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Human Factors and the Road to Single Pilot Operations

Michael Gearhart

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Prof. Veronica Cote, Thesis Advisor

Prof. Michael Welch, Committee Member

Prof. Michael Farley, Committee Member

Contents

Abstract

The purpose of this research paper is to shed light on the feasibility and implications concerning the introduction of single-pilot operations on air transport category aircraft. As technology has been advancing over the past few decades, autonomous artificial intelligence software has started to become more popular, finding higher demands in various industries. With current issues such as the pilot shortage and raising pilot wages, airlines are looking for ways to cut down on costs and preserve a healthy work force level. The implementation of this artificial intelligence technology on the aircraft flight deck provides a potential solution to this problem. On a functional level, this software could easily prove to take on many of the tasks that current pilots face. There are, however, other considerations that play a large role in the overall feasibility of its implementation, most notably the human factors aspect of removing the first officer. Due to these human factors concerns, the likelihood that this technology can be incorporated effectively is improbable.

Introduction

With an increase in consumer demand for air transportation, continuous creation and expansion of commercial airliners, and the unrelenting call for more qualified crewmembers in the current pilot shortage, commercial airlines are looking to cut costs while also improve efficiency and effectiveness of their operations. It is estimated that the annual growth rate of passenger traffic is to rise at a rate of 4.8 percent over the next 20 years which will contribute to higher aircraft production demands (Deliotte, 2017). This demand will require airlines to hire more than 250,000 qualified pilots until 2037 to meet this growth (Boeing, 2017). The consequence of this increased crew demand equates to addition costs in recruitment, training, retention, and salary pay. With these looming figures the airlines are likely to seek out various cost-cutting techniques in order to offset the expenses associated with this growth. While there are a variety of ways to cut costs in the industry, one in particular could prove to not only boost annual net income but also potentially solve, or greatly diminish, the pilot shortage. By introducing single-pilot operations for Part 121 air transportation operators, the pilot crew requirements can be halved along with a decrease in expenses needed to recruit and train these individuals. The advances in onboard avionics systems have allowed for air transport aircraft to become highly automated, enabling the system to conduct almost every phase of flight autonomously. With such capabilities it is an enticing prospect for the airlines to move toward this shift. However, should this transition take place, the safety impact could prove to be compromising.

Historical Perspective

As aviation evolved from its early conceptions throughout the 20th century, its complex nature also began to shift. During the pre-jet era, aircraft would require a crew of five individuals including: two pilots, a flight engineer, a navigator, and a radio operator. This crew size would shrink expeditiously once jet aircraft and other advances in radio communications and navigational aid technology were realized. The radio operator and navigator became obsolete (Fadden, Lindberg, Morton, & Taylor, 2008). It was during the 1960s that the three-person crew, captain, first officer, and flight engineer, was the norm.

The flight engineer’s main task within the three-person crew was to monitor and operate complex aircraft systems such as pressurization and fuel consumption. The captain and first officer’s focus was navigation, aircraft control, and communication. Jet aircraft systems and operations simplified in-flight adjustments and troubleshooting failures were significantly reduced (Fadden, Lindberg, Morton, & Taylor, 2008). Due to this increase in engine reliability, in contrast to its piston-engine predecessor, jet aircraft now completed most of the work delegated to the flight engineer. Upon the advent of the Boeing 737, Boeing’s team of researchers and engineers looked into the performance and accident history of previous airplane designs in order to maximize effectiveness and safety for its new aircraft. The conclusions indicated that in-flight troubleshooting sometimes led to more serious problems, with the flight engineer’s intense focus on system problems often distracting one or both of the pilots. Furthermore, jet engine reliability was much higher than piston engines, requiring little to no flight troubleshooting or adjustment (Fadden, Lindberg, Morton, & Taylor, 2008). Due to the advances in aircraft systems, paired with the efficiencies and reliability they carried with them, airlines would eventually come to render the flight engineer obsolete.

Methods of Implementation

Before implementation of single-pilot operation (SPO) technology can be put into place, the current dual-pilot operation hierarchy and responsibility gradient must be analyzed. Current operations see a two-pilot team consisting of one pilot flying and another pilot monitoring the flight. The pilot flying takes responsibility of directing the aircraft in line with the approved flight plan and continuously monitors the flight path for any deviations. In the next seat over, the pilot not flying primarily focuses on navigating, controlling and monitoring radio communications, cross monitoring the actions of the pilot flying, assisting in high workload situations, and taking over flight tasks in the event that the other pilot is incapacitated (Bassien-Capsa, Lim, Liu, Ramasamy, & Sabatini, 2017).

Part 25 of the Federal Aviation Regulations outlines these tasks in a legal sense, requiring that a minimum flight crew must be established so that safe operations may be conducted, taking into consideration the workload on individual crewmembers, the accessibility and ease of operation of necessary controls by the appropriate crewmember, and the kinds of operations authorized under 14 CFR 25.1525 (Minimum Flight Crew, 2017). Essentially, for a transport-category flight to be legal, the flight must consist of a crew that can balance workload such that neither crewmember is overwhelmed, and controls are accessible to either crewmember who is responsible for such control manipulation. Presently, few transport category aircraft with three required crewmembers are in use by major U.S. airlines. All modern transport aircraft, including the super-jumbo A-380 , are flown by only two flight crewmembers.

