“Staying ahead of the aircraft” and Managing Surprise in Modern Airliners

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Abstract. The pilot’s task in commercial aircraft operations has changed from flying the aircraft by means of manual control, to increased monitoring of the cockpit. The increase of automation provides a high level of stability and reduces variations and disturbances, leaving crews with little exposure to surprise. Current training programs are similarly focused on dealing with anticipated problems and pre-determined responses, provide little opportunity to prepare for the unexpected and unforeseen. In this paper we frame the research agenda for investigating how pilots cope with surprise and confusion in modern aircraft. An interview study with pilots has been carried out, identifying areas for further investigation regarding manual control, procedure applicability, system knowledge and training for unexpected events. A crew-aircraft control model has been developed to frame the functions and processes to be further investigated.

1 INTRODUCTION

The current generation of commercial aircraft are designed with highly automated and reliable systems, a development that has many safety benefits. However, as the cockpit operations grow increasingly stable, the amount of variations and disturbances decrease, leaving the crew with little exposure to surprises and unforeseen situations. The effects on the operational work environment are not well understood, since the crew’s ability to deal with the unexpected has received less attention in the aviation industry. Crew training, for instance, is primarily focused on dealing with specific
anticipated problems, and dealing with unexpected events is not explicitly addressed. Similarly, potential disruptions and faults during operation are anticipated and addressed through systems design and procedures.

A resilience engineering approach to complex and dynamic systems, such as commercial aviation, recognises that operational life contains fluctuations, unexpected events and disturbances that do not always fit the textbook examples and trained scenarios (e.g., Dekker & Lundström, 2006; Loukopoulos, Dismukes, & Barshi, 2009). To be resilient it is necessary to be well-prepared for anticipated failures, but also to be “prepared to be unprepared” (Paries, 2011). Recent aviation accidents demonstrate the necessity of crew abilities to cope with situations beyond the procedures and standard crew training. Examples include, for instance, the ditching of the US Airways A320 in the Hudson River after an unlucky bird strike (NTSB, 2010) and the successful management of the Qantas A380 engine explosion leading to a series of events and faults (ATSB, 2010). Although the initial threats of these events were anticipated, the full consequences of the failures, given the situational circumstances were not, leaving the crew to rely on their individual experience and expertise.

This paper structures the initial findings, main issues and questions identified at an early stage of the EU-FP7 research project Manual Operations of 4th Generation Airliners (Man4Gen) from the theoretical perspectives of cognitive systems engineering (Hollnagel & Woods, 2005; Woods & Hollnagel, 2006), sensemaking (Weick, Sutcliffe, & Obstfeld, 2005) which is one of the macrocognitive functions described by Klein, Klein, Hoffman, & Hollnagel (2003), and resilience engineering (Hollnagel et al., 2011). It thereby defines a research agenda for tackling the problem of preparing flight crews of highly automated airliners to cope with the unexpected. Results from a pilot interview study and descriptive modelling attempts are presented to scope and frame the research area to be investigated in the project. The focus is twofold: (1) what is required to “stay ahead of the aircraft” while “flying as usual” to minimise and prepare for surprise and (2) what strategies pilots use to deal with surprise and confusion. The focus and term descriptions are presented below in Section 1.1 and further illustrated in the crew-aircraft model in Section 2.1.

1.1 “Staying ahead”, Surprise and Confusion

The terms “staying ahead”, “surprise” and “confusion” have been used by the industry and academic partners in the Man4Gen project to focus and discuss the problem area to be investigated. Below we describe what the terms from a sensemaking perspective.

The expression of “staying ahead of the aircraft” has been used within the project to describe the crew’s current “awareness” (of e.g., the aircraft systems, environment), their expectations and their ability to anticipate and respond to future events. In sensemaking “staying ahead” can be described as the retrospective and prospective processes of data framing, re-framing and anticipatory thinking (Klein, Snowden & Pin, 2010; Klein, Wiggins, & Dominguez, 2010; Weick et al., 2005). Sensemaking involves the
continuous process of fitting the data (what we observe) into a frame and fitting a
frame around the data (what we expect) (Klein, Wiggins, & Dominguez, 2010). To “stay
ahead” further requires the prospective process of anticipatory thinking. Recognising
and preparing for difficult challenges is directed by where we focus our attention,
which is based on our expectations. This is a highly contextualised process where
responses are simultaneously being identified based on the constraints of the situation
(Klein, Snowden & Pin 2010).

