Functional Requirements for Onboard Intelligent Automation in Single Pilot Operations

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There is growing interest in the concept of Single Pilot Operations (SPO) within commercial flight operations due to the potential economic benefits. Prior research has focused on architectures and safety concerns related to SPO, but has not examined what functionalities automation would need to fulfill in the replacement of a co-pilot. Through guided interviews conducted with experienced commercial airline pilots, this effort demonstrates what functionalities would need to be replicated by an on-board intelligent system. These interviews revealed both desired and potentially deficient qualities of co-pilots, providing some guidance into how automated systems could be designed to best replace current human co-pilots. The interviews also provided perspectives about the issues of pilot selection and training, and the social implications of the use of an automated system in the cockpit rather than a human co-pilot. Given the results from the interviews, we developed a list of a dozen functionalities and capabilities that an onboard intelligent system should be able to replicate in order for a single human pilot to be able to manage the workload in piloting an aircraft in transport missions.

I. Introduction

FOR the last 10 years, there has been growing research in a concept of flight operations known Single Pilot Operations (SPO), which is focused on reducing the commercial cockpit to a single pilot from the current crew of two pilots. NASA Ames and NASA Langley have spearheaded this effort in the United States[1], but DARPA is also interested in this problem[2]. Internationally, researchers in the UK have also been exploring this possibility[3]. The European low-cost airline Ryanair has publicly asserted it would like SPO on short haul flights, and the Brazilian aircraft manufacturer Embraer has announced it wants to provide single-pilot capabilities in roughly 10 years[4].

Reducing the crew in the cockpit, both commercially and in military aircraft has a long history since the WWII era where transport aircraft could have as many as 5 people in the cockpit. The reduction from 5 to 2 over the past 70 years is due to advances in digital processors, avionics, control augmentation including automated flight control systems and cockpit design including glass cockpits[5]. In the current cockpit crew of 2, there is a Captain and a First Officer (FO). These crewmembers assume the roles of Pilot Flying (PF) and Pilot Monitoring (PM), which can switch between the two throughout the flight. In SPO, it is anticipated that only the Captain position will remain as a sole human in the cockpit. The FAA's stance is that there is no apparent safety benefit to be gained from single-pilot operations, largely driven by the risk of pilot incapacitation. Such occurrences are very rare but do occur and how to ensure safe operation in this case will be a significant hurdle in any SPO future approvals[6].

While the safety issues for SPO are yet to be fully addressed, the economic case for SPO is clear. There is a projected increasing pilot shortage through 2022, although the demand will likely be more in Asia and the Middle East[7]. In addition, it is estimated that the aggregate flight crew cost per cockpit seat over a 20-year service life of an aircraft, world-fleet-wide is $6.8 trillion[6] so reducing the need for one seat in a cockpit represents significant cost savings across a fleet of aircraft.

With the Captain as the only physical human presence in the cockpit, one theory for future SPO operations posits that many co-pilot functions will need to migrate to a ground control station. Indeed, research is underway

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investigating ground control strategies for remote assistance[1,8]. Another theory is that significant improvements need to be made in automating the co-pilot's functions on board the aircraft, instead of shifting them externally. A derivative proposed architecture has one pilot in the highly automated cockpit, with onboard personnel serving as a back-up pilot, such as commuting pilots, flight attendants, and flight marshals[6].

Regardless of what such a resultant SPO architecture would look like, which will likely be a combination of the various proposed architectures, it is widely accepted that automation will have to substantially increase in the air and on the ground for such a SPO concept to be successful[1,6]. To this end, substantial co-pilot functions, and even possibly functions currently assigned to the Captain, will be automated in the future.

While previous SPO research studies have looked at various crew-related issues such as task allocation between a single pilot and ground operations[1], and the effects of remote versus co-located communication[9], there has not been a comprehensive functional analysis of those tasks that would need to shift to an onboard automated intelligent system, along with the systemic impacts that such a shift would have. This study addresses this gap by interviewing experienced current commercial pilots, with responses categorized by major themes including automation in the cockpit, training and personnel selection, attributes of effective and poor co-pilots, and the social costs of SPO. We then translate these comments into design requirements that will need to be incorporated into an onboard intelligent autopilot that replaces the co-pilot.

