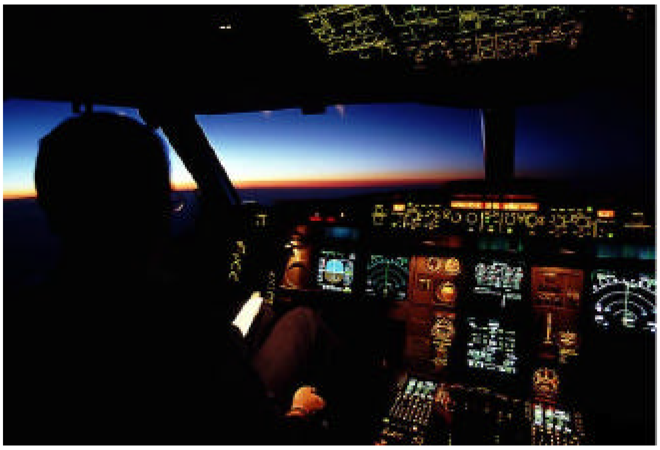
UNDERSTANDING DESIGN PHILOSOPHY CAN HELP PILOTS BENEFIT FROM MODERN AUTOMATED FLIGHT SYSTEMS

Original idea from Etienne Tarnowsk

A set of guidelines or "Golden Rules" for the operation of automated systems can help crew members to remain fully aware of the status of the aircraft and its sophisticated systems – ready to react should an unexpected or critical event arise.

This text is an adaptation of a paper presented at the 4th Global Flight Safety and Human Factors Symposium at Santiago, Chile. The ICAO symposium took place in April 1999.



Development of Airbus Industrie's fly-by-wire cockpits has adhered to a set of design rules which dictate the operational philosophy. A principal rule is that the essential systems should give pilots full authority with a simple intuitive procedure, while minimizing the risks of over-stressing or over-controlling the aircraft.

Others are that the cockpit design should simplify the pilot's task by enhancing situational and system awareness, with automation assisting the air-crew by achieving tactical tasks that it can perform better than a human operator.

The cockpit is designed in such a way that fosters inter-pilot communication. Finally, the process used for systems design includes human factors considerations that help minimize the potential for pilot error.

Using design rules such as these has made it possible to remove many types of errors on the flight deck. Despite a generally high degree of acceptance among pilots, however, the operation of automated systems is not always achieved with optimum results, and some difficulties are still

experienced by aircrew. A proper understanding of automation design philosophy -combined with a set of practical operational guidelines - can help pilots to benefit more fully from the efficiencies of their aircraft's automated systems.

In deciding what functions to automate, Airbus Industrie was guided by the fact that the pilot's strength lies in the area of decision making and performing strategic tasks, while automation is able to perform many tactical tasks. The automated systems on Airbus aircraft, consequently, are designed to complement the aircrew and are not intended to challenge the pilot's role and responsibility.

In deciding how these various automated systems should function, designers addressed three domains of operation. In the green domain -the one in which the aircraft is within the normal flight envelope - automation is error resistant and therefore strives to keep all parameters within the green. In the amber domain, where potential risk is present, automation is error tolerant.

This means that if any parameter drifts into this domain of operation, automated systems attempt to restore it to the normal green domain. Approaching the red domain, which is outside the limits of the aircraft's flight envelope, automation provides a warning to the pilot so that the human operator can decide how best to address a serious situation.

AIRCREW FEEDBACK

Most airlines prefer that their aircrews use automated systems throughout a flight because these systems are thought to be very efficient and reliable. Most pilots, in turn, appreciate the latest generation of fly-by-wire aircraft with their so-called glass cockpits.

As pilots grow more and more familiar with today's automated environment, their confidence in automation grows as well. Pilot workload decreases and the flight deck becomes a more comfortable workplace.

On the other hand, a number of incidents and even accidents indicate that some concerns - usually related to automated systems' level of reliability, air traffic control (ATC) clearances or use of flight management systems (FMS) - are warranted. Both newcomers and pilots experienced with glass cockpit operation have expressed some reservations about automation.

The reliability of the current generation of automated systems is at least 10 times greater than their progenitors. Pilots are less likely to encounter situations that demand difficult decisions, often under pressure and perhaps while suppressing anxiety or even fear. Moreover, the extensive use of the autoflight system can cause pilots to hesitate to take over when an unexpected event arises. The high level of reliability tends to lead to overconfidence in automation and to operating complacency, with an associated lack of vigilance or an over-tolerance for errors.

Some pilots feel taken aback by an automated system when it issues an unexpected warning or when the system does something that is not anticipated. This distrust, however, often arises because of a lack of knowledge or a misunderstanding about system logic.

