AUTOFLIGHT AUDIT

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BY WAYNE ROSENKRANS

Check-up targets efforts to mitigate complexity of flight guidance systems.

The Flight Deck Automation Working Group, a U.S. government-industry committee launched in 2006, is scheduled to complete next year an assessment of how well airlines have addressed safety vulnerabilities identified in flight deck automation, including the effectiveness of efforts to improve mode awareness during autopilot/flight director operation and to mitigate mode confusion.

Mode awareness/confusion has been described as situations in which "the flight crew believe they are in a [flight guidance system] mode different than the one they are actually in and consequently make inappropriate requests or responses to the automation" or in which "the flight crew does not fully understand the behavior of the automation in certain modes, i.e., when the crew have a poor 'mental model' of the automation."[1] Sometimes, this is simply called losing track of the automation.

The subject has been studied for decades. "The current set of autoflight modes is large and has expanded over the years: A typical transport may have approximately 25 thrust, lateral and vertical modes," said a 2004 report by Boeing Commercial Airplanes researchers. "The complex rules behind vertical navigation and other modes sometimes make it difficult for pilots to anticipate aircraft flight path behavior. … Boeing research shows that some pilots incorrectly assume that all vertical navigation modes always take altitude targets from the flight plan [programmed into the flight management system]. … Although the flight mode annunciation on the primary flight display highlights changes with a transient green box, Boeing research indicates that 30–40 percent of these changes go undetected."[2]

Previous solutions primarily focused on policies, procedures and training pending the adoption of new airworthiness standards for flight guidance systems — completed in 2006 in the United States — and the arrival of more human-centered flight deck technology.

The airline accident most often cited for raising consciousness of the mode awareness/confusion issue occurred in April 1994 when the flight crew of an Airbus A300 experienced loss of control and crashed during an approach to Nagoya, Japan (*ASW*, 10/06, p. 44). The U.S. Federal Aviation Administration (FAA) later said, "Contributing to that accident were conflicting actions taken by the flight crew and the airplane's autopilot."

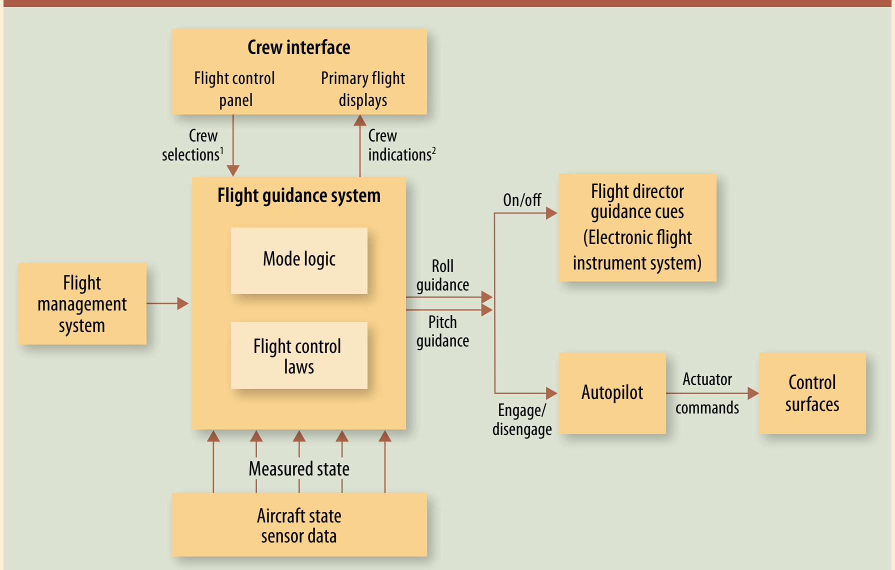
A Broad Assessment

Established by the Performance-Based Operations Aviation Rulemaking Committee (PARC) and the U.S. Commercial Aviation Safety Team (CAST), the Flight Deck Automation Working Group's findings and recommendations are expected to help airlines, and other specified types of operators, optimize pilot training, among other objectives. The FAA said in May 2008 that this PARC/CAST working group is making progress but could not yet discuss its ongoing deliberations. In earlier communication, however, the working group said, "In the past decade, major improvements have been made in the design, training and operational use of on-board systems for flight path management (autopilot, flight director, flight management systems, etc. and their associated flight crew interfaces [Figure 1]). In spite of these improvements, incident reports suggest that flight crews continue to have problems interfacing with the automation and have difficulty using these systems. But appropriate use of automation by the flight crew is critical to safety and to effective implementation of new operational concepts, such as required navigation performance (RNP) and area navigation (RNAV)."