II. Method

Eleven commercial passenger aircraft pilots were interviewed in a guided, open-ended environment, face-to-face with the interviewer. Experience ranged from 8,000 – 22,000 hours. Ten were Captains, and the remaining pilot was a FO. All but one of the eleven had significant military flight experience. Ten of the pilots were male; one of the Captains was female. Aircraft types flown ranged from various Airbus 300 series aircraft, as well as Boeing 737s, 767s, 777s, and MD-80s.

As previously mentioned, under normal flight the roles of PF and PM may switch between the Captain and FO. In this paper, we tried to keep the roles assigned to Captain and co-pilot to reflect the anticipated future SPO architecture, but depending on the task, co-pilot could mean FO or PM.

III. Results

A. Current Automation in the cockpit

Pilots of the Boeing 777 and the Airbus aircraft were overall very impressed with the design and capabilities of current automation. Pilots flying the 777 agreed that they spent about 7 minutes for a typical flight actually "flying" the aircraft, meaning touching the controls. The Airbus pilots stated they "flew" their aircraft about half that time. However, while the pilots would generally not want to operate the aircraft without the automated assistance, they also expressed concerns with the current automation systems.

Several pilots stated that during flight they often asked, "Why is it [the automation] doing that?" thus exhibiting classic mode confusion that has been well-documented in numerous accident reports[10] One pilot said that he did not believe even the check airmen (those pilots that administer pilot certification examinations, known as checkrides) fully understood the system.

Pilots also expressed a concern with being able to understand the capabilities of advanced automation systems of the future. Future systems will likely continue to exhibit increased autonomous capabilities relative to the systems of today, and the pilots indicated they are unsure of what to expect from such systems.

When discussing the future of SPO, several of the pilots recalled an oft-told joke in aviation circles that the cockpit of the future is one with a human pilot and a dog, and the purpose of the dog is to bite the hand of the pilot if he touches anything. This joke was memorialized in a 2010 cartoon (Figure 1).

One problem noted with current cockpit design and increasing automation, particularly on Boeing aircraft, is the seemingly arbitrary nature of what is automated in the cockpit. For example, in the 777 flaps do not automatically position themselves, thus requiring crew interaction, yet this is standard on Airbus and many military aircraft. In addition, many but not all items in an electronic checklist are automatically sensed and set, and it often appears to pilots that there is "no rhyme or reason" for what is or is not automated. In addition, the need to override certain electronic checklist items due to anomalous conditions can also cause a spike in workload.

The group was also in general agreement that complacency is a problem because of the advanced automation in modern commercial passenger cockpits. Several pilots admitted to missing checklists and radio calls as a result, which highlighted the importance of a co-pilot in the cockpit to help combat complacency and boredom.

The last significant comment made in regards to cockpit automation concerned the upkeep for the software that powered the cockpit displays and related aircraft automation. Software upgrades for these systems come approximately every 3 months, making it very difficulty for flight crews to stay on top of the myriad of procedural changes that accompany such upgrades. Such problems have led to failed checkrides for pilots who missed an upgrade notification, according to the interviewees.

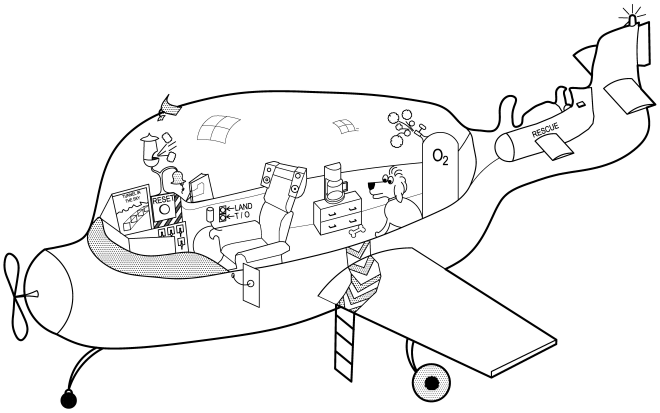

Figure 1. A cartoon depicting the SPO cockpit of the future, complete with a dog to stop the pilot from making mistakes[11].

