THE AUTOMATION DEBATE REVISITED
COMPUTER CLASH

Mark Wolff

JUST ON FIVE YEARS AGO, A CHINA Airlines A300 crashed on landing at Nagoya, Japan, killing 264 passengers and flight crew.

An important factor in the accident was a "clash of wills" between the pilot and the aircraft's automation system – with the pilot the loser.

The Taiwan-based aircraft was being flown on approach by its 26-year-old co-pilot. About two minutes before landing, the aircraft went into "go-around" mode unprompted by the flight crew.

Despite several warnings from the pilot, the co-pilot continued to try to land the aeroplane. The auto-pilot was trying to pitch the nose up while the co-pilot was trying to pitch the nose down.

The crew then switched the go-around mode off. However, they quickly found the aircraft was too high to land, so they turned the go-around back on.

The aircraft started to climb sharply and approach a stall. The A300 stall-prevention system automatically increased the engine thrust, but this increased the climb angle. The result was that the aeroplane stalled in an extreme nose-high configuration, smashing into the ground tail-first. There were only seven survivors.

The A300's automatic systems contributed to the accident in two ways:

- The system continued to try to go-around even though the plane was still being flown by hand.
- The stall-prevention system's actions in increasing thrust contributed to the stall.

The Nagoya crash was an early example of how a breakdown in the flight crew-automation interface can affect flight safety.

Although this accident involved an A300-600, other accidents, incidents and safety indicators demonstrate that the issue is not confined to any one aeroplane type, aeroplane manufacturer, operator or geographical region.

This point was tragically demonstrated by the crash of a Boeing 757 operated by American Airlines several months after the Nagoya crash.

The aircraft crashed into Mount San Jose, Cali, Colombia, after a loss of situation awareness by the flight crew. The flight was cleared direct to Rozo VOR, for vectors to the ILS approach into Cali. The crew proceeded to enter "RO" into the flight management computer (FMC), but should have entered "ROZ", the three-letter identifier for the Rozo VOR. Due to an FMC database error, the flight computers misinterpreted the command and initiated a 160° turn to the left, direct to Bogota.

The flight crew asked, "Why is it turning left?" but continued to descend. Due to the darkness obscuring the valley, the crew was

After two attempts at landing, this China Airlines A300-600R crashed at Japan's Nagoya Airport on 26 April, 1994. 262 passengers and crew were killed.

REUTERS

Only four passengers of the 160 people on-board this American Airlines 757 survived when it crashed into a mountain near Cali, Colombia on 20 December 1995.

without visual awareness. Seconds later, the ground proximity warning system began to sound. Full power was initiated, the aircraft pitched up, and the flaps were retracted. Unfortunately, the crew forgot to retract the spoilers, and the aircraft struggled to climb. Less than 200ft from the summit of the mountain, the aircraft hit the ground. One hundred and sixty people died. Only four survived.

The Nagoya and Cali accidents sparked intense discussion about the difficulties of flight crew interacting with flight deck automation.

As a result, the US Federal Aviation Administration (FAA) launched a study to evaluate the flight crew-flight deck automation interfaces of current generation transport category aeroplanes.

The aeroplanes included in the study were: Boeing models 737, 757, 767, 747-400, 777; Airbus models A300-600, A310, A320, A330, A340; McDonnell Douglas models MD-80, MD-90, MD-11; Fokker models F28-0100/-0070.

The study looked beyond flight crew error to contributing factors from design, training, operations and regulatory processes. It concluded that the major concerns were flight crew understanding of automation's capabilities, decision making and vulnerabilities in flight crew situation awareness.

The research team found pilots were often confronted by "automation surprises". "Why did it do that?", "What is it doing now?" and "What will it do next?" were common questions, indicating poor understanding of automation processes and decision points.

When pilots get into unusual situations, they appeared to make different decisions about the right automation level to employ, or whether to turn the automation on or off.

Flight crew situation awareness issues included vulnerabilities in automation mode awareness, and flight path awareness.

The report made 51 recommendations in the areas of incentives for safety, management of automation, situation awareness, communication and coordination, processes for design, regulatory and training activities, methods and tools for design and certification of aircraft systems, knowledge and skills, and cultural and language differences.

A follow-up analysis of the US aviation safety reporting system by the Ames Research Centre showed in detail the kinds of problems that have been occurring.

The analysis turned up a number of major automation problems: lack of monitoring, automation failure, programming errors, distraction due to programming and mismanagement and confusion of automation systems.

Lack of monitoring: The study showed that trust and over-reliance in the automation

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A study by the Federal Aviation Administration showed that the type of programming errors were:

- **Incorrect route entered (46 per cent).**
- **Inadequate programming of VNAV climb, descent and approach profile (37 per cent).**
- **Wrong fix entered (17 per cent).**

system breeds complacency.