The working group also said that its scope of work includes updating and revising safety recommendations from a June 1996 report by the FAA Human Factors Team,[3] reviewing airline crews' recent experience with flight deck systems in situations such as RNP RNAV approaches and departures, analyzing recent accident/incident data, and recommending and prioritizing best practices — possibly via a training aid — to enhance operational use of these systems.

Ten years ago, the Automation Subcommittee of the Human Factors Committee of the Air Transport Association of America (ATA) updated policy guidance for members on potential improvements in pilot training. The ATA said at the time, "We believe that action is required in the near term by carriers

Flight Control System Automation Overview



Notes

1. Buttons pressed and knobs set on flight control panel.
2. Indicator lamps illuminated/off on flight control panel and green/white textual mode annunciations on primary flight displays.

Source: Langley Research Center, U.S. National Aeronautics and Space Administration

Figure 1

or their pilots to prevent commonly occurring [mode] errors."[4]

More recent incentives to sustain industry attention to mode awareness/confusion include an international initiative to replace nonprecision approaches with "precision-like" approaches that take full advantage of the existing flight guidance systems in airline fleets, RNP RNAV operation and global navigation satellite systems in areas of the world that lack modern infrastructure and precision approach guidance (*ASW,* 9/07, p. 20).

The *Global Aviation Safety Roadmap* (*ASW,* 1/07, p. 28) also envisions wider use of autoflight technology. The plan encourages airlines to implement use of a flight path target–flight path director or vertical modes of the autopilot, flight director and flight management system, or both, to reduce the risk of approach-and-landing accidents. These efforts may have to overcome existing automation policies prohibiting pilots from using some flight guidance system modes and/or requiring them to use other modes.[5]

Latest Pilot Reports

The captain of a Boeing 757, in a February 2007 report to the U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS), said, "Upon receiving approach clearance [at 10,000 ft on radar vectors], the first officer [as pilot flying] selected 6,100 ft … on the airplane mode control panel [manufacturers use different terms, including *flight control panel* (Figure 2)], and flight level change [as] the descent mode. Flight level change [mode] provided no protection for subsequent altitude restrictions on the approach. I was verifying the flight management system programming and ascertaining the aircraft position relative to ATANE intersection (minimum crossing altitude 10,000 ft MSL) as we began our descent. The aircraft was at approximately 9,400 ft slightly outside ATANE when I directed the first officer to pull up."[6]

The captain of a McDonnell Douglas DC-9 in February 2007 reported, "After leveling at Flight Level 340 [approximately 34,000 ft], my first officer (the pilot flying) … wiped his fingers, the throttles and the autopilot [mode] control panel with a wet wipe [and] inadvertently knocked the autopilot out of the altitude hold mode and into climb mode. We did not immediately notice the slow climb because of continuous light turbulence. When the altitude alerter [activated] at 34,250 ft, the first officer disconnected the autopilot and descended back to Flight Level 340. The altitude deviation was probably about 300 ft [in reduced vertical separation minimum airspace when ATC contacted the crew]."[7]

The captain of a 737-700 in December 2007 reported, "[As pilot flying, I] had the aircraft in heading select and vertical speed modes. In the turn [to 325 degrees], passing through approximately 300 degrees, we encountered moderate wake turbulence from a preceding aircraft. We did not recognize at the time that the flight director roll mode changed to control wheel steering mode from heading select mode after encountering the wake. … Neither of us recognized that the aircraft went past the assigned heading in control wheel steering mode until air traffic control issued a corrective heading and advised 'no delay' on our climb through Flight Level 260 for traffic. Total course deviation was about 70 degrees."[8]

