TASK ANALYSIS OF TWO CREW OPERATIONS IN THE FLIGHT DECK: INVESTIGATING THE FEASIBILITY OF USING SINGLE PILOT

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This paper describes a task analysis of two crew operations in the flight deck in Part 121 Operations from gate to gate on a cross country flight. In addition, several non-normal scenarios were analyzed. Literature and operations materials were combined to develop the task lists. A primary source for this study is "An Exploration of Function Analysis and Function Allocation in the Commercial Flight Domain" by McGuire, et. al. (1991). Once the tasks were identified, they were set to an actually flight time schedule. Each task was assigned to either the Pilot Flying (PF) or the Pilot Monitoring (PM) in today's operations. Additionally, tasks were categorized as: discrete or continuous; heads up or heads down; simultaneous with other tasks or performed serially; and whether any tasks are redundant.

Introduction

Whether space, ground, or sea, whether military or civilian operations, automation is enabling the reduction of humans required to perform a task. While self-driving cars are currently most prominent in the headlines, efforts in commercial aviation and in military aviation to reduce personnel in the air and on the ground are marching forwards. In 2013, the National Aeronautics and Space Adminstration investigated reducing the flight crew on aircraft in Part 121 operations from 2 to 1. In the military, concepts of operation such as the Optionally Piloted Vehicle in the Future Vehicle Lift Army aircraft are looking to allow a two-, one-, or zero-crew complement to perform different pilotage and mission duties in a single aircraft platform. The Army's Synergistic Unmanned/Manned Intelligent Teaming effort looks to allow a single human mission commander to manage many unmanned and manned aviation assets during a mission.

What is the role of the human in the midst of all this automation? What is the best way to integrate increasing automation into current operational environments? The first step in answering these questions is understanding the role that the human and the automation currently hold. The study described in this paper begins to better understand these roles. Part 121 operations (see FAA 14 CFR Part 121), is a well documented operational environment that is covered extensively by government regulations, aircraft and avionics manufacturers' procedures, and operators (e.g., airlines, cargo handlers) procedures. For this reason, and because the commercial market is looking for ways to reduce crew complement, the Part 121, two-crew operations was the subject of this study.

The goal of this study was to enumerate all of the flight tasks currently conducted by the Pilot Flying (PF) and by the Pilot Monitoring (PM) in today's operations. They included whether the tasks are discrete or continuous, heads up or heads down, simultaneous with other tasks or performed serially, and whether any tasks are redundant.

To achieve this goal, literature and operations materials were combined to develop the task analysis. One source is worth mentioning here in the introduction since it provided the bulk of the material and served as the starting point for task list development. This is the report entitled, "An Exploration of Function Analysis and Function Allocation in the Commercial Flight Domain" by McGuire, et. al. (1991) This report provides a lengthy and detailed task description at a fairly low level of granularity, without being specific to any particular aircraft. While this report was created in 1991, it still reflects most of what goes on in the modern flight deck. In addition, the "USAirways Boeing B757//767 Pilot Handbook" (2006), Transport Canada's "Multicrew Aircraft Standard Operating Procedures" (Transport Canada, 2014) the Aeronautical Information Manual (FAA, 2008), and a task analysis of approach and landing (Leiden, 2002) were also used in creating the task analysis.

Four attributes were used to categorize each task in the task analysis. The first attribute was task duration: discrete or continuous. The second attribute was whether the crewmember performing the task had their 'heads-up' (looking at primary flight displays and/or out the window) or 'heads-down' (e.g., programming the FMS, tuning radios, dealing with systems). The third attribute was the type of task being performed: doing (e.g., select, retract, modify), communicating (e.g., talking or listening to ATC), observing (e.g., scan, monitor), or cognitive activity (e.g., evaluate, consider, compare). The fourth attribute assigned a mission management category (aviate, navigate, communicate, or manage systems) to each task.

Despite the thoroughness of these documents, there are still aspects of flight crew tasks that were not covered. These are cognitive aspects of a crew's duties, managing automation (automation is generally assumed to be fully functional), task management, and monitoring the other crew member.

Flight Crew Roles in Part 121 Operations

A two-person crew consists of a Captain and a First Officer. The Captain is the final authority in the flight deck and responsible for the flight and the First Officer is second in command. Two crewmembers on the flight deck provide redundancy, workload distribution, and increased monitoring (including monitoring each other). Prior to moving the aircraft from the gate and after the aircraft is parked at the gate, duties and tasks are assigned specifically to the Captain or the First Officer. Once the aircraft starts to move on the ramp, one crewmember will take on the role of Pilot Flying (PF) and the other that of Pilot Monitoring (PM). These roles are not assigned specifically to the Captain and First Officer (e.g., the Captain can be the PF or the PM) but at least one and only one of the crewmembers must be designated as PF. The PF is responsible for operating the controls for taxiing on the ground, and operating the flight controls (either manually or through automation) in the air. The PM is responsible for handling communications, monitoring the PF, assisting the PF where needed, and monitoring the overall situation of the aircraft. In addition, the PM generally handles systems management and contingency management.

