

F-35 Lightning II Cockpit Vision

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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.***

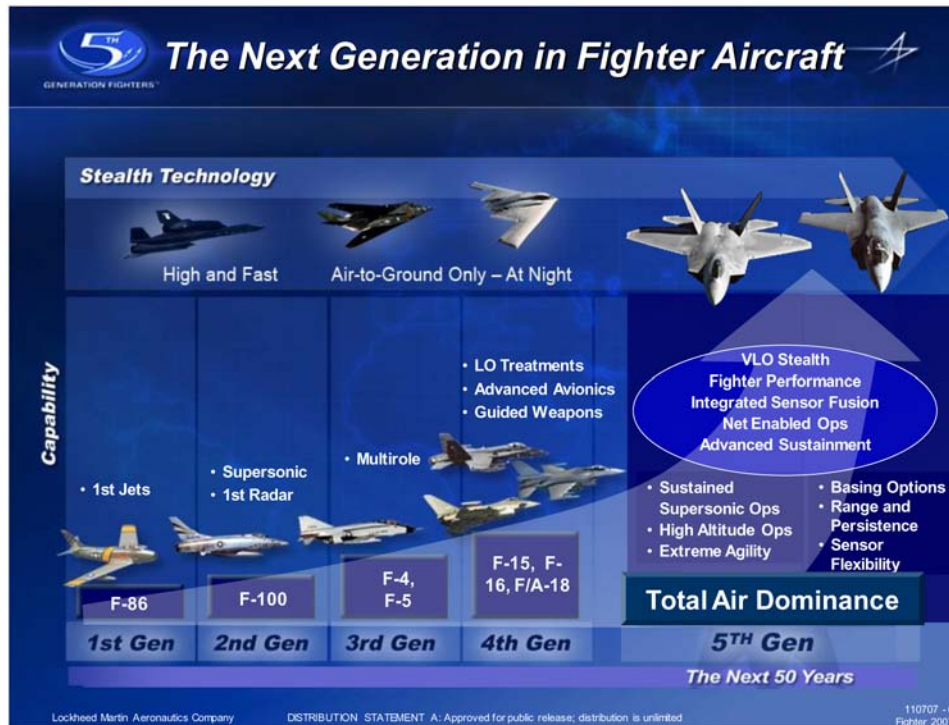


Figure 2. Fighter Generations

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 these 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



Figure 3. F-35 Lightning II Cockpit

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

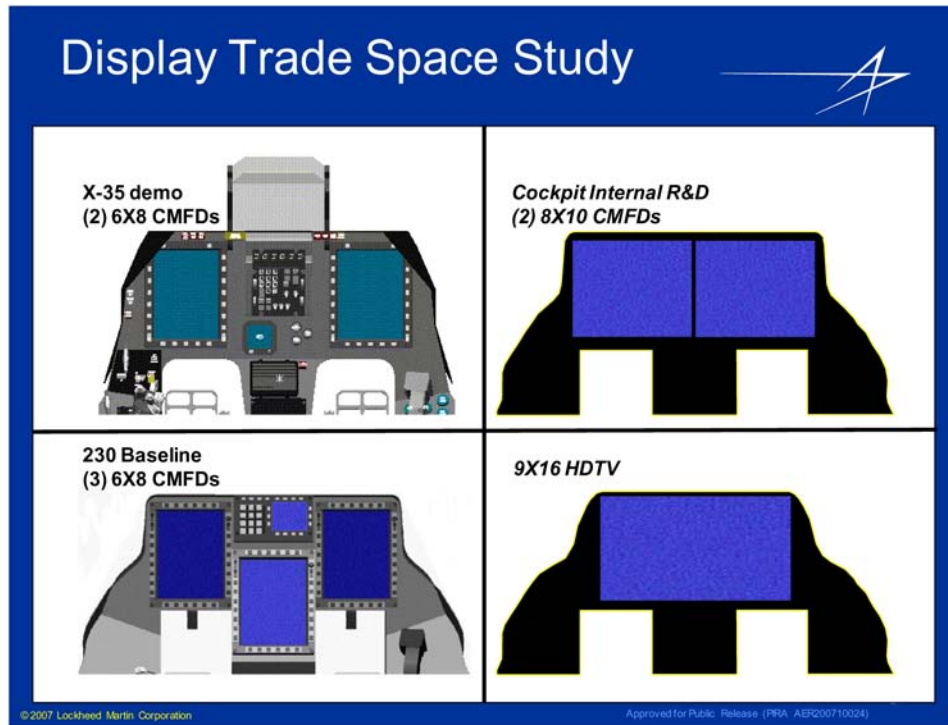


Figure 4. Display Trade Space

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



Figure 5. Helmet Mounted Display

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 announced 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

