUD). In these configurations a Helmet Mounted Display (HMD) would have to be used as a virtual HUD. During this trade study a large number of current 4th generation fighter pilots were polled and to a person they asked for the largest displays possible. Initially, the lower left configuration with three displays was the preferred design. As the cockpit design progressed the pilots migrated to the upper right configuration as their preferred design. This configuration incorporates two 10 × 8 inch displays butted together with a small septum in between. The decision to adopt the two large displays caused two major engineering challenges.

The first challenge was in the area of processing power. Each display is controlled by an independent computer and graphical processor unit (GPU) which must be able to function stand-alone, if necessary. The move from three displays to two means one less computer and GPU is available for rendering PVI.

The second challenge was the elimination of physical bezel buttons and keypad. The preferred design left no room in the cockpit for a physical keypad. The HFE team suggested three co-primary control schemes which did not require buttons: cursor hooking, touch, and voice recognition. Through the triple availability of cursor hooking, touch, and voice every function may be accessed. Co-primary means that pilot preference and flight conditions determine which control method is used.

Head-up Display

In lieu of a physical HUD the F-35 uses a Helmet-mounted Display (HMD) as shown in Figure 5. The F-35 is the first modern fighter to use an HMD to the exclusion of a HUD. The HMD projects two identical images onto the visor, one for each eye, focused at infinity. HUD vector symbology as well as sensor video is projected onto the visor.

One of the most interesting sensors on the aircraft is the Distributed Aperture System (DAS). Surrounding the aircraft are 6 staring infrared cameras which are sensitive to thermal radiation. Video processing computers seamlessly stitch the

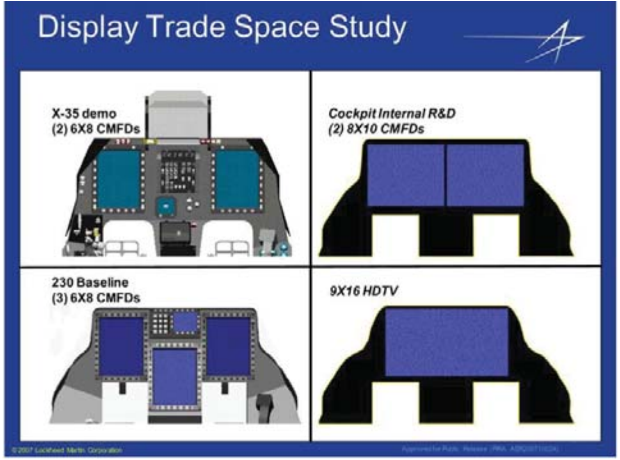


Figure 4. Display Trade Space

Figure 5. Helmet Mounted Display

individual images together into a 4π steradian sphere for the pilot to look through. As she positions the helmet line of sight the appropriate portion of the imaged sphere is projected onto the visor. This makes it possible to "look through the aircraft structure". Because the cameras are located external to the cockpit pilots have remarked that "it is like flying Wonder Woman's glass airplane." This capability is extremely useful when trying to position the aircraft from a hover over the landing spot.

CONTROL AND DISPLAY LOOPS

Figure 6 shows the pilot centered design approach. The pilot sits at the center of two control and display feedback loops: Tactical and System. She must be equipped to "kill and survive" as well as "drive the bus." The design teams used a divide and conquer strategy in order to work each loop concurrently. The first team concentrated on the system loop and the Integrated Caution and Warning System (ICAWS) while a separate team concentrated on the tactical loop. The loops are equally important. Representatives from each team met weekly to coordinate their designs and to arbitrate use of the controls and displays.

The challenge for the teams was in how to properly share the same controls and displays to support both control loops simultaneously. For example: is it more important to see a missile about to hit the aircraft or an engine problem which will result in immediate loss of thrust? There is not always an easy answer. An automated scheme for filtering and arbitrating display space is built into the software.

Both loops use a combination of aural and visual indications to alert the pilot. The teams agreed that the controlling software should never be allowed to change a display without pilot consent. This is because the software never really knows what is most critical to the pilot at the moment. Remember, the over arching philosophy rests on letting pilots do what pilots do best and letting computers do what computers do best. The pilot has the final consent/say-so while the computer organizes, prioritizes, and presents information.

Tactical Loop

The tactical loop is most glamorous because this is where the pilot "flies and fights." This loop assembles tactical data, transforms it into information, and then presents the fused and integrated picture. The mountain of incoming sensor data must be turned into information to allow the pilot to be lethal and survivable. Even the best integrated sensor fusion is not perfect. In these cases the pilot is allowed to drill down into the data and override what is being displayed.

Figure 7 is an example of the Tactical Situation Display (TSD) programmed into a 10 × 7 inch window. The TSD is the "one-stop-shopping" display onto which the fused and integrated tactical picture is presented. This picture allows the pilot to observe, orient, decide, and act based on what is happening outside of the aircraft. Note that the top one inch of the display is dedicated to a portion of the system loop.