Flight Following

The *Flight Deck Automation Issues* Web site <www.flightdeckautomation.com>, funded by the FAA and operated by a contractor for safety research by the public, has accumulated evidence of mode awareness/confusion while tracking 94 human factors issues in flight deck automation. Two of the most relevant issues tracked regarding

Generic Flight Control Panel for Human Factors Research

ALT = altitude hold mode/altitude selector; AP ENG = autopilot engage/disengage; CRS = course selector; FD = flight director on/off; FLC = flight level change mode; HDG = heading select mode/heading selector; APPR = lateral approach mode; NAV = lateral navigation mode; VS = vertical speed mode

Source: Langley Research Center, U.S. National Aeronautics and Space Administration

Figure 2

mode awareness/confusion are "mode awareness may be lacking" and "mode selection may be incorrect."

According to the Web site, the most compelling evidence that *inadequate mode awareness* can have fatal/severe consequences is the accident investigation report from a 1992 Airbus A320 accident in France and the 1995 report of a flight simulator experiment in which 11 of 12 pilots deviated significantly from the intended flight path after researchers induced uncommanded vertical mode changes, even though each mode change was annunciated normally. The A320 accident report noted that "the abnormally high rate of descent was the result of an unintentional command on the part of the crew because they believed the vertical mode selected on the autopilot to be other than that which was actually selected," the Web site said.

The strongest example of *incorrect mode selection* cited by the Web site is the accident investigation report from the 1979 DC-10 inadvertent stall accident over Luxembourg. The U.S. National Transportation Safety Board's accident report said, "When the captain selected 320 kt into the autothrust system speed window, he may have either intentionally or unintentionally pulled the autothrust system speed selector knob. The action would have changed the autothrust selection from the N1 mode to the airspeed mode. This in turn would have caused the autopilot IAS [indicated airspeed] HOLD mode to disengage and revert automatically to the vertical speed mode of operation. … The autopilot commanded an increasing angle-of-attack while attempting to maintain a preselected vertical speed, which exceeded the limit thrust performance capability of the aircraft at higher altitudes."[9]

Airworthiness Standards

In May 2006, an amendment to U.S. Federal Aviation Regulations (FARs) Part 25.1329, *Flight Guidance System* — the first amendment since 1964 — became effective. The European Aviation Safety Agency and the FAA harmonized these regulations. In the course of rule making for these FARs in 2004, the FAA said, "Studies have shown that lack of sufficient flight crew awareness of modes, transitions and reversions is a significant safety vulnerability. … Newer designs enable functions that were not possible for automated systems when the regulations were adopted. … The newer designs also tend to be more complex from the crew's perspective, and vulnerable to flight crew confusion over mode behavior and transitions."[10]

During design, manufacturers are now asked to consider specific past sources of mode awareness/confusion: Pilots have confused knobs for setting the airspeed command reference target versus the heading target on the mode control panel because knobs were not differentiated by shape and position; erroneous entries of targets have been made by pilots operating a single switch, such as a concentric rotary switch, to select diverse categories of targets; misinterpretation has resulted from inconsistent arrangement of the mode control panel, compared with the arrangement of flight mode annunciations on the primary flight display (Figure 3, p. 34); pilots have mixed up the autopilot and autothrust controls; and pilots inadvertently have changed flight modes because of the light control force required to operate a switch.