Crews were found to be so reliant on automation that they sometimes fail to cross-check with the raw data, as is evident in this safety report, "VNAV was selected and aircraft began accelerating to 310kt. Rate of climb was reduced. At 14,000ft Captain went to VOR manual to check distance and discovered he was 3 miles beyond 8 DME fix already. The captain was unsure of the altitude when crossing the 8 DME fix. Reduced climb rate due to increasing speed to economy climb was not monitored adequately to assure meeting the crossing restriction. The LAC 041/8 DME fix should have been entered by crew and displayed on map. Crew relied too heavily on 'glass' and for a short period, lost situational awareness."

Automation failure: Some modern aircraft are built so aerodynamically clean that minor errors in the autopilot system are not as noticeable to crews. The main problem found with automation failure was not so much the monitoring of the automation systems, but rather in the monitoring of raw data equipment. In some cases, the lapse of time from initial recognition of failure to focussing on the raw data information was too long.

An example: "...one of the problems was that I was relying on the FMC too much for departure and not cross checking with the departure plate... In the future I will rely on traditional navaids for FMC backup. I also made the mistake of using too small a scale for the NAV display. On a larger scale I would have seen the error."

Another example resulted in an aircraft penetrating special use airspace because of a malfunctioning FMC: "...we had possibly entered [a military operations area], which closely paralleled the right side of our course. To guard against further incidents of this nature in the future, we would keep the NAV chart immediately available and closely monitor our position... to ensure that we remain well clear of all special use airspace."

Misprogramming: As with any control device, human error by crews programming automatic navigation systems is possible. Prior to actual programming of the automation systems, crews must plan the appropriate actions to take. The study showed that the type of programming errors were:

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- Inadequate programming of VNAV climb, descent and approach profile (37 per cent).
- Wrong fix entered (17 per cent).

Unfortunately, programming errors are not noticed immediately in digital flight guidance systems, as this example illustrates: "Just after centre issued our clearance, I was relieved and went on a rest period in the cabin. Normally this is where somebody would check the FMS route with the book, but with the shift change and some complacency, none of us did. The result was a NAV deviation that centre discovered ... In the future, I will check our FMS loaded route with the flight plan filed route section and will also make a greater effort to guard against complacency.

Distraction due to programming: Over half of the problems reporting distraction due to programming were in the descent and approach phases of flight – less that one-fifth were during cruise.

One example illustrates the need to be alert – especially on final: "Nearing completion of a three-hour flight ... cleared for a night visual approach to runway 35R at DFW. The visibility was exceptionally good. The pilot flying had approximately 100 hours in the aircraft ... The flight management system (FMS) was programmed for runway 35R and the pilot flying was using the map display on the HSI for lineup as the runway lights were not yet visible. Just as the 36 L/R lights were coming into view, the TWR offered 35L (no ILS) and the crew accepted ... the pilot flying looked out and saw the 36 L/R lights and mistook the runway pair as runway 35 L/R ... and a landing was made." The main factor in the incident was found to be preoccupation by crew on FMS/instrumentation late in the approach when outside vigilance was more important.

Mismanagement/confusion: Mismanagement of automation is about systems awareness. There were three categories of mismanagement found in the study: wrong expectations of the system (42 per cent); improper decision making (42 per cent) and total misuse or lack of training on the systems (16 per cent).

The ability of crew to plan ahead and anticipate is essential to the effective operation of on-board automation systems. Crews must also allow enough time to program the systems.

Effective decision making depends on knowing when to revert from automation control to manual control. A case in point: "Finally, I shut off the autothrottle ... At this point, I finally wised up and decided to quit battling the autoflight system (which I obviously was not really in command of at the time). Almost immediately I was able to get the aircraft on heading, on airspeed, on altitude and in the configuration I desired ... I waited too long to hand fly the aircraft."

The top issues: Flight deck automation has been well received by pilots and the aviation industry as a whole. Indeed, accident rates for advanced technology aircraft are lower than those of comparable conventional aircraft.

Nevertheless, pilots, scientists, and aviation safety experts have expressed concerns about flight deck automation, fearing that pilots may place too much confidence in automation, and concerned that they might lose manual flying skills. And the human factors research community is worried that pilot-automation interfaces may be poorly designed.

Only recently has a complete set of data and associated evidence about the issues been published.

A meta-analysis of all incidents and accidents relating to automation was completed last year by Ken Funk of Ohio University and Beth Lyall of Arizona-based Research Integrations Ltd for the Federal Aviation Administration.

