Experimental Investigation of Flight Crew Strategies in Handling Unexpected Events

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EXPERIMENTAL INVESTIGATION OF FLIGHT CREW STRATEGIES IN HANDLING UNEXPECTED EVENTS

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This paper reports a flight simulation study where airline flight crews were to handle unexpected situations, as part of the "Manual Operations for 4th Generation Airliners" (Man4Gen) EU research project. The analysis of their behaviour combined a cognitive systems engineering perspective with behavioural analysis methods used in aviation industry. Hollnagel's Contextual Control (COCOM) and Extended Control (ECOM) Models are applied to examine the strategies with which the flight crew responded to the simulated events. The outcome of this analysis is combined with the results of industry expert analysis of the actions that flight crew were expected to perform. ECOM illustrates the different strategies applied to handling the situation.

Modern civil aviation has become an extremely safe mode of transport, an accomplishment that can be largely attributed to the application of reliable and advanced aircraft systems. Despite the high levels of automation found in all main aircraft systems, ranging from fuel control to flight control, the flight crew remains to be responsible. In the rare circumstances that automation fails, the crew can be faced with (a chain of) unexpected events and are in those situations expected to respond appropriately. The "Manual Operations for 4th Generation Airliners" (Man4Gen) EU FP7 research project is investigating the risk assessment and decision making strategies applied by flight crews facing an unexpected situation in a modern airliner (see www.man4gen.eu). The project aims to contribute to *short-term* recommendations to the aviation community, to increase the overall resilience of the crew-aircraft system. Cognitive Systems Engineering (CSE) techniques are applied to investigate and better understand the actions, behavioural patterns and strategies of the flight crew-aircraft Joint Cognitive System (JCS). The research question investigated in this paper is: Which strategies are applied by the flight crew to recognise unexpected threats and respond? We will report the results of an experiment that was carried out in a research flight simulator, where twelve flight crews were subjected to a scenario with three unexpected events. Hollnagel's Extended Control Model (ECOM) (Hollnagel & Woods, 2005) is used to identify the difference in strategies applied by the crews, and related to performance measures currently being used in aviation industry.

Background

CSE sets out to investigate the ways in which people work within the applicable context for the work, here the flight crew operating in the flight deck. Studying work practice in an operational setting warrants the main contextual factors to be included in the analysis; factors such as the influence of organizational, as well as cognitive and situational demands (Woods & Hollnagel, 2006). By examining crew behaviour in an operational setting, the identification of interactions between the crew members, as well as with the aircraft and systems are included in the analysis. Within CSE, both people and technical systems are considered as elements collaborating as a Joint Cognitive System, which enables an analysis of how the humans and systems function together. CSE methods analyse the behaviour of this JCS to describe the patterns and characteristics of observable behaviour (Hollnagel & Woods, 2005). In the experiment described here we consider both pilots – Pilot Flying (PF) and Pilot Monitoring (PM) – along with the aircraft automation and systems, as the JCS.

At the core of the CSE perspective is the closed loop relationship between human perception and action, which can be illustrated by both ECOM and the Contextual Control Model (COCOM) sensemaking and control loop (Hollnagel & Woods, 2005). COCOM and ECOM models have been applied in the analysis of human-machine systems – in aviation and beyond (e.g., Feigh, 2010; Kontogiannis & Malakis, 2011; Rankin, Woltjer, Field & Woods (2013) described how COCOM can be applied within the crew-aircraft JCS context. The knowledge and experience of the flight crew form the basis of the interpretation of a situation the crew encounters. Their understanding of the situation is built up from interacting with the cockpit displays and interfaces, as well as the physical cues (noise, vibrations) from the aircraft. This understanding is what the crew's actions and decisions are based on. Their actions, combined with external events, yield useful feedback which modifies the understanding, forming a closed perception and control loop.

The ECOM consists of four parallel control loops, very similar to the COCOM loop described above, where cognition is described as control (Hollnagel & Woods, 2005). ECOM describes the multiple layers of performance of the crew-aircraft JCS, illustrated in Figure 1. We applied this model to examine the distribution of tasks and roles across the crew members and aircraft systems (see more elaborate method description in Field, Rankin & Woltjer, 2014). ECOM can be used to describe how both anticipatory and compensatory control is exercised by the JCS, in this paper primarily in response to an unexpected event in the experiment simulation. As the crew-aircraft JCS responds to the situation, the distribution of activities over the ECOM layers may change. An example of this is how the use of different automation levels affects the crew's actions and interaction with the aircraft.

Method

Experiment

The experiment applied an operationally relevant situation for trained line pilots, and aimed to investigate how the crew deals with an unexpected event. Of particular interest was to study the crew risk assessment and decision making. The scenario included events that crews were unlikely to have encountered during routine training. Events were designed to address the main project goals: automation failure and reversion to manual control; an event that required authoritative decision making; a challenging and ambiguous situation.