System Loop

The system loop may not be as glamorous, but it is critical for safe flight. Regardless of how magnificent the tactical loop is, if the pilot cannot safely get the aircraft to and from battlespace, all is lost. The aircraft system manager works silently behind the scenes monitoring the various subsystems and only interrupts the pilot on a need-to-know basis. The entire top inch of the display is dedicated to system monitoring. The system loop uses this area to keep the pilot apprised of her aircraft. In the event of serious problems the pilot may instantly reconfigure the display to bring up the ICAWS information.

Figure 8 shows a series of onboard failures. They are color coded, automatically prioritized according to severity, and written in human readable terms. In this example the pilot has linked into the onboard checklist in order to remedy the faults. The checklist is color coded and presents a clear sequence of mitigating actions which the pilot should implement.

The ICAWS software constantly monitors various subsystems such as fuel, hydraulics, engine, and flight controls. The internal aircraft monitoring system generates mountains of data. The ICAWS must categorize, prioritize, and turn this data into useful information for the pilot to act upon. At the top of the prioritization tree are WARNINGS which are shown in red and audibly annunciated in English. Warnings are defined as failures so extreme that loss of life or major aircraft damage is certain if not tended to immediately. CAUTIONS are next in priority, are displayed in yellow, and are audibly heard as "deedle-deedle." CAUTIONS indicate failures in which damage may occur, but the sense of urgency is much less than a WARNING. Finally, INDICATIONS are displayed in green and are least severe. Most can be ignored without hazard or, at most, tended to when time allows.

The aircraft has been provisioned for 3-dimensional audio. Currently, the communications suite uses this capability for left-right audio discrimination of the various communications channels. It is not being used by the ICAWS, yet. The human factor engineers are beginning to explore multiple simultaneous audio channels with voices and tones which seem to originate within the aircraft at the location of the faulty subsystem. This may prove to be a means getting more and better information to the pilot.

In the unlikely event of catastrophic engine failure in hover mode the F-35 is equipped with an automatic ejection seat. This feature is only armed and available at the extremes of the vertical landing envelope. At first thought an auto-eject function seems extreme to most pilots, but once they are made aware of the time critical urgency and the total inability of the human to command a manual ejection during low

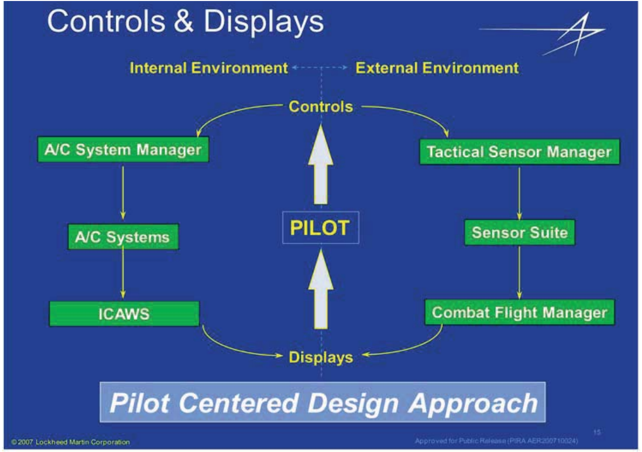


Figure 6. Control and Display Loops

altitude hover, most are thankful for this capability. This is a clear example of letting the computer do what computers do best.

INFORMATION CHALLENGE

With the F-35's array of tactical sensors, internal monitoring, and networked datalinks it becomes increasingly difficult to manage data and to turn this data into useful information. It is all too common for information dominance to become information overload. At times the aircraft knows so much about the internal and external environments that it swamps the pilot with "interesting, but irrelevant information." Information overload overwhelms even the best pilots, increases workload, and degrades their situation awareness. The design challenge is to present and prioritize only the information the pilot needs at the time. This is easier said than done.

It is through robust modeling and simulation that information leveling algorithms are developed and tested. In system loop simulations the pilot is presented with conditions and failure modes which totally tax her ability to maintain aircraft control. These are primarily takeoff and landing calamities the likes of which should not be expected to occur more than once in tens of thousands of hours of flight. Of course, the pilot must be trained to deal with these unlikely situations.

In tactical loop simulations the pilot is presented with nearly impossible air and surface threats. Here the tactical loop is exercised and pushed to the limit to increase pilot lethality and survivability. These missions represent the worst-case anticipated wartime scenario with postulated future threats.

Now combine the two into a full mission simulation and the pilot is faced with an inbound missile and imminent engine loss of thrust at the same time. Both control and feedback loops get exercised in worst-case scenarios. At some point the workload is beyond what the human can perform and situation awareness is in the map case. It is at this edge of man-machine performance that we really make progress and get a glimpse of what is needed for 6th generation tactical aircraft. It is conceivable that the 6th generation will be pilotless. The term "displaced reality" describes the condition when the pilot is resident at some distant location controlling a myriad of tactical vehicles.