The other area of concern involves ATC clearances, which essentially comprise two types: the short-term clearance involving a new heading or airspeed, and the clearance that requires revisions to an existing flight plan. Pilots appreciate

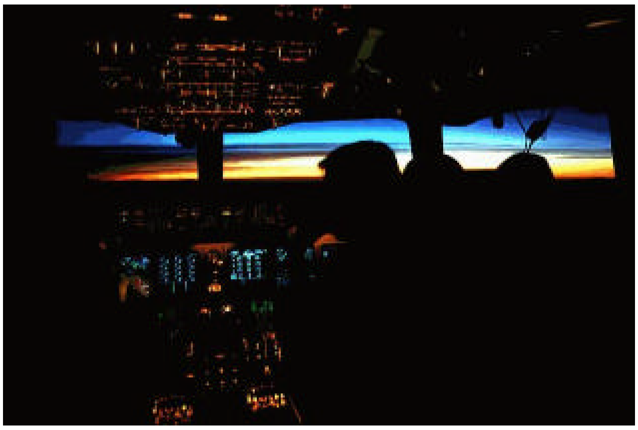
being able to revise their FMS flight plan with information gleaned from their navigation display as to the location of the aircraft versus an ideal trajectory and other predictive factors. But some ATC clearances are difficult to accommodate on an FMS because of the system's limited number of planning functions and its inability to match all types of clearances. Some pilots develop ways to work with the multipurpose control and display unit (MCDU) to approximate a clearance; they even insert incorrect data in the MCDU to achieve a result. These personal solutions require a lot of estimating as well as keystrokes, which means considerable heads-down time with serious implications.

The difficulties and problems pilots report with flight management systems include both initialization errors or in-flight programming problems. Although some revisions take time to input in the control and display unit (CDU), pilots prefer to implement them even under time pressure. The consequences include further increases in workload, especially in the terminal area, heads-down time during initial approaches and many last-minute revisions or control and CDU entries. The latter often are done under time constraints without proper task-sharing or a true cross-check by other aircrew members, which means that entry errors could go undetected, at least until late in the flight.

Some peripherals that use the FMS position data - examples include the navigation display and the enhanced ground proximity warning system (EGPWS) - are misused. Precautions such as cross-checking for accuracy are not followed, and navigation database errors may include major problems such as map shifts that are not easy to detect. The flight management and guidance system (FMGS) performs guidance tasks under the direction of the pilot who controls the autopilot, flight director and autothrust. Experience has shown that pilots can experience mode confusion or may mismanage the autopilot flight display because of the large number of modes available, some of which could be misinterpreted.
There also can be unnoticed or unexpected mode changes, differences between expected and actual aircraft performance, poor crew communication, and passive delegation by the pilot to the flight management and guidance computer (FMGC)

OPERATIONAL GUIDELINES

Many recommendations on automated operation are found in the standard operating procedures (SOPS) and flight crew operating manual (FCOM). Most airlines request that pilots use automated systems extensively, according to the manufacturer's recommendations - a sensible policy since those recommendations are dictated by the design philosophy. Many airlines endeavour to develop their own set of guidelines for automated operation since these can only help their pilots in controlling and managing the systems.



Experience also has demonstrated that many of the problems encountered by aircrews could be avoided if the crew understood fully how the automation system works. Conversely, system reliability is such that training skills acquired for dealing with abnormal situations might not be retained.

Since teaching automated systems on a need-to-know basis clearly is inadequate, training must inculcate a thorough understanding of system behavior, the interdependence between automated systems, and the factors that contribute to potential errors.

It also must be hands-on as much as possible on specific training devices such as part-task trainers to specifically instruct crews on FMGS operation, a practice that would make the operation of automated systems more instinctive and natural.

Guidelines for automated operation apply to different aspects such as controlling the aircraft, using the flight management system, and using the display units.

In flying a fly-by-wire protected aircraft by hand, only one pilot should be at the controls at any time. The handling of the control stick should be relaxed when encountering turbulence, and in the event of an extreme situation such as wind shear, the control stick may be pulled full aft if necessary to recover without concern about the aircraft stalling.

In using the autopilot, aircrew must keep two questions in mind as they program FMGC interfaces: how should the aircraft behave now, and how should it behave next? They must also select the appropriate mode for a given task, keeping in

mind the current accuracy of the FMS. The flight control unit (FCU) should be used for simple clearances, more specifically at low altitude in terminal airspace, and the MCDU for clearances involving major revisions. The autopilot, flight director and auto-thrust must be monitored actively on the proper interfaces, with appropriate tasksharing and cross-checking among crew members.

