Exploring Changes in Pilot Behaviour during Distributed Crewing

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Abstract. Changes to crewing configurations in commercial planes are likely to emerge as a means of reducing operating costs. An exploratory study was conducted whereby two pilots with commercial experience enacted a normal and emergency flight scenario in a simulated flight deck in two conditions: 1) co-located crew, and; 2) distributed crew. Operational Event Sequence Diagrams (OESDs) were created to represent pilot actions and interactions to explore how pilots' behaviour changed during distributed crewing. Extracts of OESDs are provided to illustrate similarities and differences, and the implications for the future flight deck are discussed.

Keywords. Distributed Crewing; Behaviour Change; Operational Sequence Diagrams; Aviation

1. Introduction

Crew costs are a significant proportion of overall operating costs in commercial aircraft, accounting for up to 35% for small aircraft, and 19% for larger aircraft (Alcock, 2004, EasyJet, 2013 cited from Harris et al. 2015). The term 'distributed crewing' is used in this paper to describe when a sole pilot in the cockpit (P1) operates an aircraft in conjunction with a second pilot on the ground (P2), in place of two pilots co-located in the cockpit. A distributed crewing configuration could have the potential to reduce crew costs when high workload phases of flight (e.g. take off and landing) are staggered such that the pilot on the ground is able to 'co-pilot' multiple aircraft. Cost for commercial airlines (rather than freight) is an insufficient driver for changes in crewing configuration unless an equivalent or enhanced level of safety can be demonstrated. Whilst the Germanwings Flight 9525 crash resulted in the European Commission reinstating the 'rule of two' demanding two crew must always be present in the cockpit (http://ec.europa.eu), Harris et al. (2015) put forward that being able to control the aircraft from the ground may lead to enhanced, not reduced levels of safety. The authors believe an important step when considering safety with an alternate crewing configuration, is to understand how pilots' behaviour may change, so adjustments to technology and Concepts of Operation (ConOps) can be altered to mitigate any risks. Strategies for mitigation may also inform improvements to safety that could apply to current operations in dual 'co-located' crewing. Evidence of the impact on pilot behaviour during distributed crewing with present day technology and ConOps, is scarce in the literature, prompting the focus of this paper.

Harris et al. (2015) argue that OESDs provide a simple yet rigorous basis upon which allocation of work can be assessed. They demonstrated the utility of OESDs for scenario-based analysis of the number and type of functions between 2 pilots during take-off. They illustrated how advanced automation could enable single pilot operation by reducing the functions assigned to the pilot. This paper describes and exploratory study that is seeking depict functions and interactions undertaken with existing ConOps and present day technology (rather than advanced automation).

OESDs graphically use standardized symbols to depict the activity and interaction between teams of agents in a system. This makes them particularly useful for analyzing distributed teamwork or collaborated activity (Stanton et. al, 2013). OESDs were used to provide a 'baseline' of the functions undertaken by, and interactions between, pilot 1 (P1) and pilot 2 (P2) when co-located in the cockpit during a normal and emergency scenario (take off, and engine failure after take-off (EFATO)). OESDs created for P1 and P2 when undertaking the same flight scenarios during distributed crewing were used to highlight similarities and differences in behaviour from this baseline to gain insights into how pilots may respond to distributed crewing.

2. Methods

2.1 Participants

Pilot 1 was a male First Officer male from a major international airline company with 10,000+ flying hours. Pilot 2 was a female former commercial co-pilot with 900 flying hours. The pilots had not met prior to the study.

2.2 Setup

Microsoft Flight Simulator X: Steam Edition (FSX) was run on a flight simulation PC (Processor: Intel Core i7 4790k, Memory: 32GB Corsair Vengeance Pro 1866MHz, Graphics Card: Gigabyte G1 GTX 980 Ti, SSD: Samsung 850 Pro) with 3 LG 23" IPS LED monitors each to provide a extensive outside view. Participants were given a Trust GXT 340 Headset for sound and microphones and had access to a standard English keyboard and mouse. Aircraft controls comprised of Saitek X52 Pro Flight controls and Saitek Pro Flight Rudder Pedals. The aircraft used throughout the study was the Boeing 787-800 Rolls Royce Dreamliner. Mumble software was used for voice communications and ShareX software was used for screen capture. A video camera mounted on tripod was used to capture pilot behaviour. In the co-located crew condition, participants were located side-by-side in the same room in a university building to reflect the proximity of a typical cockpit, allowing visual non-verbal communication and the capacity to monitor each others physical actions and general demeanor. To evoke the conditions of distributed crew, where communication would be limited to voice over microphone without visual presence, the participants were separated in different rooms on different floors of a university building.

2.3 Procedure

Prior to the role-play, both pilots were walked through aircraft generic OESDs for current operations relating to the scenarios under examination. This orientated them to the expected functions and interactions for P1 and P2, providing an opportunity to discuss any specific procedural differences from their own commercial experience. Next, they were provided an opportunity to familiarize themselves with the simulator environment during a normal phase of flight. This also provided the opportunity for the pilots to get a feel of each other's abilities. Both scenarios (normal take-off and EFATO) were run in the co-located crew condition, then repeated in the distributed crew condition, with a short break in-between whilst the equipment was being moved. Following completion of the scenarios, both pilots were asked to give feedback on their experience.