SUMMARY/CONCLUSIONS

The F-35 Lightning II is the most advanced tactical cockpit ever designed. Figure 9 highlights some of the important capabilities. The unique design philosophy of *"return the pilot to the role of tactician"* dominates. This was accomplished by allowing the pilot to do what pilots do best and letting computers do what computers do best. Together man and machine become more lethal and more survivable.

Figure 7. Tactical Situation Display

CONTACT INFORMATION

Michael L. Skaff
Principal Systems Engineer
Lockheed Martin Aeronautics Company
1 Lockheed Blvd.
Ft. Worth, TX 76101

DEFINITIONS/ABBREVIATIONS

Air Systems Integration Facility
combined Mission Systems and Vehicle Systems full mission simulator

CTOL
Conventional Takeoff and Landing

CV
Carrier Variant USAF - United States Air Force

DAS
Distributed Aperture System

FPA
Focal Plane Array USMC - United States Marine Corps

GPU
Graphics Processing Unit

HFE
Human Factors Engineering

HMD
Helmet Mounted Display USN - United States Navy

HOTAS
Hands On Throttle and Stick

Figure 8. Integrated Caution and Warning System (ICAWS)

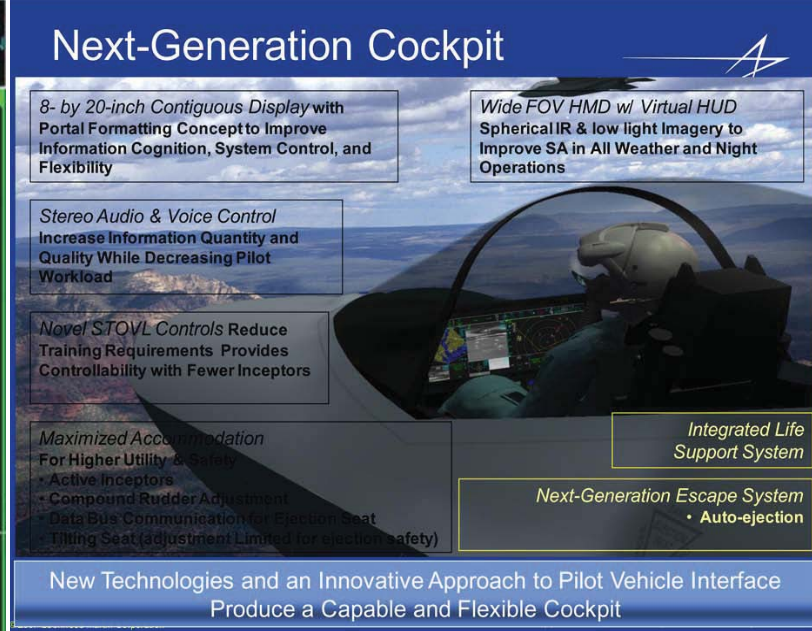


Figure 9. F-35 Cockpit Highlights

F-35 Simulator - AA & AG Modes/ Avionics, DailyAirForce 12 Nov 2010

10 Mins long video shows F-35s' AA and AG modes

https://www.youtube.com/watch?v=5lPZDc8mzsY

HUD
Head Up Display

LED
Light Emitting Diode

Mission Systems
team which is responsible for tactical avionics

PCD
Panoramic cockpit Display

PVI
Pilot Vehicle Interface

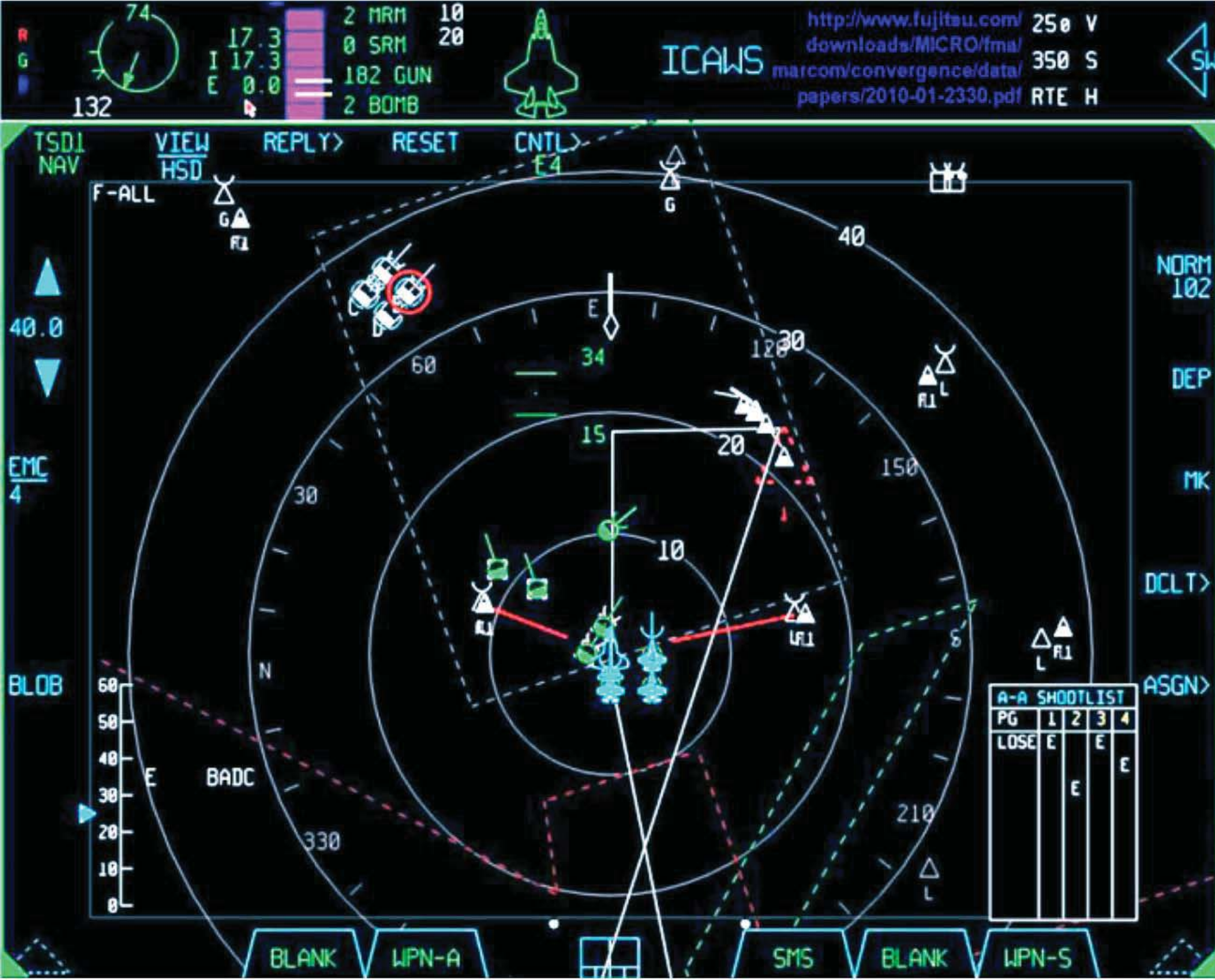
STOVL
Short Takeoff and Vertical Landing

Vehicle Systems
team which is responsible for flying qualities, flight control software, non-tactical subsystems

VLO
Very Low Observable

DISCLAIMER

Statement A: Approved for public release; distribution is unlimited; JSF10-122, 2/23/10.



"An example of the Tactical Situation Display (TSD) programmed into a 10 × 7 inch window. The TSD is the "one-stop-shopping" display onto which the fused & integrated tactical picture is presented. This picture allows the pilot to observe, orient, decide, and act based on what is happening outside of the aircraft. Note that the top one inch of the display is dedicated to a portion of the system loop." **http://www.fujitsu.com/downloads/MICRO/fma/marcom/convergence/data/papers/2010-01-2330.pdf**

FLIGHT TEST: F-35 Simulator - Virtual fighter 31 Jul 2007 Mike Gerzanics

https://www.flightglobal.com/news/articles/flight-test-f-35-simulator-virtual-fighter-215810/

"...Integrated avionics