When a suspected malfunction arises or when an aircraft behaves in an unexpected manner, pilots must immediately select the desired target (i.e. altitude, heading, speed, etc.) on the FCU or hand fly the aircraft to the target without trying to resolve the problem or re-program the system. In cases of straying from the green domain of the operating envelope, where the autoflight system turns off, the aircraft should be hand flown back as soon as possible. The crew should not attempt to re-engage the autopilot while the aircraft is still outside the green domain. Guidelines for FMS operation involve three requirements: firstly, checks of FMS navigation accuracy are needed to determine how to use the basic navigation tool (the navigation display), select the recommended autopilot mode, and confirm whether peripherals such as EGPWS are usable; secondly, the crew should monitor the TO waypoint on the navigation display to confirm the proper flight plan sequencing; and thirdly, the crew should aim to maintain an actual flight plan as close as possible to the programmed flight plan so as to anticipate deviations.

Pilots must anticipate their actions on the MCDU and use all available FMS functions to prepare for a possible diversion to another airport, a different runway or a holding pattern. The FMS and any flight plan revisions should be used to match an ATC clearance if time permits and if they do not require complex or tricky programming or induce too much heads-down time in the terminal area. Provided that FMS navigation is accurate, FMS managed modes should be used whenever they facilitate an ATC clearance.

Efficient communication between the crew members is a must. When a pilot flies by hand, his intentions have to be communicated to the pilot not-flying (PNF), who inputs the required revisions on the MCDU or programmes the FCU. When the aircraft is flown through autopilot, the pilot-flying performs the programming revisions and then briefs the pilot-not-flying. Both pilots cross-check the MCDU revisions or FCU inputs and actively monitor the FMS using the primary flight display or the navigation display, as required.

Cockpit displays provide many parameters according to rules that must be clearly known and understood by the pilots. As a general rule, pilots should use the most pertinent parameter to monitor any given task. Aircrew also must "fly ahead of their aircraft" by periodically cross-checking FMS accuracy and taking the appropriate action if a problem is revealed. They need to check the electronic centralized aircraft monitor (ECAM) system display pages to detect any drift of a parameter and to monitor fuel consumption, and should periodically update the secondary flight plan in anticipation, for example, of a potential diversion.

When there arises a warning or caution having an associated ECAM procedure, the situation should be analyzed by reviewing the ECAM system display before taking any ECAM actions. The aircrew should validate the condition indicated by the ECAM prior to taking any further action, and adapt the scan of the primary flight display to the level of automation selected.

If the aircraft is being hand flown with the autopilot, flight director and autothrust disengaged, the crew should scan the basic primary instruments and any selected targets, and if flying with the flight director, autopilot or autothrust engaged, the aircrew should add the flight mode annunciator (FMA) and its targets to the scanning process.

They also should analyze the overall aircraft status so that they can keep system awareness updated. Aircrews also need to adapt their scanning of the primary flight display according to the flying reference selected. If the flight path vector (commonly known as the Bird) is selected, the Bird and track must be scanned, and if flight path vector is selected off, the scan includes the pitch attitude, heading and the vertical speed.

The aircraft navigation display must be monitored and used according to the FMS rules:

1. Use the ARC and ROSE NAV display modes if the FMS navigation accuracy is correct;

2. Adjust the navigation display range and mode according to flight progress and to peripherals (e.g. radar, EGPWS);

3. Monitor the TO waypoint at the top right corner of the navigation display; and

4. Select the appropriate additional information on the electronic instrument system (EIS) control panel according to flight progress.

Finally, in case of any doubts, the crew should opt for raw data and consider reverting to a ROSE very high frequency omnidirectional radio range/ instrument landing system (VOR/ILS) display mode.

CONCLUSION

It is not difficult to draw an analogy between a pilot and the goalkeeper of a soccer team. When the team plays well, attacks or defends efficiently and consistently, the goalkeeper has few opportunities to act. Yet, it is the goalkeeper who bears most of the responsibility should the situation turn critical during the match. This is why he must keep himself in the match by following every play, ready to react and stop the ball when necessary. The objective of the aviation "game" - with the pilot-in-command as goalkeeper and the two crew members and automation system, together, as the team - is to complete the flight safely and efficiently. Thus, the pilot-in-command is ultimately responsible for the safe operation of the aircraft in all circumstances.

When they are followed by aircrew, the guidelines for the operations of automated systems allow the crew members to remain "in the loop," ready to react when an unexpected or critical event occurs. The guidelines can be summarized by Airbus as golden rules that are a direct consequence of the cockpit design philosophy :

- Fly, navigate and communicate - in that order;
- keep one head up at all times;
- Cross-check FMS accuracy;
- Know the FMA at all times;
- Use automation appropriate for the task; and
- practice task sharing and redundancy.

The coming decade will see the continued evolution of automated aircraft operations. Communication via data link will become quite abstract and sophisticated, clearances will be negotiated and transmitted automatically between ATC and the aircraft's flight management system, and yet pilots will retain ultimate control.