Results

The first step was to develop a timeline of crew tasks. A flight plan from LAX to JFK was created for a midsize passenger jet. The flight phases were broken down into three segments: Departure, Cruise, and Arrival. Obviously, a significant portion of that is taken up in cruise (nearly 5 hours). During cruise, the duties were fairly constant and the number of tasks was relatively low. Based on the roles and responsibilities defined in the handbooks and operating procedures, tasks were assigned to either the pilot flying (PF) or the pilot monitoring (PM). In addition, several system failure contingencies were evaluated. Not surprisingly, the task load is very high during the departure and arrival phases of flight and relatively low during cruise. The PF has a significantly greater number of tasks than the PM. This is due to the fact that the PF is responsible for the closed continuous monitoring, evaluating, and managing of all flight parameters. Over a normal flight, the maximum number of tasks at a given time for the PF is 22, for the PM is 18. The maximum combined (both PF and PM) tasks occurring at the same time is 37. All of these maxima occur during departure. The maxima during arrival are 16 for the PF, 12 for the PM, and 27 for the combined tasks. The average combined tasks are 19, 16, and 15 across departure, cruise, and arrival, respective.

Task Categorization

For an additional perspective on what the crew members are doing, the tasks were categorized based on a number of factors: Verb type, Contiuous tasks, Mission Mangement type, and Heads Down tasks.

Verb Type. This perspective on task type has to do with the type of verb that the crewmember is performing – DOING, COMMUNICATING, COGNITIVE activity, or OBSERVING. All the verbs were placed into one of these four categories. There were 33 verbs in the DOING category and they consisted of verbs such as activate, select, configure, and open. There were 10 verbs in the COMMUNICATING category and they consisted of verbs such as report, request, announce, and acknowledge. There were 8 verbs in the COGNITIVE category and they consisted of verbs such as compare, consider, evaluate, and compute. There were 6 verbs in the OBSERVING category and they consisted of verbs such as monitor, detect, scan, and identify. The PF had nearly 300 DOING tasks, compared to a little over 100 for the PM. The PM had all of the approximatly 150 COMUNICATING tasks. The PF had approximatly 150 COGNITIVE tasks, as opposed to the PM's count of about 35. Finally, the PF had almost 200 OBSERVE tasks, while the PM had about 175.

Continuous Tasks. It is interesting to note that there were only 8 OBSERVING verbs in the previous categorization. However, the total number of OBSERVING tasks in a flight are second only to the DOING tasks. The reason for this is that OBSERVING tasks are contiouous for both PF and PF throughout the flight. Whereas some tasks are discrete and may only be performed a few times throughout the flight. To further explore this phenomena, the tasks were categorized into Contiuous and Discrete. Continuous tasks are those that the crewmember is supposed to constantly be monitoring/controlling. Some may actually be truly continuous such as manual control of the wheel and column. Most are intermittent such as a scanning pattern over a number of instruments. During the Departure phase of flight, nearly 60% of the PF's task are contiuous vs. 8% of the PM's tasks. While the total number of tasks decreases during the Cruise phase, over 80% of the PF's tasks are contiuous while the just over 40% of the PF's tasks are

continuous. The Arrival phase reflects the Departure phase with the PF having over 40% continuous tasks and the PM having 8% again.

Mission Management Tasks. Tasks were also categorized according to the traditional mission management categories of Aviate, Navigate, Communicate, and Manage Systems. Not surprisingly, the PF has the lion's share of the Aviate tasks (~500) and Navigate tasks (~140) verses the PM's ~50 and ~20, respective. The reverse is true for Communicate and Manage Systems tasks where the PM has ~100 of each and the PF only has less than 10.

Heads Down Tasks. Both PF and PM are responsible to maintaining situational awareness regarding the flight. The PM is valued for being a second set of eyes outside of the cockpit to avoid obstacles and to identify hazards. Many tasks are called 'heads down' because they take the crewmember's focus away from the outside world and focus them on instrumentation and documentation in the cockpit. Heads down tasks do NOT include viewing the Primary Flight Display or the Navigation Display. Again, not surprisingly, very few PF tasks are heads down during any phase of flight. However, for the PM, nearly 50% of his or her tasks are heads down during departure, 80% during cruise, and 70% during arrival.