The F-35's avionics are highly integrated, and for weapons targeting and employment the system must have a point of interest. A cursor designates the system's point of interest and is controlled by the slew switch/cursor control on the throttle. The cursor navigates within the active portal, indicated by a yellow corner hash mark. The portal of interest (PoI) can be the HMD, DAS, radar, EOTS or tactical situation display (TSD). Changing PoIs is primarily accomplished using the data management switch on the sidestick. The cursor's shape changes as function of the PoI and target type (airborne or surface).

The large display area is a palette on which a detailed picture of the tactical situation can be presented. Fused data from the active and passive sensors, as well as datalink information, is used to present the tactical situation in real time. Typically a pilot will use half the display (10 x 7in) for the TSD. The display scale can be tailored to the situation, with ranges from 18.5km (10nm) to 1,185km available. Own ship position, as well as that of other formation members, is in blue. Ground and airborne points/targets are colour-coded: green friendly, yellow undetermined and red hostile.

Target depictions are graphically coded to indicate where the information came from. For airborne targets, shown as a lollypop, the circle is either hollow, half filled or full. Hollow indicates on-board data alone filled indicates only off-board sensors half filled means both on- and off-board sensors are seeing the target. The stick of the lollypop is at first a velocity vector. When the sensors get a lock, the stick increases in length, approaching but not touching the targeted aircraft. The stick extends to touch the targeted aircraft when the fused sensors determine the F-35 has a launch solution on its target. Geographic boxes/lines can be displayed to show areas such as missile engagement and no-fly zones.

Shoot list

To give me a better feel for the F-35's capabilities, Skaff set up two scenarios, one air-to-air and the other air-to-surface. For the air-to-air engagement, my four-ship formation of F-35s targeted four Red aircraft. Using the cursor I locked on to all four aircraft to develop a shoot list. When locked to a target, an expanded data block is presented on the TSD. This identifies the aircraft type, as determined by the numerous sensors, with system confidence level for the determination. Also presented are target range, closure velocity, aspect angle and which sensors are seeing the target.