2.4 Analysis

The screen capture data was synched with the audio data as a data source for creation of OESDs, enabling communication and setting changes to be observed. Standard symbols from MS Visio were used to depict the activities as recommended by Stanton et al. (2013). The columns were labeled 'P1' to represents the role played by the captain, and

'P2' for the role played by the co-pilot or ground pilot. Whilst Harris et al. (2015) labeled their OESD columns to represent 'pilot flying' and 'pilot monitoring' this was less appropriate for our analysis as the task of 'flying' or 'monitoring' role swapped between pilots at different stages of the flight. Depiction using P1, P2 to represent human agents was found to be easier to depict and clearer to understand. Rectangles were used to represent communication between pilots. For the purpose of more granular analysis different line-styles were used to represent domain specific categories of communication (e.g. solid line for a verbal exchange, and a dashed line for 'confirmation/cross-check'). The slanting quadrilateral was used to depict an interaction between the pilot and the aircraft interface (touch screen input, switch array etc.). Standard flight control actions (e.g. roll, pitch, yaw and normal throttle use) were not included as they were considered to be continuous. The OESDs were printed out and similarities and differences between crewing configurations highlighted. The video data showing pilots interacting with the simulator setup was used to better understand non-verbal behaviour of pilots (such as glancing over to check on the co-pilot) to gain a richer understanding of the differences identified.

3. Results

In the normal take off scenario, take off was successful in both crewing conditions and the aircraft was brought to cruise conditions without incident where after-take off checklist was performed. In the EFACTO scenario, the plane was turned around and safely landed back at the departure airport without further incident in both crew configurations. In both scenarios and both crewing configurations, the correct checklists were performed, judged by similarity to the aircraft generic OSEDs previously constructed and validated by two separate SMEs.

3.1 Similarities in behaviour in different crewing configurations

During EFATO, very few procedural items changed between crewing configurations. During normal take off, in the initial stages very little difference was observed and the resulting OSEDs were identical for different crewing conditions both in terms of the order and content of communications and actions between P1 and P2 (see figure 1).

3.2 Differences in behaviour in different crewing configurations

The most significant differences between crewing configurations were observed during normal take off, rather than EFATO. A section form the OESDs illustrating some of these differences are depicted in Figure 2. After the initial stages, in the co-located crew configuration, P1 calls for the flight director to be turned on and P2 undertakes this action and responds verbally as a confirmation. P2 continues to give commands that are enacted and verbally checked by P2, culminating in the Autopilot being turned on and verbally confirmed by P2 (see figure 2, left 2 columns). In the distributed crew configuration, P1 calls for the Auto Pilot to be turned on prior to making adjustments in the flight director. Whilst P2 undertakes this action, P1 vocalizes the check when the action is complete. P1 then continues to call and enact turning on the flight director and inputting headings into the Mode control panel (MCP). P2 then vocalizes the check when the action is completed (see figure 2, right 2 columns). Another example of where procedure differed during normal take off was during checklists. When co-located, the checklist was conducted automatically by P2 without confirmation from P1. During distributed crewing P1 called for the appropriate checklist and P2 called the items whilst enacting them, with P1 confirming each item. During EFATO the only key differences in procedure were P1 engaging Autopilot far earlier in distributed crewing configuration than with co-located crewing, and performing an additional confirmation when moving the fuel control switch to cut-off, requiring P1 to physically look away from the Primary Flight Display (PFD) to check the setting.

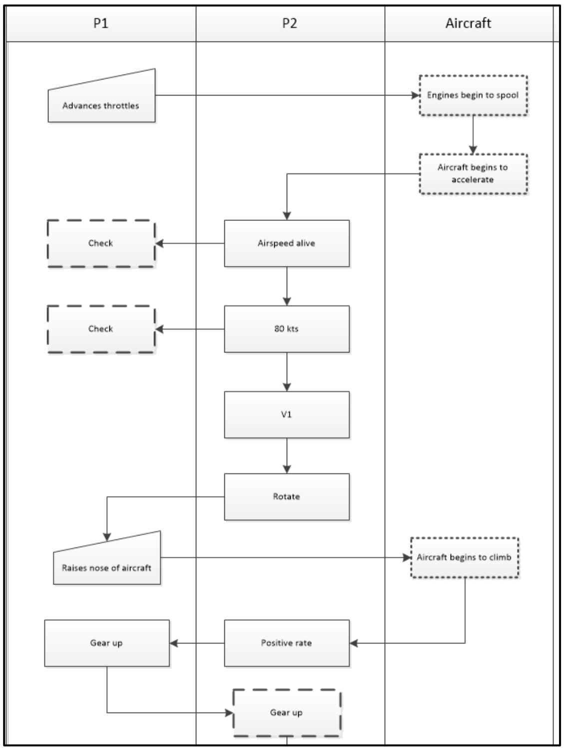

Figure 1 - Excerpt from OESD showing constant pilot behaviour in different crewing configurations during first stages of normal take off