Contingencies

Contingencies. When a contingency or non-normal occurs, the crew task load not only increases, but some of the assignments shift from one crewmember to the other. Examples of these situations are system degradations or system failures, extreme weather, onboard emergencies, and fires. In these cases, the PM has a significant increase in the number of tasks. Non-normal checklists are almost exclusively performed by the PM. In these contingencies involving system failures, the PM will have an average of 30 additional tasks. In general, if multiple contingencies occur, these tasks are cumulative. For example, if an engine fire requires an emergency landing, fuel may need to be dumped if the aircraft is too heavy to land. Similarly, if all engines are inoperative, then it is likely that the loss of all generators checklist will be required (or the APU start). The PM's task workload can increase significantly. In these cases, the PF often takes over some of the PM's tasks such as communicating with ATC or dispatch. Not surprisingly most of these tasks that are assigned to the PM are heads-down. Because the PF assumes some of the PM's duties, there is an increase in the PF's heads-down time as well.

Discussion

Automation Issues and Opportunities

The question of what tasks and functions to allocate to the automation and what to allocate to the human – especially when looking to decrease the crew complement – is does not have an easy answer. Automation is quite amenable to repetitive, precise, deterministic, and long duration tasks. Similarly, any task that involves computations, memory (declarative, retrospective, prospective), or vigilance is probably best performed by automation instead of the human pilot. It is tempting to consider simply removing a crewmember and all the associated tasks that go with that role. This is essentially what occurred when commercial flightcrews

replaced virtually the entire role of the flight engineer in the 1980's. However, the results of this study suggest caution in this approach.

Replacing the PM. The PM has a relatively low task count and based on this, it may seem easier to replace the PM. However, when contingencies occur, the PM is crucial. Humans have a unique capability for dealing with contingencies, especially when multiple contingencies occur. It is difficult to program automation for all contingencies. In addition, communications tasks are often best handled by humans given the vagaries of communication that will still exist if there are any humans in the loop (e.g., air traffic control, tactical operations center).

Replacing the PF. The PF has a number of factors that make that role attractive to automate. A majority of the PF's task are continuous tasks that involve, amoung many things, monitoring and observing. But humans are not good monitors when it comes to highly reliable systems (Parasuraman, 2010) and automation is excellent when it comes to continuous tasks that involve vigilance. Also, automation is quite capable of handling the DOING verbs and the PF performs an overwhelming percentage of those DOING tasks. The problem with replacing the PF is that it is a common understanding that some human is always responsible for 'flying the aircraft' (Wiener, et al, 2010). The human has qualities of personal responsibility and a strong will to live that automation does not posess.

Recommendation – New Roles for Humans and Automation

Rather than attempt to replace either the PF or the PM, it is likely that a new role be created for a single pilot and that the automation complement that role (Schutte, 1999). This is because human skills are necessary for some aspects of both the PF and PM's jobs. Creativity, situation awareness, responsibility and accountability are required in both positions. A new role should be defined for the pilot in the flight deck - perhaps a moniker of Pilot In Command (PIC). The pilot would be in command of all the automation resources. The PIC could safely say to the automation, "You two have got the airplane, while I look into why this checklist hasn't solved the problem," and rest assured that the automation will let the PIC know if there is any problem. However, the PIC could also intervene and 'manually fly' the aircraft. The PIC can take control of a difficult to handle aircraft (e.g., United 232 (NTSB, 1990)) and concentrate on flying and let the automation handle basic checklists. The PIC will remain the "last line of defense" for aircraft problems. And the automation must support that role.

The PIC concept requires that the PIC can perform a variety of tasks, can dynamically allocate tasks to the automation, and can easily do so. This represents a new design challenge that is more formidable than designing for two crew operations. Currently, the PF and the PM hand off tasks to each other with relative ease, knowing that the other crewmember is just as capable of performing those tasks and is just as situationally aware. There are likely to be significant differences in capability and situation awareness between the pilot and the automation. Protocols and procedures will need to be created for allocating tasks while ensuring that 'someone' is always flying the airplane. One way of viewing this design challenge is to consider it as CRM between two agents – pilot and automation. Interfaces and procedures will need to be developed to enable inter-agent communication, leadership and command, and decision-making. Automation is not especially communicative in the CRM sense, and ground

support must communicate through the bandwidth 'keyhole' that can constrict communications. The SAFEdeck design approach (Schutte, et al, 2017) represents an attempt to design such a flight deck. SAFEdeck uses a single inceptor for both flying the aircraft and interacting with the automation so that the PIC can easily transition between high autonomy and low autonomy.

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