DISPLAY DESIGN IN THE F/A-18 HORNET

Photo by Lori Losey. Courtesy of Dryden Flight Research Center.

Advanced automation in high-performance aircraft like the F/A-18 Hornet can make it difficult for pilots to detect system problems.

BY MISSY CUMMINGS

When fighter pilots leave the military, not all fly for the airlines – some go into business, some go into medicine, and a few end up in academia. As a new Ph.D. in the field of cognitive systems engineering and a former fighter pilot, I am just such an anomaly. While it seems that dropping bombs and strafing targets with 3000 rounds per minute is a very different world from research and teaching, I find that the drive and competitiveness of fighter pilots are not so different from what is sometimes seen in academia. In fact, a career as a military tactical pilot has given me insights into areas of human factors/ergonomics (HF/E) that most people only get a glimpse of through books and lectures. Transitioning from operational flying into human factors research seems natural to me.

For years, I complained about annoying alarms, inept software, and confusing displays, so what better way to put my frustrations and expertise to work than through research? Having both designed military displays and flown several aircraft, I have seen many examples of both good and bad display designs. Through this article, I hope to highlight some critical issues in the design of aviation computer displays from the point of view of both a designer and a user.

Glass Cockpit Design

In high-performance aircraft, where virtually every aspect of flying is controlled via a human-machine computer interface, the need for seamless human-computer interaction (HCI) is paramount. For multimission aircraft like the aircraft carrier-based F/A-18 Hornet, which is both a fighter and a bomber, adaptability and flexibility in display design are critical.

The pilot of a tactical aircraft has many responsibilities. First and foremost, the pilot must fly the plane. Automatic devices assist (automatic throttles, automatic heading, and altitude functions), but in many flight regimes, it is not advisable to use these automatic aids (for example, when bombing a target). The primary consideration for this aspect of display design is aiding the pilot in simply flying. The introduction of head-up display (HUD) technology revolutionized cockpit design and provided pilots with the ability to look outside the cockpit while monitoring various flight parameters (airspeed, altitude, heading, etc.) This instrument reduces pilot workload (the pilot does not have to constantly look in and out and reprocess environmental cues) and increases her situational awareness.

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A good example of HCI display adaptability is the glass cockpit design – those cockpits designed with computer displays – which is a central feature of the F/A-18. On page 17 is a picture of the Hornet's cockpit with important features labeled. Two of the displays, called the digital display indicators (DDI), are interchangeable; a third, the horizontal situation indicator, provides some additional redundant capabilities. A pilot can bring up whatever he wants on either digital display indicator, which is helpful in the many flight regimes the F/A-18 encounters.

For example, standard landing patterns are to the left in the Navy, which requires a pilot to look to the left for the majority of the time in the pattern. The pilot can bring up the landing checklist on the left display, or perhaps a backup compass or gyro to assist in case of an emergency. On occasion, a pilot will land at a civilian or Air Force field that requires a right-hand pattern, so it is easy to adjust the displays to reflect the change. In cockpits without computer displays, what you see is what you get, and the general instrument layout is fixed. The use of computer displays that allow flexibility is not only good design from a reliability standpoint but is also very important in meeting user needs.

The flying task also requires navigation, which in a single-seat fighter can become a burdensome task. The F/A-18 and other similar aircraft have made this job much easier through the HUD information readily available to the pilot, but the horizontal situation indicator provides additional instant real-time information about the plane's position (see below). In older analog aircraft and most general aviation aircraft today, a pilot must look at a heading indicator, mentally process additional information from a navigation fix, and then locate this information on a paper map.

Though this is not an especially difficult task, it takes dedicated mental focus and processing and interpretation of information, which often occurs under time pressure. This process is easier for slower-moving aircraft than for tactical aircraft that can sometimes cover more than five miles per minute. The horizontal situation indicator revolutionized this tedious process for tactical aircraft because it displays an icon plane in the middle of the display with a moving color map beneath it to show exact location. The map can be made smaller and larger as needed; in addition, routes can be drawn on the map so the pilot can simply follow a line if desired. In the fast-moving world of fighter aircraft, this map was a dream come true when introduced!