A surprise occurs when a mismatch between what is observed and what is expected is
detected. Hence, a surprise from a sensemaking perspective is when what is observed
does not fit the current frame (organising of data), requiring an elaboration or a re-
framing of the data (Klein, Wiggins, & Dominguez, 2010). Surprise is thus not only about
interpreting data after-the-fact but also closely related to our expectations
(anticipatory thinking). Woods & Hollnagel (2006) define surprise (with a focus on
automation surprises) as the “miscommunication and misassessment between the user
and the automation which leads to a gap between the users understanding of what the
automated systems are set up to do, what they are doing, and what they are going to
do” (pp 120-121). It is when the mismatch, or gap, is detected that the surprise occurs.
If the mismatch cannot be fitted to the current frame there will be recovery interval, or
a re-framing process, to fill the gap; a process which in everyday terms could be
referred to as confusion and problem solving. Lanir (1986) makes a distinction between
situational surprise, i.e., a surprise that can be fitted into our current frame and a
fundamental surprise, i.e., a surprise that challenges our basic assumptions of the
situation and requires a new frame. The process of re-framing to fit the current
situation in complex environments (Klein, Wiggins, & Dominguez, 2010) may be
challenging, due to, for example, fixation problems (De Keyser & Woods, 1990) and
organisational barriers (Klein, Snowden & Pin, 2010). The inability to identify the
mismatch and fill “the gap” may have disastrous effects. However, it is not always
necessary to fully understand the situation in order to respond sufficiently, as is
discussed in section 2.

2 RESULTS

Results from an interview study with 20 participants, including pilots, instructors,
examiners, and industry experts provide insights into the current issues and challenges
of flying modern airliners. The interview questions were based on findings from
academic and industry studies and working groups (e.g. ICAO, 2006; Holder, 2012;
ICAO, 2013) and highlighted the topics of surprise, confusion and problem solving,
automation and system knowledge, manual operation, training, procedures and
communication. The interviewees ranged from low-experience first officers, to
experienced captains, flight instructors and training and safety managers. Overall there
were more experienced crew in the group; 14 out of 20 participants were instructors
and examiners and only 2 were first officers. The average number of flight hours of the
participants was 10892 and the average age 49. There were 5 interviewers performing the interviews, and at least 2 were present during each interview. The interviews were recorded, transcribed and categorised according to the topics listed above. The iterative analysis process further allowed the identification of sub-categories as they emerged from the data.

Results show that both automation (e.g. sensor failures) and operational factors (e.g. ATC communication) are more common sources of surprise. A surprise or an unexpected situation is however not necessarily a significant threat, although confusion resulting from a surprise may be. On the other hand, it was also mentioned that it is not always necessary to fully understand the problem to cope with the situation successfully. For example, a common strategy mentioned to deal with confusion was “if confused about the automation, take over and fly manually”. Other strategies to cope with surprise and confusion mentioned were to “sit on your hands”, i.e., evaluate the situation before acting and to “stay ahead of the aircraft” to minimise surprise.

The examples and strategies outlined by the interviewees demonstrated potentially conflicting coping mechanisms to deal with unexpected situations in modern airliners today. An example is deciding when to disengage automated systems and take over manual control. As mentioned, manual control should be resumed when confused about what the automation is doing. However, airline operators and manufacturers recommend using automation as much as possible and many pilots also identified that “automation could make confusing situations safer if you know how to make the automation do what you want it to do”. Further, several respondents mentioned that manual flying takes effort (particularly if not well trained), and that this may degrade other abilities important in difficult situations, such as communication.

Varying views on the required level of system knowledge also highlights the challenge faced in modern airliners today. On the one hand a deeper understanding for systems and their interconnectedness may be useful to deal with surprises, but on the other hand “pilots sometimes put too much effort into identifying what is wrong with the system instead of flying the aircraft”. Similarly, procedures were seen as one of the safest ways to get out of confusing situations. However, it is important not to follow procedures blindly and sometimes it is necessary to deviate from them, while it is not always obvious when to do so. The interviewees did not think that training today sufficiently provide challenging situations that can help prepare crew for surprise (e.g., situations with no clear procedures or multiple inter-system failures).

The interview results are not conclusive as the study only covered a small sample of pilots. However, the ambiguities and trade-offs regarding manual control, procedure applicability, system knowledge and training for challenging situations are in line with the conclusions from earlier studies (e.g. ICAO, 2006; Holder, 2012; ICAO, 2013) and demonstrate that further investigation is needed. Areas highlighted are:

- How can (do) pilots “stay ahead” of the aircraft to minimise surprise?
- Which strategies do pilots use in dealing with confusion and when are these
What are the criteria that lead pilots to adjust or disregard the execution of procedures?

What is the effect of system knowledge on staying ahead of the aircraft and dealing with confusion?

2.1 The Crew-Aircraft Contextual Control Model

The crew-aircraft model (Figure 1) is an initial modelling attempt to focus the core concepts to be investigated and scope the sensemaking research strand within the project. The control model described here is one part of the analysis of pilot-aircraft functions which “serves as an archetypical pattern and narrative generator that guides how specific stories can play out in multiple situations and settings” (Woods & Hollnagel, 2006, p. 21). The model is adapted from Hollnagel & Woods (2005) Contextual Control Model (COCOM) to fit the crew-aircraft context and concepts used to frame the problem.

