The F-35 and Advanced Sensor Fusion

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

But what is a fusion engine?

What combat systems are integrated onboard?

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

The Advantages of Advanced Fusion

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

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

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

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

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

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

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

We are getting closer to a software-defined airplane.

Advanced fusion does three things for the pilot.

- **First, it assembles a single integrated picture from all of the sensors.**
- **Second,it tasks the sensors to fill in missing data**
- **Third, it shares the information with everyone else on the network.**

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

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

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

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

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

The Radar

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

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

Because an AESA scans electronically, we overcome the inertia of a physical antenna moving around and can build beams in space wherever we need. We steer these beams throughout the field of regard to perform numerous radar functions.

From the pilot's point of view, the radar seems to be doing air-to-air and air-to-surface simultaneously. It's really not. It's in very quick, serial fashion; but by the time the information gets to the displays, the pilot sees air and ground at the exact same time.

The radar does various functions such as: track while scanning, single target track and air combat mode. The modes aren't unique, but the AESA makes them even better.

Air combat mode allows the pilot to initialize a beam along the line of sight of the helmet mounted display. This capability is useful when the pilot wants to queue the radar along the helmet line of sight.

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

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

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

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

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

The Distributed Aperture System

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

The DAS is comprised of six staring focal point arrays.

These are infrared cameras flush-mounted on the skin of the airplane, which detect the entire sphere around the airplane – that's 4 pi steradians for the mathematically inclined. The entire sphere is about 41,000 square degrees whereas the radar sees about 10,000 square degrees.

There is an intersection of the two sensors however. Where they're both looking through the same angular volume of space, fusion will work them synergistically, and they can queue each other.

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

The impressive thing is that this occurs without pilot involvement.

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

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

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

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

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

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

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

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

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

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

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

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

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

EOTS

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

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

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

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

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

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

The Electronic Warfare Suite

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

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

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

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

CNI

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

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

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

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

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

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

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

The F-35 was designed based on lessons learned.

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

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

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

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

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

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

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

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