The researchers' approach was to review all of the literature and accident and incident reports available. The research team then surveyed pilots and performed automation analyses to identify flight deck automation issues. The team then surveyed aviation experts, reviewed literature and accident reports, and analysed incident reports to compile data and other objective evidence related to those issues. The work yielded a list of 92 flight deck automation human factors issues, over 700 instances of evidence related to those issues, and a large body of supporting information.

The analysis then ranked the issues in order of priority based on a range of ratings, including expert agreement, expert rating of criticality, and the number of times the issue was cited.

The study found that the top 10 issues when ranked against multiple criteria were:

1. *Automation may demand attention.* The attentional demands of pilot-automation interaction may significantly interfere with performance of safety-critical tasks – "head-down time", distractions, and so on.

2. *Automation behaviour may be unexpected and unexplained.* Automation may perform in ways that are unintended, unexpected, and perhaps unexplainable by pilots, possibly creating confusion, increasing pilot workload to compensate, and sometimes leading to unsafe conditions.

3. *Pilots may be overconfident in [handling] automation.*
Pilots may become complacent because they are overconfident in and uncritical of automation, and fail to exercise appropriate vigilance, sometimes to the extent of abdicating responsibility to it. This can lead to unsafe conditions.

4. *Failure assessment may be difficult.* It may be difficult to detect, diagnose, and evaluate the consequences of automation failures (errors and malfunctions), especially when behaviour seems "reasonable", possibly resulting in faulty or prolonged decision making.

5. *Behaviour of automation may not be apparent.* The behaviour of automation devices – what they are doing now and what they will do in the future based upon pilot input or other factors – may not be apparent to pilots, possibly resulting in reduced pilot awareness of automation behaviour and goals.

6. *Mode transitions may be uncommanded.* Automation may change modes without pilot commands to do so, possibly producing surprising behaviour.

7. *Mode awareness may be lacking.* Pilots may not be able to tell what mode or state the automation is in, how it is configured, what it is doing, and how it will behave. This may lead to reduced situation awareness and errors.

8. *Mode selection may be incorrect.* Pilots may inadvertently select the wrong automation mode or fail to engage the selected mode, possibly causing the automation to behave in ways different than intended or expected.

9. *Situation awareness may be reduced.* Reliance on automation may reduce pilots' awareness of the present and projected state of the aircraft and its environment, possibly resulting in incorrect decisions and actions.

10. *Understanding of automation may be inadequate.* Pilots may not understand the structure and function of automation or the interaction of automation devices well enough to safely perform their duties.

The pilots view: What do the pilots themselves think about automation? A survey of 132 pilots, published by Massachusetts based BBN technologies in the international journal of aviation psychology last year, reveals they are largely in agreement with the human factors community in preferring a human-centred approach to automation, in which there is shared performance, rather than fully automated systems.

Pilots were appreciative of the automation in current generation glass cockpits and claim to use it whenever it is appropriate. They want their automation to be simple and reliable and to produce predictable results. When trading off between flexibility and adaptability versus simplicity and reliability, they opt for simplicity.

Most of the pilots surveyed felt that the biggest needs for more automation were to further alleviate the workload demands imposed of them in time-constrained decision making situations. Although there were differences of opinion according to experience in different aircraft, the similarities were greater than the differences.

They indicated a desire for more and higher levels of automation. There is, however, a paradox here. On the one hand, pilots would like new automation to be simple and reliable, but they also want it to

Image Courtesy of Qantas

Reliance on automation may reduce pilots' awareness of the present and projected state of the aircraft and its environment, possibly resulting in incorrect decisions and actions.

support the most complex part of the job.

Pilots expressed a belief in the need for the pilot to remain in charge, the impossibility of foreseeing all procedural requirements, and the desirability of automation that advises rather than commands.

In the flight deck vision of 20 years ago, it was believed that we could make flight safer and more efficient through more automation. Concerns at the time included high pilot workload and human limitations in computational speed and performance of continuous manual control tasks.

To a large extent that vision has been realised. For example the flight management and autopilot systems on modern commercial aircraft have increased the ability to plan and fly precise, cost effective flight paths far beyond that possible before those systems existed.

Further, use of automation to avoid the high workload demands of continuous manual flying tasks and arduous computational tasks have given pilots more time to attend to all critical aspects of the flight. But the introduction of more and more automation has had unforeseen results:

- More head-down time due to monitoring requirements and data entry.
- Complacency.
- Skill degradation due to pilots being delegated to back-up monitors of highly reliable automated systems.

We should not define pilot roles and responsibilities by default, that is, what is left over after the automated systems afforded by current technologies are created to solve specific operational problems.