B. Good vs. Bad Co-Pilots

With the proposition that an automated system could essentially replace a human co-pilot, the participants were asked to comment on which attributes they desire in a co-pilot, which would then be reflected in an automated system designed to assist them. In summary, these attributes were:

- Can become a chameleon and mold to different Captains
- Will respectfully correct the Captain if needed
- Maintains attention to detail
- Anticipates workload
- Remains prepared
- Is fit for the job
- Maintains a good attitude
- Is proactive
- Communicates effectively, including non-verbal communications
- Keeps the Captain out of trouble
- Has in-depth systems knowledge
- Maintains high situation awareness
- Can break up the monotony
- Has excellent procedural knowledge

When asked if a co-pilot ever "saved the day", i.e., if he or she had not intervened, there could have major safety concerns during the flight, specific examples from the commercial pilots included:

- In a descent, the Captain did not react to TCAS (Traffic Collision Avoidance System) and the co-pilot took control to avoid a collision.
- The co-pilot picked up on corrections for clearances that the Captain missed.
- The co-pilot picked up on altimeter settings that the Captain missed.
- The co-pilot was extremely helpful in calling out visual ground landmarks for safe and expeditious navigation.

The commercial airline pilots were also asked to list those attributes that made a bad and/or ineffective co-pilot, which were:

- Apathetic/lazy
- A lack of appreciation for boundaries of roles
- Questioning captain's authority and decisions
- Anti-social
- A poor attitude

- Insists on talking about sensitive topics such as religion and politics
- Offensive
- Poor hygiene
- Problems paying attention

It should be noted that most pilots felt that problems with apathy and bad attitudes stemmed largely from the long length of time some pilots remained in FO status before becoming a Captain. Some of the interviewed pilots spent 20 years or more in FO status and felt that the lack of upward mobility, which affects pay and schedules since they are set by seniority, was demotivating.

Another common theme that emerged primarily from the male pilots was lengthy discussion about the importance of a deferential attitude from FOs. Several mentioned that the younger generation of FOs tended to question the Captain's rationale behind many decisions. The Captains sometimes perceive this as a lack of respect for their authority on the part of the FOs. All of these discussions included caveats that Crew Resource Management (CRM) principles were important, but there was a fine line between good CRM and respecting the ultimate authority of the Captain.

One Captain said that while he socially preferred to have a co-pilot who was friendly and generally fun to be around, he performed better when he flew with a co-pilot who was a bit of a know-it-all, a little annoying and corrected him as needed. This type of co-pilot, who he referred to as a "Bigger, brighter, faster, and farther" co-pilot, kept him on his toes, prevented complacency, and generally improved all around performance of the team.

C. Pilot Selection & Training

Several pilots mentioned that in the 1970s and 1980s, airlines preferred to hire former military single seat fighter pilots because of their prestige as highly skilled pilots. However, since the 1990s there has been a distinct shift away from the single seat fighter pilot preference to hiring pilots with large transport aircraft backgrounds, primarily because of their CRM skill set and ability to be effective team players. Several participants in this study agreed that when former military single seat pilots transition to life as a commercial pilot, they have to learn to slow their pace in the cockpit, and often they need extra training because of their lack of crew coordination skills.

Another issue raised by the pilots is the critical apprenticeship role of FOs, which allows them the ability to observe and learn from Captains. Most agreed that the bulk of learning came from observing mistakes Captains made. Under the SPO paradigm, the efficacy of the apprenticeship model may be limited.

The participants generally thought a pilot needed to spend a minimum of 1-3 years as a FO before transitioning to a Captain role. This apprenticeship period was important not only to learn the aircraft, but also to learn to cope with the eating and sleeping patterns of life on the road. The participants also felt that a significant part of FO on-the-job training revolved around them learning the timing of their interactions with and interruptions of the Captain**.**

D. The social costs of SPO

The participants were asked if they felt their job satisfaction would decrease if they lost the presence of another human in the cockpit. Initial reactions strongly indicated that being the only person would be lonely and their preference was to have another person in the cockpit, especially on long flight legs. But in almost all cases, this initial negative reaction was soon followed by a series of negotiation questions, such as "Can I watch movies?" or "Can I read a book?" Upon reconsideration and with the caveat that as long as they were allowed activities to keep themselves occupied, the pilots generally felt that the loss of the other person was not such a negative concern after all.