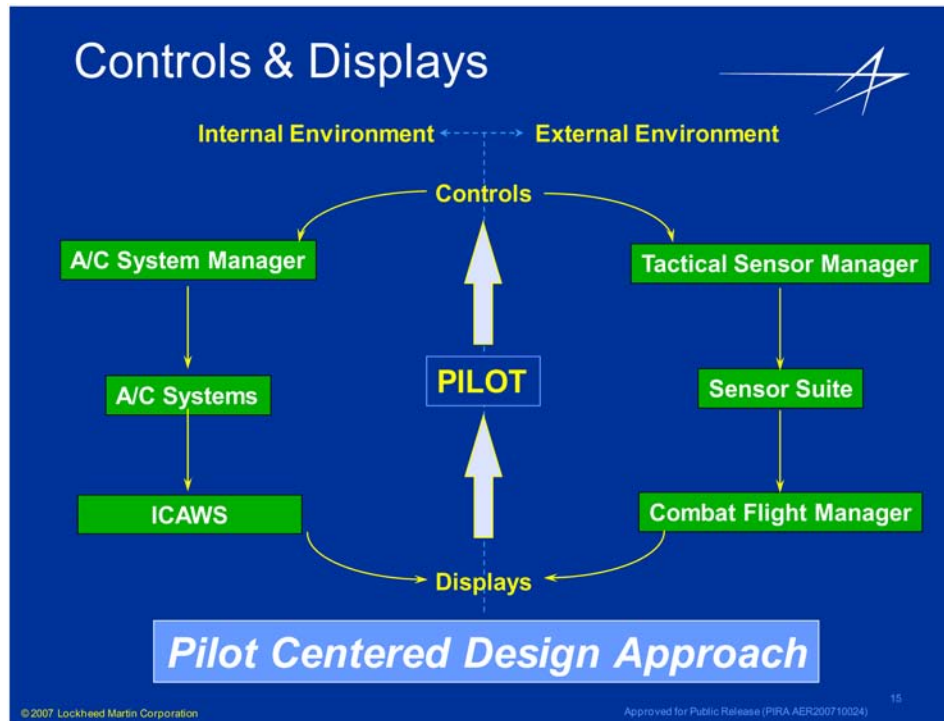


Figure 6. Control and Display Loops

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

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DAS

Distributed Aperture System

FPA

Focal Plane Array USMC - United States Marine Corps

DEFINITIONS/ABBREVIATIONS

Air Systems Integration Facility

combined Mission Systems and Vehicle Systems full mission simulator

GPU

Graphics Processing Unit

HFE

Human Factors Engineering

CTOL

Conventional Takeoff and Landing

HMD

Helmet Mounted Display USN - United States Navy

CV

Carrier Variant USAF - United States Air Force

HOTAS

Hands On Throttle and Stick



Figure 8. Integrated Caution and Warning System (ICAWS)

HUD	Head Up Display	STOVL	Short Takeoff and Vertical Landing
LED	Light Emitting Diode	Vehicle Systems	team which is responsible for flying qualities, flight control software, non-tactical subsystems
Mission Systems	team which is responsible for tactical avionics	VLO	Very Low Observable
PCD	Panoramic cockpit Display	DISCLAIMER	Statement A: Approved for public release; distribution is unlimited; JSF10-122, 2/23/10.
PVI	Pilot Vehicle Interface		

Next-Generation Cockpit



8- by 20-inch Contiguous Display with Portal Formatting Concept to Improve Information Cognition, System Control, and Flexibility

Wide FOV HMD w/ Virtual HUD Spherical IR & low light Imagery to Improve SA in All Weather and Night Operations

Stereo Audio & Voice Control Increase Information Quantity and Quality While Decreasing Pilot Workload

Novel STOVL Controls Reduce Training Requirements Provides Controllability with Fewer Inceptors

Maximized Accommodation For Higher Utility & Safety

- Active Inceptors
- Compound Rudder Adjustment
- Data Bus Communication for Ejection Seat
- Tilting Seat (adjustment Limited for ejection safety)

Integrated Life Support System

Next-Generation Escape System

- Auto-ejection

New Technologies and an Innovative Approach to Pilot Vehicle Interface Produce a Capable and Flexible Cockpit

Figure 9. F-35 Cockpit Highlights

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

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