The targets now all had upright red triangles over them, with numbers corresponding to their priority in the shoot list. On the lower left-hand corner of the TSD was a relative height scale, which showed the altitude of my aircraft and the four targets on a vertical bar. The red lollypop symbols advanced towards my formation, our presence undetected.

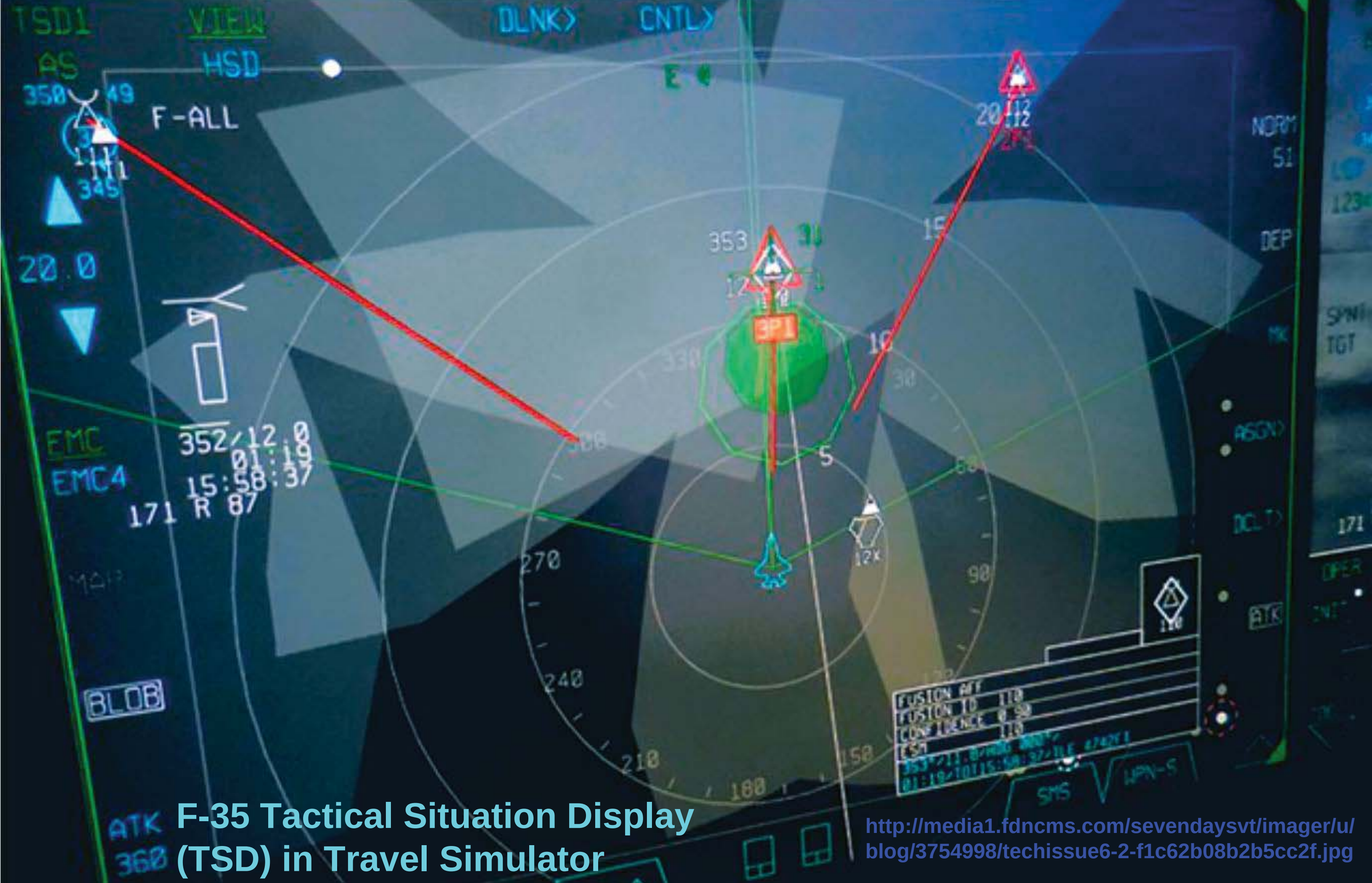
At maximum engagement range, as indicated in the HMD, I launched a generic radar-guided missile at the first aircraft in my shoot list. Using the tactical management switch on the sidestick I stepped through the shoot list to engage the fourth target, leaving numbers two and three for my wingmen. I launched the second missile at number four, and the flight of both missiles was tracked and presented on both the HMD and TSD. Time to impact was also presented, a neat feature. All four Red aircraft destroyed, the exercise was terminated to set up the air-to-surface scenario...."

The RAF pilot will be instantly fed information from all other friendly fighter jets on the same mission.