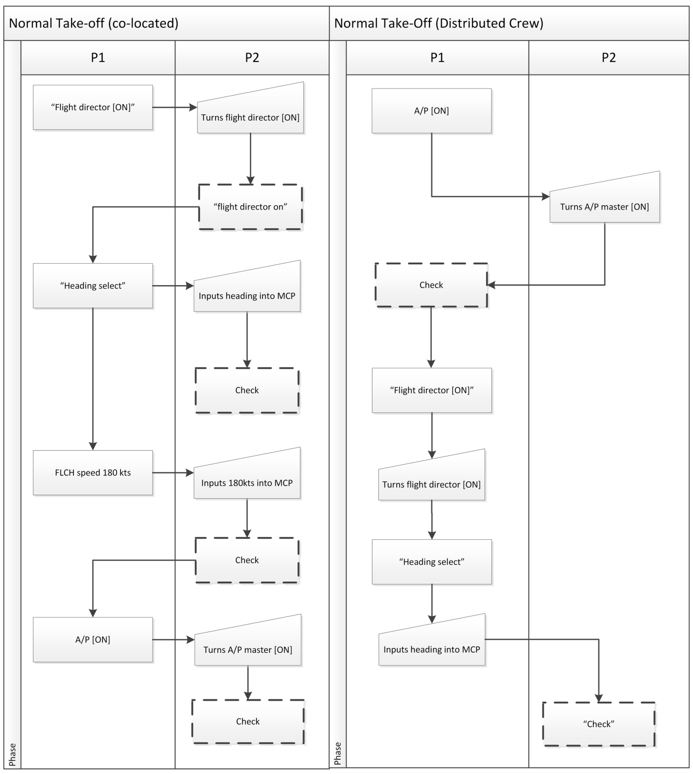

Figure 2 - differences between pilot behaviour during normal take off in different crewing configurations

4 Discussion and Conclusion

To interpret the similarities and differences between OESDs the authors drew upon the feedback provided by P1 and P2 after performing the scenarios as well as the video data showing pilots interaction with each other and the simulator environment including non-verbal behaviour. The recurring theme in differences in interaction seemed to step from P1 not able to access non-verbal information from P2. During the early stages of normal takeoff the procedures consist solely of "memory items" (i.e. the speed calls at 80/100 knots, V1 and rotate, the "airspeed alive" and "positive rate [of climb]" checks and the "Gear-up" action). These items, having been committed to memory by pilots during training are expected to be highly familiar to both pilots. Trust that actions would be enacted as expected was seen from the lack of additional verbal confirmations that were evident elsewhere.

The differences shown in figure 1 whereby P1 took over inputting the flight director after first getting P2 to turn on autopilot could be interpreted in terms of P1 adopting behaviour as if flying single pilot. By setting autopilot on first, P1 was free to concentrate on inputting headings without flying the plane. His decision to take control of this rather than call for P2 to do so may have been a desire to make sure this was done correctly and efficiently. This may have been due to a lack of trust in the technology that the setting could effectively be set from the 'ground', or perhaps the inability to 'look over and check' that the actions were being performed as requested. This analysis was bourn out when comparing the verbal confirmations during checklists. Video data showed that in the co-located crewing configuration, P1 watched P2 action the checklist items and chose not to provide a verbal confirmation. During distributed crewing, P1 confirmed each item called by P2.

During EFATO in distributed crewing, P1 deemed to engage the autopilot from the start. As the participants were aware that the scenario was an emergency (having previously enacted EFATO when co-located) this behaviour could again lead to P1 feeling the need to reduce his task workload during distributed crewing, to be effectively respond to the additional operational effort to respond to EFATO this in what may have felt like a 'single pilot' configuration when P2 is not visible. An alternate interpretation is that they anticipated more attention to be diverted to completing checklists through, for example, additional confirmations, that would have had an impact on aircraft handling. This was not borne out in the OESDs however and further studies would be needed to establish the intentions.

Figure 1 clearly shows the response of P1 was to take on a larger number of actions in the distributed crew configuration, ultimately increasing task workload (Janis, 1973). Additional checks and confirmations between P1 and P2 in the distributed crew configuration point to additional communications, further contributing to workload at a team level. High workload is known to contribute to errors, reduced performance and stress (Harris, 2011, Moray 1988, Sharit and Salvendy, 1982). Evidence of errors or a drop in performance levels was not observed in this exploratory study. A further study with larger numbers of participants is needed to establish the generalizable impact on these factors, to determine the focus for mitigating designs, ConOps and automation. Additional confirmations suggest that reduced non-verbal behavior impedes shared situational awareness of the state of the aircraft and actions undertaken by each crew member. Further analysis considering differences in team situation awareness (SA) (Endsley, 1995) and distributed SA (Stanton et al., 2006) is necessary. This work was undertaken as part of a project sponsored by Innovate UK.

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