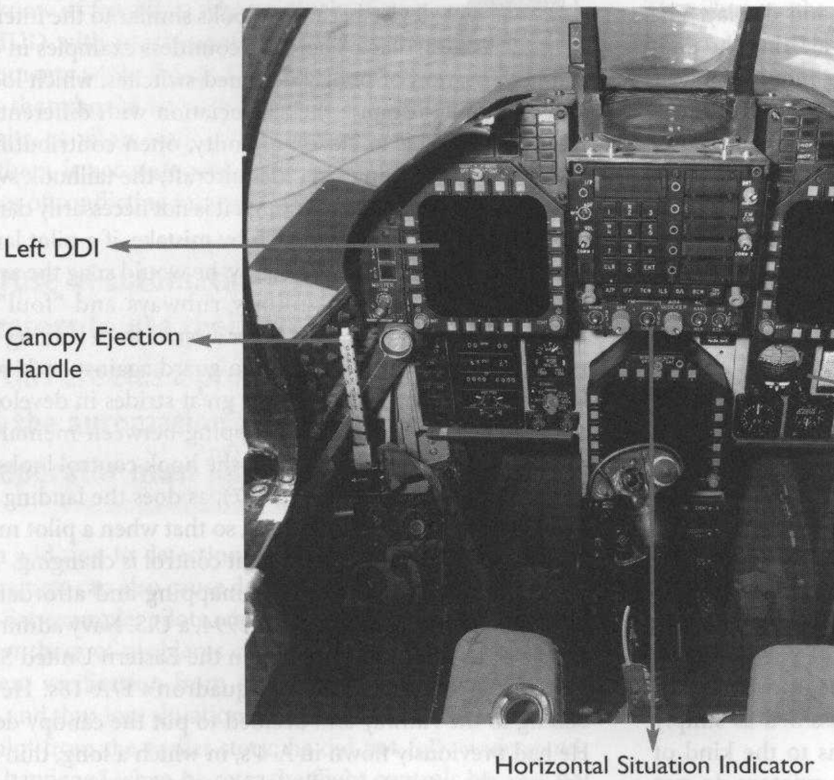
Automation Can Be Deadly

Though many elements of these displays are helpful in reducing pilot workload, for high-performance military aircraft that are controlled by computers, otherwise known as "fly-by-wire," some HCI components that designers and users do not thoroughly understand can cause not only mission failure but even deaths. Perhaps one of the best illustrations of an ill-fated interface design in a high-performance military aircraft was a rudder flight control problem in the F/A-18. The Hornet has a completely computer-controlled flight control system in which the pilot is but a mere voting member. Two flight control computers monitor both the pilot's inputs and the dynamic conditions on all control surfaces. When a pilot moves the stick to go left, right, up, or down, the computer determines whether or not this is an acceptable maneuver, and only then does it allow the pilot to execute the maneuver.

One example of military aviation mistakes that are of great concern and continue to be a problem is the bombing of wrong targets.

This high level of automation can prevent pilots from flying an aircraft out of the aerodynamic envelope, but, like all software systems, the flight control system can also experience problems and failures. If the two flight computers do not agree or there is a transient "burp" in the system, the pilot will get both a visual warning and an aural "deedle deedle" alert that a flight control problem has occurred. If the problem is deemed to be a mere transient annoyance, the pilot can hit the reset button and the flight control system will reboot in a matter of seconds, thereby clearing the warning.

NASA 1995 photo. Courtesy of Dryden Flight Research Center.



The F/A-18 cockpit.

In 1995, during carrier landing practices at an airfield in Florida, an F/A-18 landed and took off again, and as it was climbing away, the pilot heard the "deedle deedle." Without closely inspecting the flight control matrix on a lower-level display to analyze the problem, he hit the reset button to see if it would clear. This is a "Pavlovian" response that most pilots execute because if the problem clears, the problem proved to be a transient burp. If the problem remained, then further investigation was warranted that potentially required navigation through several screens.