TARGET: Could be jihadists loading weapon in Syria or a surface to air missile system in Russia (grey shading shows area where jet will be detected by the enemy defence radar)

TARGET: Red or white box showing aircraft approaching. It will be red if there is something to suggest it could be an enemy aircraft.

http://i.dailymail.co.uk/i/pix/2016/01/24/14/30884BB200000578-0-image-a-31_1453646849279.jpg



F-35 Tactical Situation Display (TSD) in Travel Simulator

http://media1.fdncms.com/sevendaysvt/imager/u/blog/3754998/techissue6-2-f1c62b08b2b5cc2f.jpg

Elbit, Harris to replace panoramic display in F-35 cockpit

28 JUNE, 2017 | SOURCE: FLIGHTGLOBAL.COM | BY: STEPHEN TRIMBLE

https://www.flightglobal.com/news/articles/elbit-harris-to-replace-panoramic-display-in-f-35-c-438871/

Elbit Systems and Harris will replace the head-down panoramic display system for the Lockheed Martin F-35 after 2019, the companies have announced.

Lockheed selected Elbit's US-based subsidiary to begin developing a new large-format, touchscreen display for the F-35 cockpit. Separately, Lockheed awarded a contract to Florida-based Harris to develop a new computer processor for the display.

The selections were made as part of Lockheed's Technology Refresh 3 (TR3) effort for the F-35, which is installing new electronics in the 16-year-old fighter fighter programme.

As part of TR3, Lockheed also selected Harris to supply a new aircraft memory system for the F-35, updating the solid-state device used to store the aircraft's operational flight programme software, mission data files and prognostics and health data.

"The new TR3 electronics pave the way for system upgrades well into the future," says Ed Zoiss, president of Harris Electronic Systems.

A technology development phase for TR3 begins in June 2017, followed by a system qualification phase 1.5 years later, Harris says. Following qualification, Lockheed would award a production contract.

The new suppliers will replace the 20in-wide panoramic display and processor for the F-35 now provided by L-3 Communications.

Since 2010, Elbit Systems of America has proposed the CockpitNG panoramic display as an alternative to the L-3 technology for the F-35, as well as for other fighter programmes, including the cancelled Boeing F-15 Silent Eagle.

BREAKING DEFENSE COLIN CLARK 26 June 2014

'A God's Eye View Of The Battlefield:' Gen. Hostage On The F-35

USAF Biography: "Gen. Mike Hostage is Commander, Air Combat Command, Langley Air Force Base, Va. 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." At his level, national strategists describe their needs to him to find out what is 'possible'. Together they iteratively shape the strategy around the realities and then he takes those strategies and translates them into capabilities that will suit/support the strategy...."

http://breakingdefense.com/2014/06/a-gods-eye-view-of-the-battlefield-gen-hostage-on-the-f-35/2/

For years, the news about the most expensive conventional weapons system in US history, the F-35 Joint Strike Fighter, has been driven by its enormous cost, design, and schedule screw-ups. The Pentagon and Congress and the public have rarely spoken about what the F-35 would do, how effectively it could destroy an enemy's air defenses, shoot down an enemy plane, or find and strike other high value targets.

Air Force Gen. Mike Hostage, who will command the largest group of F-35s in the world, recently sat down with me in his office at Langley Air Force Base to discuss what the F-35 can do in the first 10 days of war — within the constraints of what is classified. Much of what appears in the following story is drawn from months of interviews with dozens of experts in the government, the defense industry and academia to flesh out some of its more exotic and lesser known capabilities.

This is the second and final story in what we hope will become regular coverage about the F-35's capabilities as it flies closer to production and is sold around the world to America's allies. The F-16 changed how America and its friends planned to fight wars. It helped guarantee one of the most important fundamentals of modern warfare — clear skies for us and our friends so we could bring the fight to a more vulnerable enemy. The F-35 takes the place of the F-16 and also replaces the EA-6B, F-111, A-10, AV-8B, Italy's AMX and the British and Italian's Tornado. No other aircraft carries such responsibility for so many, nor has one ever cost so much.

PILOT Comment on HMDS: http://www.youtube.com/watch?v=DQkm8oLPb4c

LANGLEY AFB: If you want to stop a conversation about the F-35 with a military officer or industry expert, then just start talking about its cyber or electronic warfare capabilities.

These are the capabilities that most excite the experts I've spoken with because they distinguish the F-35 from previous fighters, giving it what may be unprecedented abilities to confuse the enemy, attack him in new ways through electronics (think Stuxnet), and generally add enormous breadth to what we might call the plane's conventional strike capabilities.

So I asked Air Force Gen. Mike Hostage, head of Air Combat Command here, about the F-35's cyber capabilities, mentioning comments by former Air Force Chief of Staff Gen. Norton Schwartz several years ago about the F-35 having the "nascent capability" to attack Integrated Air Defense Systems (known to you and me as surface to air missiles) with cyber weapons.

Hostage deftly shifts the conversation each time I press for insights on the F-35's cyber and EW. He doesn't refuse to talk, as that would be impolite and, well, too obvious.