IV. Discussion

The statements and concerns of the eleven commercial pilots raise many questions about the future of SPO. There is little doubt such operations are technologically feasible. For example, in January of 2015, a Delta Captain was locked out of the cockpit while on a bathroom break and the FO landed the aircraft on his own, without incident, and on schedule[12]. Indeed, the FAA requires that all commercial aircraft be able to flown by a single pilot from either seat. While this capability is mandatory, how to maintain single-seat operations across all possible flight contingencies is still an open question.

Thus, how to transition the current two pilot crew to a single pilot and maintain safe and robust operations over the broad spectrum of possible contingencies remains the fundamental question. An important consideration is that SPO is not an all-or-nothing proposition. At least initially, there will likely be mixed operations of one and two pilot crews for potentially long and short haul flights. How SPO would affect the relief pilot structure for long haul flights is unclear, and it may be that SPO is first demonstrated on short flights as proposed by Ryanair.

Taken in the aggregate, the pilots in this study clearly communicated the value of the co-pilot as a backup set of eyes and ears. Indeed, the "Pilot Monitoring" function is also one of independent data gathering, assessment, and verification. These are clearly safety critical functions and so therefore cannot simply go away or be absorbed by the Captain.

However, humans are not perfectly reliable in a monitoring role, and it may be that a human pilot/computer co-pilot combination may provide benefits beyond that of a human co-pilot. For example, a lack of positional awareness, arguably a primary co-pilot role, was a leading causal factor for 22% of fatal accidents from 2002 to 2011. Moreover, omission of action or inappropriate action was implicated in 28% of these accidents[13].

Given these statistics, is it possible to design an automated co-pilot that could effectively keep the Captain out of trouble? For example, as noted above, co-pilots are critical in catching clearance mistakes on the part of the Captain. Such an automated co-pilot would need to both listen as Air Traffic Control issues a clearance followed by the Captain's readback and flag any problems, all within an extremely noisy environment. Natural language processing has yet to reliably achieve this capability.

For the co-pilot position to be effectively automated, such a system would also have to be an independent agent to provide safety assurances and not be integrated with the flight control computer of the aircraft. Unfortunately, computer vision and perception cannot yet approach human abilities and the development of an independent system that can replicate eyes and ears as well as assessment and verification is still very much an area of basic research.

Recent SPO research has shown that automation that mimics the characteristics of a "good crew member" can ease the workload of the Captain[1]. Unfortunately, as evidenced by both recent accidents and pilot comments made in this study, mode confusion is still prevalent and could get worse with increasing cockpit automation. And as it would ultimately need to be certified by the FAA, the automation will have to be reliable enough to detect pilot incapacitation and independently land the plane, while also being secure enough such that terrorists could not electronically highjack an aircraft.

In terms of pilot selection, it is not clear if and how pilot selection should change if SPO were to become a reality. Pilots are now selected for their ability to be a team player, but in the world of SPO, would it be better to give priority to pilots with a single-seat background since those pilots are very comfortable in high workload, solitary situations?

However, if the future architecture includes a pilot-on-the-ground scenario, how would CRM change given the remote location of the other human? Poor CRM has been cited as a causal factor in 33 per cent of all fatal commercial jet aircraft accidents[13], so this is clearly an area that would need significant focus for the future of SPO.

Moreover, given the likely increase in automation in the cockpit, it is unclear how CRM training would need to be modified to account for an independent automated assistant/co-pilot. There is a workload cost for the Captain associated with CRM and the coordination of activities with the FO. Moreover, if the focus on CRM is retained for SPO between an automated co-pilot and a human pilot, would certain attributes and characteristics like deference as well as the ability to respectfully correct the Captain need to be imbued in the automation? And how would critical non-verbal communications such as hand gestures and head shaking between two humans be replaced between the human Captain and an automated co-pilot team?