Several interconnected loops represent the dynamics between the two crew members (Pilot Flying (PF) and Pilot Monitoring (PM)) and the aircraft. The two main simultaneous processes of sensemaking as described by Klein and colleagues: anticipatory thinking (Klein, Snowden & Pin, 2010) and framing and re-framing the data (Klein, Wiggins, & Dominguez, 2010), which together serve the purpose of ascribing both meaning and action (Weick et al., 2005) are depicted in the two main loops for each crew member. Red and blue arrows for both PF and PM (jointly and in an iterative and looping manner) represent macrocognitive functions and processes (as described by Klein et al., 2003). Yellow arrows describe aircraft processes and external events and disturbances.

Events and Feedback from the process to be controlled modify the Understanding (by
PF and PM) of the situation, in a process of (re-)framing the data. This part of the loop focuses on macrocognitive functions of situation assessment and problem detection, and macrocognitive processes of attention management and developing mental models. At the same time, both pilots engage in a loop of anticipatory thinking, which focuses on macrocognitive functions and processes of (re-)planning and mental simulation, generating Expectations based on their Understanding. Expectations reciprocally affect Understanding in that they affect attention management and mental models and thus the way in which pilots seek information. Coordination and maintaining common ground is done through communication in the cockpit (blue arrow), which also enables both loops of reframing the data and anticipatory thinking to be a crew effort.

The crew’s current Understanding of the situation leads to Actions by PF and PM through macrocognitive functions and processes of (re-)planning, generation of courses of action, and (naturalistic) decision making. Actions consist of (a) actions on Aircraft controls and displays (yellow arrows from Actions PF/PM to Aircraft) and (b) communications, verbal and non-verbal, to the other pilot or to external actors such as ATC or airline operations (blue arrows from Actions PF/PM to Events/Feedback). Note that not acting on automated process or not communicating are also important to include in the model to guide observation. The strategy to “sit on your hands”, is an example that can in some situations be useful. Not communicating, as when pilots are too occupied with other tasks to communicate, and it gets “quiet in the cockpit” is an example that some pilots suggested could be indicative of crew struggling with confusion. Aircraft actions result from pilot Actions, and processes including various automated, autoflight, and envelope protection processes (represented by the yellow Aircraft loop). Aircraft processes, PF/PM Actions, and External events and Disturbances together produce Events in and Feedback on the process to be controlled (converging at the top of the figure). These include communication events, data being shown on displays, movement of the aircraft, etc. This mix of various events/feedback (through processes of attention management) modifies the Understanding of the situation and Expectations (as described above), and the loop continues.

The macrocognitive process of uncertainty management relates to the core concepts of surprise and confusion. As described previously, surprise arises when Expectations do not match the interpretation of Events and Feedback. The surprise may result in a quick modification of the current Understanding (for example in a situational surprise (Lanir, 1986)), or in a fundamental surprise (Lanir, 1986) which may result in a longer process of questioning the frame, elaborating the frame, and reframing the data (Klein et al, 2010), which in everyday language may be called confusion and problem solving. Taking Action (for example going to lower degrees of automation closer to “manual control”) changing the Aircraft processes may also help the return to a situation where Expectations match situation assessment while trying to form an Understanding of the situation.

The goals of the process to be controlled can be described in several ways: Getting the
airplane from gate to gate, from waypoint to waypoint, keeping the aircraft within the flight envelope, avoiding collisions with the ground, obstacles and other aircraft, following the cleared trajectory or heading, etc. This suggests that anticipatory and compensatory control loops with different time horizons can be used to describe the process in more detail, as for example using the Extended Control Model (ECOM). Such modelling attempts will be further explored in next steps of the project.

3 CONCLUSIONS

The different views and challenges identified in the interviews demonstrate trade-offs faced by the aviation industry today, as the system works toward multiple goals. Safety is designed at the blunt-end of the system through increased capability and reliability and organisational demands require continuous advances creating new complexities. The need for flexibility and transparency of aircraft systems in order for the aircraft systems to cooperate as a team player in unexpected events becomes limited as variations are brought to a minimum and responses are pre-determined; or as noted by Paries (2011), flexibility is being traded for efficiency. The interviews suggest that training today does not adequately prepare pilots to cope with surprise, such as by using scenarios with ambiguous and potentially conflicting information. However, the content of training programmes is carefully regulated and under pressure as simulator time is restricted and the numbers of situations pilots can be exposed to are limited and have to be carefully designed. The initial attempts to model the processes to be further investigated in the project helps frame the scope of the research on how to prepare crew’s for the unexpected. In the next phase of the project, experiments will be carried out in aircraft simulators to further investigate the problem.

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5 REFERENCES