The experiment was carried out with a total of 12 crews of line pilots, both captains and first officers – a total of 24 pilots. All crew members were active line pilots or recently retired. Crews were unaware of the events in the scenario, and were instructed to treat the scenario as a normal operational flight. The NLR "GRACE" research simulator was used for the experiment; the flight deck was set-up in a Boeing 747-400 configuration.

The experimental scenario was developed by operational experts within the consortium including representatives from aircraft manufacturers, operators and training organisations. The scenario focused on the final descent and approach phase to an airfield, after a long-haul flight. Three key events in the scenario formed the unexpected events that were being studied. The first occurred during the final approach to the runway – an increase and shift in the wind, destabilising the approach path leading to a go-around. An additional loss of visibility at the decision height would force a go-around if necessary. During the go-around, the second event occurred, which was a subtle failure of the autopilot heading control that would necessitate a reversion to manual control to regain control of the aircraft heading. The third event was a birdstrike during the go-around climb-out that caused a failure of engine 1, and damage to engines 3 and 4. The damaged engines would surge and stall until thrust was reduced on those engines, at which point the aircraft could be stabilised. The crews were free to decide the appropriate response to the failures, and to decide on the course of action – for example returning to the airfield for a landing, or stabilising the aircraft and diagnosing the problems before landing.

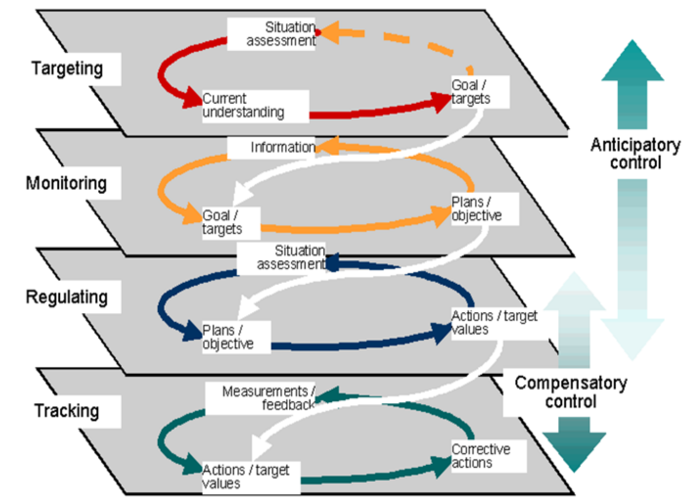
The research simulator was set up to record data for the analysis of the flight crew's actions, decisions and behaviour, including simulator log data, audio and video recordings. At the end of the experimental scenario, the flight crew were debriefed by the project researchers. Recordings of the debriefings were transcribed, and contributed to the analysis. The crew's communication and actions were captured during the analysis by transcribing the video and audio recordings.

The data used in the COCOM/ECOM analysis presented in this paper consisted primarily of the observation log, video data (of the cockpit, flight crew and displays), and audio recordings from the flight deck and debriefing interviews. Performance of the crews as compared to expected actions and decisions was rated by three industry experts, to determine the crews that exhibited desirable and undesirable behaviour. The performance ratings were an account of the decisions made and actions taken as either carried out or not carried out.

Analysis

For the description of the degree and kind of control that the crew-aircraft JCS displayed during the simulator session, the COCOM and ECOM models were translated to an operational context for classification of the observations from the experiment. The ECOM was used to classify the behavioural patterns, and the COCOM was applied to assess the degree of control.

To operationalise the ECOM, the four layers - Targeting, Monitoring, Regulating and Tracking - have been defined through the experimental data and context of the crew-aircraft JCS, as described in Figure 1. Assigning the observations to the different layers was done through an iterative process of classifying the observations based on the theoretical descriptions of the ECOM model (Hollnagel & Woods, 2005). Dataset from two crews were used to develop the classification scheme using three independent raters. This classification scheme was documented and extended iteratively reaching full inter-rater consensus while being applied to the remaining datasets.



Extended Control Model	ECOM layer	Activities in flight context
	Targeting	Setting and resetting high-level goals of what may happen in the future
	Monitoring (planning)	Carry out monitoring and planning actions, where is the A/C going to be and how it is going to get there.
	Regulating	Executing the tasks as part of the plan that has been put together in the monitoring layers.
	Tracking	Actions that have a direct impact on the A/C control surfaces, direct effect on the A/C behaviour

Figure 1. The Extended Control Model, ECOM (Hollnagel & Woods, 2005), with activities described in a flight context.

Patterns of activities in relation to context were classified according to the four ECOM layers were identified, for a selection of flight phases/segments and crews: Engine management (after birdstrike); Trajectory management (second approach after Go-Around) to landing; Manual reversion (after HDG failure).