One other training consideration raised by the pilots in this study is the important role of the FO as apprentice. The military has two seat versions of its single seat fighters to provide for both training and evaluation, so one could imagine a future where some commercial aircraft would also have similar configurations. In addition, with the number of cameras that will likely be required to provide monitoring and back up verification, the cockpit of the future will always be recorded from many different angles. As a result, would it then be possible to use these cameras as training aids to help replace the apprentice experience that would be lost in SPO?

The use of these cameras could also address another performance issue related to social facilitation. The removal of one pilot from the crew of two could lead to an environment of underperformance since there is no one to observe the Captain in an SPO setting, potentially leading to higher onset rates of complacency. The use of cameras in the SPO cockpit may provide a similar effect of keeping the pilot on his toes as a watchful co-pilot, but clearly more research is needed to examine this.

In terms of social interactions, it was interesting that initial reactions of pilots were that they prefer the company of another person, but if allowed to entertain themselves through other media, the prospect of a solitary job was not as bleak. In a recent study examining how pilots would perform given one pilot in the air and the other in a ground control station, results showed while pilots preferred to be physically together, there were no significant performance differences[9]. Moreover, past research has also demonstrated that for cooperative tasks with a common goal, there is little impact on performance when communication occurs remotely as opposed to face-to-face[14].

Lastly, the social costs in breaking a long-standing dyad for SPO are not trivial, but are not necessarily negative. Throughout the interviews, repeated mentions were made of morale problems caused by pilots remaining in FO

positions for extended time periods. Moreover, many of the interviewees felt that complacency sets in after about 3 years of the same role in the same aircraft. Assuming that the apprenticeship issues could be solved, SPO operations could help alleviate these problems.

There are other physiologic and social issues that are undoubtedly affected by the difficulties of a job that requires constant travel and long periods of time away from home. Airline pilots and flight crews are twice as much at risk of melanoma as compared to the general population[15] and issues with fatigue and circadian rhythms are well-documented[16,17]. And the divorce rate for pilots is high, estimated to 75%[18]. Thus, reducing the number of humans needed to work in these difficult environments could have quality of life of implications.

V. Conclusions

Given the results presented here, we propose that for an onboard intelligent system to be successful in the replacement of a human co-pilot, it will have to exhibit the following functionalities and capabilities:

- Natural language processing capabilities that match human capabilities, allowing the pilot the ability to request various actions from the automated system.
- The ability to intuit when to interrupt the pilot based on context and seriousness of an emergent or urgent situation.
- Independent monitoring of aircraft system states, either through computer vision or through an intelligent health and status monitoring system.
- The capability to recognize, interpret, and act upon non-verbal communications from the pilot
- Error monitoring of the Captain in terms of incorrect communications and inappropriate actions or incorrect timing of actions, as well as the ability to effectively communicate these errors back to the Captain.
- Override capability for the Captain to veto system decisions.
- The ability to take over flight control and potentially land the aircraft in extreme conditions for pilot incapacitation or gross error.
- The ability to self-diagnose when the system performance is degraded, and the communication of any discovered degradation to the pilot
- The ability to "fail gracefully"; that is, when the system performance is degraded it does not compromise the pilot's ability to safely control the aircraft.
- The ability to inform the Captain through visual or auditory displays what the automated system is "thinking" including indications of what actions the automation may be about to perform.
- A computer vision system that can detect external threats and landmarks, and communicate these in an appropriate manner to the Captain.
- Not create excessive pilot cognitive workload.

One commercial Captain with over 20,000 hours had this to say about single pilot operations, "[Going from two to one pilots] is actually a subject we discuss frequently in the cockpit, and the nearly universal opinion (at this time) is that we can see a cockpit with only one pilot (although certainly not with current systems in use)..."

With such recognition by seasoned pilots themselves, an imminent pilot shortage, a strong business case, and demand from industry for SPO of commercial aircraft, it is likely this will become a reality either in the US or perhaps first in another country.

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