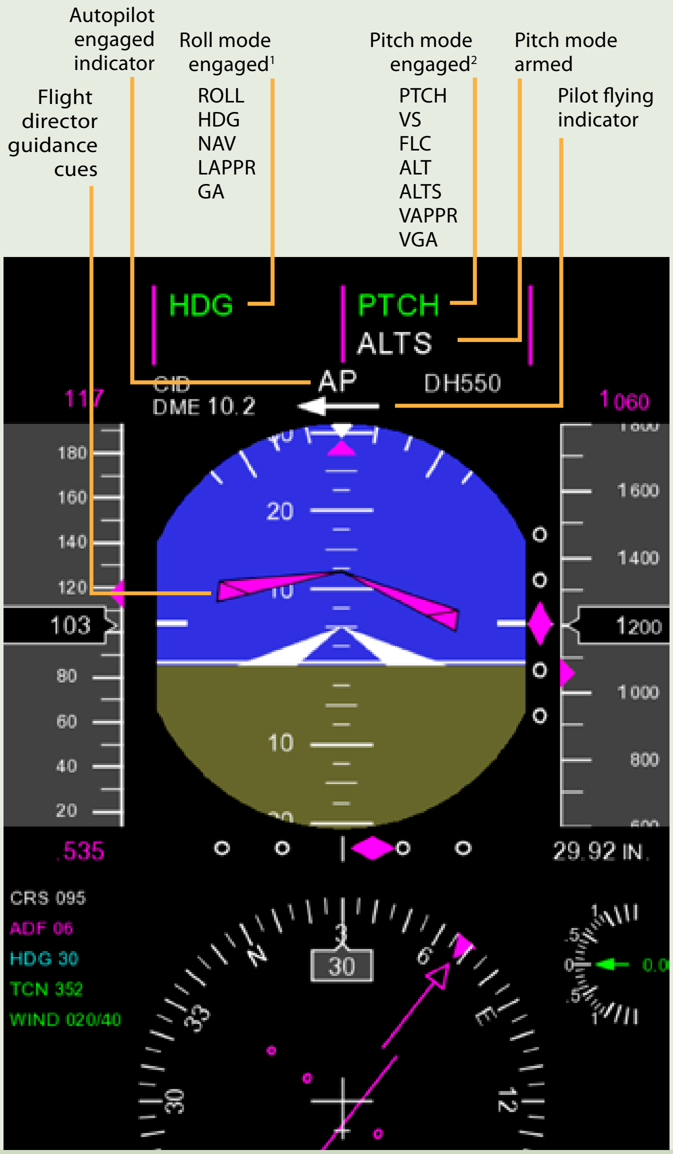
In FAA Advisory Circular 25.1329B, *Approval of Flight Guidance Systems*, special attention has been given to operationally relevant mode changes. The FAA said, "Annunciation of sustained speed protection should be clear and distinct to ensure flight crew awareness. … The transition from an armed mode to an engaged mode should provide an additional attention-getting feature, such as boxing and flashing on an electronic display … for a suitable, but brief, period (for example, 10 seconds) to assist in flight crew awareness."

Aural alerts may be warranted when, for example, the autopilot holds a sustained lateral control command or pitch command to compensate for an unusual operating condition, or the airplane nears the limits of the autopilot design in the pitch axis, roll axis or the amount of trim applied unintentionally in either axis. The advisory circular, and some human factors specialists, refer to such alerts as *bark before bite.* "A timely alert enables the pilot to manually disengage the autopilot and take control of the airplane prior to an automatic disengagement caused, for example, by a lateral condition such as asymmetric lift and/or drag caused by airframe icing, fuel imbalance or asymmetric thrust," according to the AC.

Solutions at Hand

CAST worked earlier in this decade with air carriers and manufacturers on the mode awareness/confusion issue to generate safety enhancements as a "short-term tactical solution" for reducing the risk of loss of control. CAST safety enhancements appear in a February 2003 report by the CAST Joint Safety Implementation Team.[11] One example is no. 36, which says, "Develop specific guidelines for eliminating mode confusion. Implement guidelines on new [airplane] type designs and study the feasibility of implementing guidelines on existing type designs. Implement changes per the feasibility study. … To avoid problems due to

Generic Primary Flight Display for Human Factors Research



ALT = altitude hold mode; ALTS = altitude select mode; FLC = flight level change mode; GA = lateral go-around mode; HDG = heading select mode; LAPPR = lateral approach mode; NAV = lateral navigation mode; PTCH = pitch hold mode; ROLL = roll hold mode; VAPPR = vertical approach mode; VGA = vertical go-around mode; VS = vertical speed mode

Notes

1. One engaged roll mode and one engaged pitch mode appear in green on the first line.
2. One armed roll mode and one armed pitch mode appear in white on the second line.
3. Autothrust modes typically annunciated on the primary flight display were not included in this example.