The COCOM classification scheme describes the degree of control that the crew-aircraft JCS has in a specific time period of performance. A classification of the control mode (strategic, tactical, opportunistic, scrambled) per flight phase was made using the literature definitions proposed by Hollnagel & Woods (2005), based on three parameters: (i) subjectively available time; (ii) evaluation of outcome, and (iii) selection of action. These were assessed by two of the project researchers that also performed the ECOM classification.

Results

This paper reports the trajectory management (second approach after Go-Around) flight phase analysis, and focuses on the broadest variability of performance between the crews – using 6 crews to illustrate the differences. The ECOM classification was used to identify patterns of observed performance within the ECOM layers. Then the subjectively available time, kind of evaluation of information, and what information was used for the basis of decision and action were assessed, from which a COCOM control mode was identified. The industry expert ratings of the crew performance were related to the ECOM and COCOM results in the sensemaking analysis, as a rough indication of how the crew performed against the key actions expected for specific moments in the scenario. These 6 crews - the top and bottom 3 performers (as rated by the industry experts) - illustrate a description of the ECOM control strategy and COCOM control mode for the activity of performing the second approach, i.e., flying the approach to landing after the go-around and birdstrike. Results are illustrated in Table 1, which includes the percentage of the score that the industry raters assigned to each crew out of the maximum number of performance events related to this specific activity. The trajectory management activity is to a large extent concurrent to the activity of engine management, thus, prioritization that the crews did between the two activities was included in the analysis of control modes.

Table 1. *Analysis results for trajectory management assessment and decisions.*

Crew	ECOM strategy	COCOM control mode[1]	Performance %
6	Evaluation, double check, actions follow through across levels	Strategic/tactical	75
10	Prioritize evaluation and problem solving, actions, risk assessment and evaluation. Take time.	Strategic > tactical	75
11	React and extend planning horizon, buy time	Tactical > Strategic	75
5	Identify & assess, consider alternatives in plan and execution, prioritize flying	Tactical (opportunistic)	38
12	Actions without prior evaluation, information not discussed	Scrambled (opportunistic)	13
4	No discussion, limited evaluation, aim to land	Opportunistic (scrambled)	0

In general, higher performance (according to industry performance rating definition and scoring) seems to relate to patterns where there is interaction between the ECOM layers of Targeting, Monitoring, Regulating, and Tracking. Most activities are triggered as part of procedures or checklists at the monitoring/planning layer and then subsequently discussed between the crew at the regulating layer; decisions for actions are made, and finally implemented at the regulating and/or tracking layers. If, on the basis of feedback and evaluation, minor adjustments need to be made by the crew to the execution of the plan; this is then done at the regulating layer. If the trajectory needs to be changed to reach the same goal of the flight, these “flight plan” changes are discussed and decided at the monitoring layer, while higher level goals and prioritization (e.g., runway, alternate airport) is done at the targeting layer. Thus, if there is a regular and frequent interaction between the activities at the various layers of control, performance tends to be of a better quality. For these complex events crews are required to act simultaneously at multiple layers, determining strategies for multiple activities.

The ECOM layers analysis shows that crews with less desirable performance tend to have difficulties in the follow-through and follow-up in the interactions between the layers. For example, if monitoring/planning decisions and observations are not lifted to the targeting layer when necessary , important considerations regarding choice of runway, and consideration of alternate, and other trade-offs and prioritization of goals may be disregarded. This in turn may lead to lower-layer activities that could be better adjusted to situational circumstances if they would be evaluated and reoriented by higher-layer activities, but instead continue to execute plans that are not well-adjusted to circumstances.

Though this ECOM/COCOM analysis was applied in an experimental setting, it is possible to apply the method to understand how crews respond to events – in a training session for example. Identifying the behavioural patterns would help instructors to understand the

[1] Mode 1 / Mode 2 means characteristics of Mode 1 and 2, roughly to the same extent. Mode 1 > Mode 2 means first mostly characteristics of Mode 1, then mostly of Mode 2. Mode 1 (Mode 2) means mostly characteristics of Mode 1 with characteristics of Mode 2 to a minor extent.

performance of the crews, and identify how crews can be assisted in the ways that they develop their decision making and problem solving strategies.

Conclusions

COCOM and ECOM classification schemes were applied in an operational context for the cockpit environment of the NLR B747 experiment. This operationalization should be seen as a result of the study as this is (to our knowledge) the first application of COCOM/ECOM to a cockpit environment. In general, higher performance (according to industry performance rating definition and scoring) seems to relate to patterns where there is interaction between the ECOM layers of Targeting, Monitoring, Regulating, and Tracking. Crews with less desirable performance tend to have difficulties in the follow-through and follow-up between the interactions between the ECOM layers. The analysis contributes to an in-depth understanding of crew actions anchored in an operational context as well as an academic understanding of CSE contextual control concepts.

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