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For the ill-fated pilot on that day, the problem cleared immediately, and he approached the runway again. After touching down and taking off again, at about 50 feet, one of the rudders locked, causing significantly asymmetrical rudder positions. This dangerous rudder configuration caused the aircraft to roll instantly on its back and fall to the ground. The pilot had perhaps a second to recognize the problem, evaluate it, understand the situation was unrecoverable, and eject. However, he was a junior pilot, and it is also doubtful that even the most experienced pilot could have recognized the situation. He did not eject and was killed when the plane struck the runway.

In the subsequent mishap investigation, a problem was discovered with the flight control system and display. The display would clear automatically without alerting the pilot that the problem was not fixed, thus lulling him into a false sense that all was well. Had the pilot scrolled through numerous other displays, he would have seen that the rudder positions were not in agreement while in the landing pattern, which is a high-workload environment and requires a great deal of situational awareness. He did not check and trusted the computer to let him know if there was an additional problem. Six months later, the failure happened again to another pilot just as he was launched from an aircraft carrier, and he, too, was killed. Both aircraft accidents were categorized as pilot error, but in truth the accidents were caused by latent error. Given cognitive constraints, especially in a highly automated plane like the F/A-18, these were accidents waiting to happen.

Types of Pilot Error

This case highlights two very important considerations for the design of computer displays: those of possible human errors and automation related issues. The Navy Safety Center says that more than 80% of Navy aircraft mishaps are caused by pilot error. Interestingly, when reading a military accident report, error is classified as simply error. The reports make no distinctions as to the kind of error made, and generally most military aviators do not know that different types of errors exist.

Mistakes are a classification of error that are generally thought to be the cause of a significant portion of aircraft accidents, especially those that involve high-performance aircraft that can quickly saturate the pilot with information. One example of military aviation mistakes that are of great concern and continue to be a problem is the bombing of wrong targets. These types of mistakes are most likely caused by inadequate information, a lack of situation understanding, and time pressure. Unfortunately, mistakes in high-performance fighters are costly in terms of both planes and lives.

Yet another class of errors involves incorrectly executing the right intention, known as *slips*. One type of slip is *capture error*, whereby an action originally intended for a particular goal is "captured" by a habit or another well-rehearsed pattern. Capture errors occur frequently in checklists that are executed by memory, which happens more frequently in the military than in commercial aviation. For example, suppose a checklist is started, but when the pilot reaches a particular item (e.g., the landing gear handle), he inadvertently switches to a different memorized checklist – in effect transposing the two.

Lapses, or the failure to execute an action, are also common errors in tactical aircraft, especially when executing procedures in stressful situations. All too often, a pilot will be interrupted in the middle of a checklist or procedure, causing her to miss a step or fail to complete an intended action. Lapses are the reason pilots still occasionally land with their landing gear up or forget to put hooks down at the appropriate time when landing aboard an aircraft carrier.

Another type of slip often seen in military aviation is the description error, in which the correct action is directed toward the wrong device because it looks similar to the intended artifact. There are countless examples in early military aviation of poorly designed switches, which looked and felt similar despite their association with different systems, and located in close proximity, often contributing to accidents. For example, in older aircraft, the tailhook switch was confused with others. Though it is not necessarily dangerous to select the tailhook switch by mistake, if a pilot landed with the hook down inadvertently, he would snag the arresting wire placed on all military runways and "foul" the runaway. This would prevent other aircraft from landing until the arresting system was fixed. To guard against such problems, military aviation has made great strides in developing affordances and improving mapping between mental and physical objects. In later aircraft, the hook control looks like a hook (see the photo on page 17), as does the landing gear handle, which resembles a wheel, so that when a pilot moves these levers, it is clear exactly what control is changing.