Source: Langley Research Center, U.S. National Aeronautics and Space Administration

Figure 3

unexpected mode changes, automated flight system logic should be designed to be error-tolerant or, at a minimum, provide an alert when the desired mode is in conflict with aircraft energy state. … To ensure flight crews have a comprehensive knowledge of the automation system(s) functional operation, airlines/operators should ensure that their training/standardization programs emphasize these skills."

The ATA's key recommendation was that pilots deliberately scan the flight mode annunciations to determine whether autopilot and/or autothrust are engaged and in what modes — not merely to confirm the result of each auto-flight mode selection considering that so many mode changes are designed to happen without pilot action. Another suggested countermeasure was collecting and analyzing all mode awareness/confusion events, etc. through a pilot voluntary reporting system and, if required, proactively "changing the expectation" of pilots by highlighting the identified issues in training.

Mode awareness/confusion also has been addressed by the Flight Safety Foundation *Approach-and-Landing Accident Reduction Tool Kit.* Examples of the tool kit's recommended countermeasures are checking that the knob or push-button is correct for the desired function before each mode/target selection, monitoring the flight mode annunciation and calling out all mode changes in accordance with standard operating procedures, and cross-checking the altitude entered on the mode control panel with the selected altitude shown on the primary flight display.

The 2004 revision of the *Airplane Upset Recovery Training Aid* also contains relevant information.[12] An FSF safety seminar presentation by Boeing in October 2007 highlighted this training aid and cited several pilot-induced errors involving maneuvering at high altitude in a mode that does not protect against thrust and buffet margins.

"When using LNAV [lateral navigation] mode during cruise, the mode provides real-time bank angle–limiting functions and will keep the commanded bank angle from exceeding the currently available thrust limit," Boeing said. "This protection is not available when LNAV mode is deactivated. Heading select mode does not protect against too much bank.

And often when maneuvering around storms … crews have left the bank angle setting at something used during low-altitude operations. … A common technique [in threat and error management] is to set the mode control panel bank-angle selector to 10 degrees when at cruise."[13]

On the Drawing Board

The focus of a team from the NASA Langley Research Center and Rockwell Collins reflected one of the major research directions: in-depth human feedback for qualitative insights combined with exhaustive mathematical probing of flight guidance system models by other software for quantitative validations of mode logic and behavior. In the late 1990s, this team created its first software model of a flight guidance system, connected it to a desktop computer simulation of a flight deck and reviewed the mode behavior and human-machine interface with avionics design engineers, pilots and human factors specialists.

Their second strategy applied software engineering, specifically two formal analysis methods in which outputs of mathematical formulas change in response to inputs of different variables, called *model checking* and *theorem proving.* This strategy enabled software-based "exploration" of all possible scenarios and combinations of modes — how, for example, some pilot inputs are ignored as irrelevant by the active mode logic. These researchers said in 2003, "Even though our [formal analysis of a simplified model of a regional jet flight guidance system] was only partial, we were able to find hidden modes, ignored operator inputs, unintended side effects, lack of feedback regarding current modes, and surprises in how off-normal modes can be entered and exited in our example specification."[14]

As one example of related activities by airframe manufacturers, Boeing has been communicating through FSF safety seminars and aviation human-computer interface conferences its efforts to rethink flight guidance system design, test prototypes and provide supplemental educational modules in support of deeper pilot understanding of existing automation behavior.

A clean-slate design for a future flight guidance system has been presented at industry conferences. One Boeing presentation, for example, said that this new design has discarded the concept of pilots memorizing rules for each mode — a limitation imposed decades ago by the avionics architecture itself — with "indications directly related to flight path behavior (e.g., CLIMB, LEFT TURN)."

By starting from scratch, the designers gained the opportunity to make each automated method of flight conceptually correspond with the manual method used by pilots; make infrequent tasks as simple as common tasks; clarify when flight is linked/unlinked to strategic targets in the flight management system or tactical targets entered on the mode control panel; and provide a "preview line" for tactical target entries. They said, "In the new design, approach, landing, go-around and even taxi guidance use the same modes and interfaces as up-and-away flight, resulting in only seven modes to cover the entire domain and providing an extreme level of simplicity and consistency." ●

Notes

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