Automation should be designed to complement human abilities. To keep pilots involved and informed, we must determine meaningful ways for automated systems and pilots to share functions, exploiting automated capabilities without squeezing the flight crew into purely monitoring and managing roles.

One of the myths about the impact of automation on human performance is that as investment in automation increases, less investment is needed in human expertise. In fact, many sources have shown how increased automation creates new and different knowledge and skill requirements.

New knowledge and skill demands are most relevant in relatively rare situations where different kinds of factors push events beyond the routine – just those circumstances that are most vulnerable to going sour through a progression of misassessments and miscommunications.

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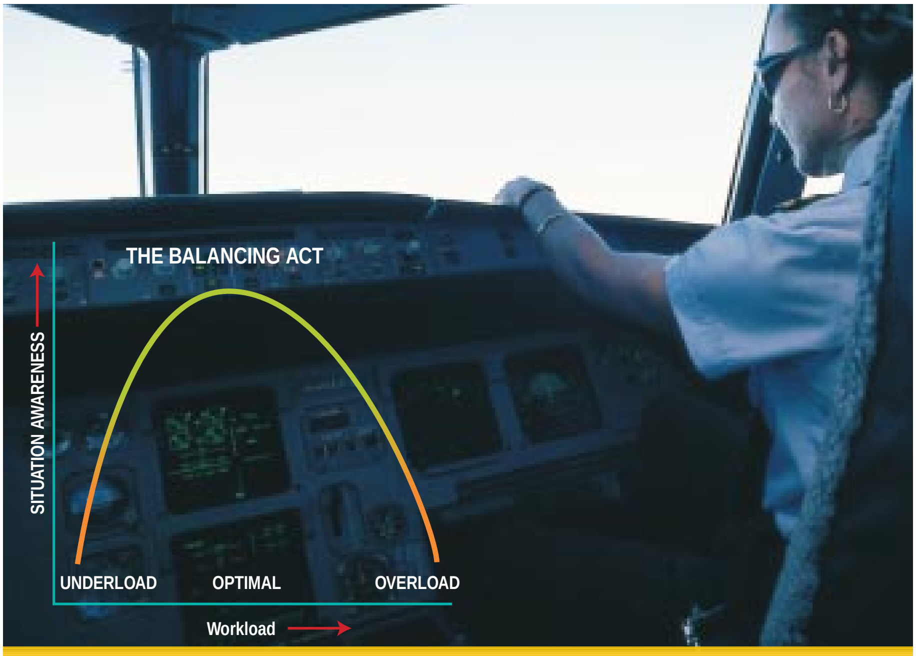

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A matter of balance

Stuart Lau

The FAA interfaces report determined several hazardous states of awareness: absorption, fixation and preoccupation.

Absorption is about focusing on a specific task while disregarding other tasks. Absorption is the main reason that some operators have put in place procedures restricting the use of automation during periods of high workload, such as restricting programming of the FMS during operations below 10,000ft.

Fixation is sometimes referred to as tunnelling. It means the state of being locked into a specific task while the environment demands that your attention should be directed to another, more critical task. Fixation often occurs during stressful situations, and is hard to self-diagnose. If fixation is a problem, the unaffected crew member must sharply break the fixation to enable the affected pilot to refocus.

Preoccupation is often likened to day dreaming. It means that the subject's attention is not on the task. Increased interaction can be helpful in preventing the mind wandering.

Fatigue, underload and complacency each decrease vigilance and can all contribute to a lack of situation awareness.

Fatigue stems from long duty periods, back-of-clock flying and long haul flights covering several time zones.

Fatigue is best addressed by implementing safe scheduling practices, including sensible rest and duty periods.

Overloading and underloading crew with tasks is also risky. The most common cause of an underloaded crew is too much reliance on automation. This can lead to complacency, hampering ability to recognise system failure or unexpected behaviour.

The FAA human factors team were also concerned that flight crew may not be provided with sufficient information about the energy state of the aircraft. Stall warning systems provide information about the energy state of the aircraft, but are not activated until the aircraft reaches a very low energy state, which can be too late.

Heads up guidance systems (HGS) are an emerging technology that will improve overall situation awareness by providing easily assimilated information on energy state and guidance. Another energy state management tool associated with HGS is the angle-of-attack limit bar. The bar appears automatically during periods of low energy state, such as windshear and ground proximity warning systems escape situations.

Achieving optimal situation awareness while operating highly automated aircraft is a balancing act.

The key is moderation. The most efficient flight decks strike a moderate balance among workload, flight crew interaction and improved attention management skills. Too much or too little of any one factor will compromise situation awareness of flight parameters and the status of the aircraft.

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