He starts off with what sounds like a shaggy dog story.

"When I was a youngster flying F-16s we would go fly close air support at the National Training Center for the Army," he tells me. "They would have a large ground force: blue guys, OpFor [opposing forces], they'd go out and have big battles on the ground. And they would bring the [Close Air Support] CAS in to participate. They'd let us come in, we'd fly for 30 minutes and then they'd shoo us away because they wanted to have their force on force and if they allowed the CAS to participate during force on force it fundamentally changed the nature of the ground battle."

Want To Shoot Someone? Turn Off The Cyber

Then he brings us back to the issue at hand, and mentions the Air Force's Red Flag exercises, the pinnacle of the service's force-on-force training: "Fast forward to today. We do Red Flag for the purpose of giving our young wingman those first 10 days of combat, or first 10 combat missions in a controlled environment because what we've studied over the years of conflict is the first 10 missions are where you're most likely to lose your fleet. So if you can replicate that first 10 in a controlled environment with a very high degree of fidelity, you've greatly increased the probability that they're going to survive their actual first 10 combat missions. So Red Flag is the closest we can get to real combat without actually shooting people."

Allies are a key part of the Red Flag exercises, especially as the F-35 becomes the plane flown by most of our closest allies, from Britain to Israel to Australia and beyond. But the toughest, most realistic exercises at Red Flag occur when it's only American pilots flying against each other.

During those Red Flag-3 exercises they integrate space and cyber weapons into the fight, including those the F-35 possesses. Those capabilities make are "so effective that we have to be very careful that in a real world scenario we don't hurt ourselves allowing them to play."

Then he gets back to the point at hand. "So, to answer your question, it has tremendous capability. We're in the early stages of exploring how to get the most effectiveness out of cyber and space, but we're integrating it into the Air Operations Center; we're integrating it into the combat plan; and it is absolutely the way of the future. And you're right, the AESA radar has tremendous capacity to play in that game."

Boil all that down and it comes to this. Gen. Hostage is saying that the F-35′s cyber capabilities are so effective — combined with space assets, which are often difficult to distinguish in effect from cyber capabilities — that the planes have to stop using them so the pilots can shoot at each other.

The obvious question that arises from this is, how can a radar system also be a cyber weapon? We've all seen those World War II movies where the radar dish sweeps back and forth. The energy beams out, strikes the enemy plane and comes back as a blip. What makes an AESA radar special is the fact that it beams energy in digital zeroes and ones — and the beam can be focused. This allows the radar to function as both a scanning radar, a cyber weapon and an electronic warfare tool.

AESA Radar, Cyber And IADS

Here's an excellent explanation for how we go from radio and radar and military systems that are not connected to the Internet yet remain vulnerable to hacking that I've cribbed from my deputy, Sydney Freedberg, from a recent piece he wrote in Breaking Defense about cyberwar. An enemy's radios and radars are run by computers, so you can transmit signals to hack them. If the enemy's computers are linked together then your virus can spread throughout that network. The enemy does not have to be connected to the Internet. You just need the enemy's radios and radar to receive incoming signals – which they have to do in order to function.

So, as a former top intelligence official explained to me about two years ago, the AESA radar's beams can throw out those zeros and ones to ANY sort of receiver. And an enemy's radar is a receiver. His radios are receivers. Some of his electronic warfare sensors are also receivers.

But neither Hostage nor many others I spoke with were willing to be specific on the record about how effective the AESA radar, working with the aircraft's sensors like the Distributed Aperture System and its data fusion system, will be. So the following is information culled from conversations over the last three months with a wide range of knowledgeable people inside government and the defense industry, as well as retired military and intelligence officers.

As the F-35 flies toward the Chinese coast and several hundred incoming PLAAF J-20s streak toward them in the scenario outlined in the first piece of this series, spoofing (using the enemy's own systems to deceive him) will be a major part of our attack.

Enemy radar may well show thousands of F-35s and other aircraft heading their way, with stealth cross-sections that appear to match what the Chinese believe is the F-35′s cross section. Only a few hundred of them are real, but the Chinese can't be certain which are which, forcing them to waste long-range missiles and forcing them to get closer to the US and allied F-35s so they can tell with greater fidelity which ones are real. The Chinese will try and use Infrared Search and Track (IRST) sensors, which have shorter ranges but provide tremendous fidelity in the right weather conditions. But that, of course, renders them more vulnerable to one sensor on the F-35 that even the plane's critics rarely criticize, the Distributed Aperture System (DAS).

Sensors, Data And Decisions

The DAS is a remarkably sensitive and discriminating set of six sensors that gives the pilot data not just from in front of his aircraft, but directly below, above and to the sides — in military parlance he's got 360 degree situational awareness. How sensitive is the system? I've been told by two sources that the DAS spotted a missile launch from 1,200 miles away during a Red Flag exercise in Alaska. But DAS, just as with the older Defense Support Satellites used to search the world for missile launches, may not know exactly what it's looking at right away.