Despite efforts to promote mapping and affordances, description errors still occur. In 1994, a U.S. Navy admiral in charge of all the Navy airplanes in the Eastern United States went for a ride in one of my squadron's F/A-18s. He was taxiing to the runway and decided to put the canopy down. He had previously flown in A-4's, in which a long, thin gray bar was the canopy handle (this caused some description slips because it looked similar to the hook handle). However, in the Hornet, the canopy handle is not a handle but a very small switch located in an isolated spot. When the admiral reached for the canopy switch in the Hornet, his previous experience took over and he inadvertently grabbed the canopy eject handle, which looks like an A-4 canopy handle only painted in bright yellow (see page 17). Instead of lowering the canopy, he blew it sky high.

Automation and Complacency

Addressing potential *automation bias* is another area that becomes more and more critical as technology advances. Automation exists everywhere on every level in the F/A-18 and is the reason that it is a leader in air combat aircraft in the world today. So it is a significant HCI issue to design the best interfaces that capitalize on the strengths of automation without compromising the pilots' skills. Because the F/A-18 is so complex, pilots learn quickly to trust the automation. This trust can lead to complacency in several forms.

Complacency due to automation bias can make it difficult to detect system problems. There have been many instances of "lost" aircraft when the automation of the internal navigation system failed, but not outright. This system can drift slightly, so unless a pilot cross-references some other navigation aid and a drift actually occurs, it is relatively easy to fly off-course. Fortunately, the Global Positioning System has helped to alleviate this, but the fact remains that complacency can cause problems in detecting automation failures.

The use of head-up displays is also an area where pilots can become complacent. Most pilots feel overwhelmed once the HUD is taken away because they have trusted it so heavily. I know of few pilots who routinely, if ever, cross-checked the HUD with much smaller, harder-to-see stand-by dial instruments while flying. *Confirmation bias* is another element that should be considered in the design of tactical cockpits, as pilots want to believe that what the computer tells them is accurate and often ignore or discount other sources of conflicting information.

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In addition to detection problems, complacency toward automation can also cause degradation of situational awareness. For example, pilots who rely on computer automation to alert them of problems can become complacent in independent verification from other sources of various system states and thus lose situational awareness. This occurred with the pilot from the earlier story; he did not fully understand what happened when he reset the flight controls because he trusted the automation to alert him if the problem didn't clear. Because of the complexity and high workload of the demands of a system like the F/A-18, automation bias, complacency, and the loss of situational awareness can quickly set in.

Interestingly, with all the trust that goes along with the many F/A-18 subsystems, the one system pilots are very wary of is the Mode 1 automatic pilot. This system will fly a plane to landing without any intervention from the human pilot. It was designed to help pilots come aboard the aircraft carrier at night and in bad weather and has an excellent record in both reliability and precision. There is no question that the computer can land a plane better on a carrier than can a human, and it is certainly more consistent. However, pilots are extremely reluctant to use this system.

Most pilots prefer the Mode 1A approach, whereby the computer flies the plane to 200 feet above and half a mile back from the intended point of landing, and then the pilot takes over. Because the computer has been making the corrections down the glide slope, the Mode 1A approach can actually be more difficult than flying the entire approach because the pilot is missing states of knowledge and must go through a high learning curve to get the feel for the energy state of the aircraft. This case illustrates yet another drawback to automation – that of skill degradation. Overuse of automation can cause system operators to use their skills infrequently, and this creates a problem when difficulties with the automation are encountered and the operator must intervene. This is a concern for pilots, especially in the particular critical skill set needed for landing aboard an aircraft carrier.

The problems I encountered and have related here occurred despite the use of a user-centered design approach. They illustrate the enormous complexity involved in designing fighter cockpits. Despite these problems, the cockpit of the F/A-18 represents tremendous strides in human factors and cognitive systems engineering in military aircraft. I consider myself lucky and at a distinct advantage in my field to have flown the F/A-18. That amazing experience continues to benefit me in my research in military command and control display design, and it also helps in the classroom. Fighter pilots are never at a loss for crash and burn stories, which are very effective when the glassy stares in the classroom become epidemic.

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