That's where the F-35′s data fusion library comes in, combing through threat information to decide what the plane has detected. The plane, after combing through thousands of possible signatures, may suggest the pilot use his Eletro-Optical Targeting System (EOTS) or his AESA radar to gather more data, depending on the situation. The F-35 that spots the apparent missile launch will share its data with other F-35s and the Combined Air and Space Operations Center (CAOC), which will be managing all the data from US and allied aircraft and satellites so that bigger computers on the ground can crunch the data from those sensors and make recommendations if any single plane hasn't gathered enough information with enough fidelity. (Of course, the CAOC can also do that whole command thing and coordinate the F-35s flying with other aircraft, ships and ground troops.)

The loop will be complete once a target is identified. Then the plane's fusion center will recommend targets, which weapons to use and which targets should be killed first.

Given the Chinese government's vast and persistent espionage enterprise it won't be surprising if the J-20s boast some of the F-35′s capabilities, but I have yet to speak with anyone in the Pentagon or the intelligence community who says the Chinese appear to have developed soft are and sensor capabilities as good as those on the F-35.

Spoofing And Electronic Warfare

The other side of the cyber conflict is what is usually called electronic warfare, though separating cyber and electronic warfare becomes awfully difficult in the F-35. The AESA radar plays a prominent role in this arena too, allowing sharply controlled and directed energy attacks against enemy planes, surface to air radar and other targets.

While Growlers, Boeing's EA-18G, have extremely powerful, broadband jamming capabilities, the F-35′s combination of stealth and highly specific electronic beams is a better combination, Hostage tells me during the interview.

"If you can get in close, you don't need Growler-type power. If you're stealthy enough that they can't do anything about it and you can get in close, it doesn't take a huge amount of power to have the effect you need to have," he says.

One of the keys to spoofing is, I've heard from several operators, being careful to avoid overwhelming the enemy with high-power jamming. That's another problem with the Growler approach.

"The high power-jamming is 'I'll just overwhelm them with energy since I can't get in there and do magic things with what they're sending to me,'" Hostage says.

Much of this electronic warfare, as well as the F-35′s intelligence, reconnaissance and surveillance (ISR) capabilities, are made possible by a core processor that can perform more than one trillion operations per second. This allows the highly classified electronic warfare suite made by BAE Systems to identify enemy radar and electronic warfare emissions and, as happens with the EOTS, recommend to the pilot which target to attack and whether he should use either kinetic or electronic means to destroy it.

In our interview, Gen. Hostage points to the plane's ability to gather enormous amounts of data, comb through it and very rapidly and simply present the pilot with clear choices as a key to its success.

“People think stealth is what defines fifth gen[eration aircraft]. It’s not the only thing. It’s stealth and then the avionics and the fusion of avionics. In my fourth gen airplane, I was the fusion engine, the pilot was the fusion engine. I took the inputs from the RHWG, from the Radar Homing Warning Gear, from the radar, from the com, multiple radios, from my instruments. I fused that into what was happening in the battlespace, all the while I’m trying to do the mechanical things of flying my airplane and dodging missiles and all these sorts of things,” he says.

Combine the fusion engine, the ISR sensors, the designed-in stealth, the advanced helmet, and the eight million lines of software driving what it can do, add weapons to the stealthy weapon bays, add a pilot and that is what allows you to “break the enemy’s kill chain,” as Hostage likes to put it.

“What we’ve done with the fifth generation is the computer takes all those sensory inputs, fuses it into information. The pilot sees a beautiful God’s eye view of what’s going on. And instead of having to fuse three pieces of information and decide if that’s an adversary or not, the airplane is telling him with an extremely high degree of confidence what that adversary is and what they’re doing and what all your wingmen are doing. It’s a stunning amount of information,” Hostage says.

Combine that information with the kinetic, cyber and electronic warfare capabilities of the F-35 and we may know why South Korea, Japan, Israel and Australia have all recently committed to buy substantial numbers of F-35s, in spite of the aircraft being behind schedule, facing significant technical problems and, of course, being really expensive overall. Several sources with direct knowledge of the negotiations — from government and industry — tell me that each country went in to discussions with the Pentagon with a great deal of skepticism. But once country representatives received the most highly classified briefing — which I hear deals mostly with the plane’s cyber, electronic warfare and stealth capabilities — they all decided to buy. That kind of national and fiscal commitment from other countries may say more about the aircraft’s capabilities than anything else. After all, some of those countries are staring right at China, the country that has rolled out two supposedly fifth generation fighters. And Russia, the other country trying hard to build a rival to the F-22 and the F-35, sits not far behind.

“...“What we’ve done with the fifth generation is the computer takes all those sensory inputs, fuses it into information. The pilot sees a beautiful God’s eye view of what’s going on. And instead of having to fuse three pieces of information and decide if that’s an adversary or not, the airplane is telling him with an extremely high degree of confidence what that adversary is and what they’re doing and what all your wingmen are doing. It’s a stunning amount of information,” Hostage says....”