A key concept to dual-pilot operations is crew resource management (CRM). CRM is an essential component to safe, proper, and successful execution of flight tasks. In order for operations between crewmembers to be successful, attitude is perhaps the most important variable (Garland, Hopkin, & Wise, 1999). Both pilots must display a positive, interdependent attitude to ensure that communication is both coherent and effective. It could be argued that their own personal performance is a hallmark of this positive attitude. Ultimately, proper group processes promulgate from appropriate CRM, resulting in effective team functioning which include clear communication, task delegation, and situation awareness (Garland, Hopkin, & Wise, 1999, p. 196). By utilizing the skills, knowledge, and experience of the other pilot, appropriate decision-making is more successful and task delegation is more effective.

Given the crucial nature that CRM bears on the ability for a flight to be conducted safely, it stands to reason that always having at least two crew members on the flight deck is necessary. Taking a look back at the regulations set forth by the FAA, it is specified that all large commercial aircraft are required to be flown by a flight crew consisting of not less than two pilots (Composition of Flight Crew, 2017). However, it is also specified by authorities that the aircraft must be capable of a single pilot operating the flight fully in either seat (Bassien-Capsa, Lim, Liu, Ramasamy, & Sabatini, 2017). This essentially means that there are already SPO elements in the design of current flight decks.

Looking toward the actual implementation of SPO for transport category operations, each of the two-pilot tasks will require a new distribution between man and machine. Whereas with dual-pilot operations the pilot flying ensures that the aircraft is in line with the flight plan and corrects for any deviations (with the pilot not flying taking care of all other communication and navigation tasks), SPO has the single pilot assume a strictly supervisory role (Bassien-Capsa, Lim, Liu, Ramasamy, & Sabatini, 2017). Ultimately, the one pilot would monitor the automated systems controlled by the artificial intelligence system (AI), and coordinate required tasks with a ground crew. Currently, both pilots require constant communication with one another. With the proposed system, however, most of the interactions on the flight deck are between a human and a written software. This does not wholly cancel the need for CRM. Besides the coordination between the pilot and air traffic control, ground crews, and potentially other aircraft, there must still be an interaction between the pilot and AI controlling the flight. This comes in the form of human machine teaming (HMT).

HMT would require that output results are comparable to that seen in successful CRM. This means that some of the key ergonomic elements to be considered for system design include: facility of learning and remembering key functions, efficiency and intuitiveness of using automated functions, and avoidance/reduction of pilot-induced errors (Bassien-Capsa, Lim, Liu, Ramasamy, & Sabatini, 2017). The AI system would need to learn, communicate, and correct deviations much like that of a second crewmember.

In order for such functions to occur at the desired level of safety and accuracy, designers have conceived the Virtual Pilot Assistance (VPA) system. The main objectives of VPA are to decrease pilot workload, decrease flight deck complexity, increase aircraft surveillance capacity, and facilitate collaborative work and information sharing between the aircraft, air traffic control, and ground crews (Bassien-Capsa, Lim, Liu, Ramasamy, & Sabatini, 2017). The four major systems comprising VPA are communications, surveillance, flight management/control, and human-machine interface (HMI) systems. Each of these bear essential functions, but it is the HMI system, more specifically utilized as a cognitive human-machine interface, that is of particular significance when it comes to successful implementation of SPO.

In order for the system to evaluate pilot workload management, stress levels, fatigue, and incapacitation, the cognitive human-machine interface incorporates psychophysiological sensors which monitors pilot vitals in real time. This means that the pilot would be physically wired to the machine. The system itself incorporates adaptive learning, meaning that through its evaluation of the pilot’s vitals, changes can be made to the surrounding environment (refer to Appendix A). These changes can include transition to higher levels of system automation, reducing screen clutter, and transferring noncritical tasks to the ground crew (Bassien-Capsa, Lim, Liu, Ramasamy, & Sabatini, 2017). In the event of pilot incapacitation, the system will go into a fully automated state. An alert will be sent to the ground crew and a link will be set up between the aircraft and a ground operator who can then remotely pilot the aircraft to a safe location for landing.

Human Factors

Liveware-Liveware

From a functionality standpoint, VPA captures a competent level of autonomy, factors in appropriate failsafe technology, and diminishes task saturation on the part of the pilot during stressful situations. That being said, physical functionality is only one piece of the puzzle that embodies the successful implementation of this technology. The human factors considerations, or how the implementation of this technology will affect the pilot, the ground crew, air traffic control, etc., is of the highest importance in determining whether or not it is feasible to employ.

As mentioned earlier, when initial training first began for CRM in the 1980s, research determined that the most critical components for success between crewmembers and the safe conduct of the flight was highly dependent upon the attitude of the team. Without a cohesive relationship between the crewmembers, the likelihood of an effective flight is lessened. Two crewmember working together with a positive, professional relationship on the flight deck can achieve much more together than either one of them alone. This enhanced ability to conduct an effective flight manifests itself in seven particular team processes. These include: (1) leadership, (2) communication, (3) assertiveness, (4) situation awareness, (5) mission analysis or planning, (6) adaptability, and (7) decision making (Garland, Hopkin, & Wise, 1999). While leadership and decision making tend to be skills that put more emphasis on the captain of a two person crew, giving greater definition to the intracockpit authority gradient (this will be discussed in more detail later), the remaining five skills should see a relatively equal level of competency among all pilot crewmembers. Both pilots should complement one another’s skills in these emphasis areas, allowing for more coherent communication, enhanced situation awareness, and easier adaptability.

Crewmembers also hold the responsibility of keeping one another informed of flight status as well as taking note of the other pilot’s ability to handle tasks. The United States Army Aviation Center identified key roles that pilots should perform in their interaction with one another, emphasizing situation awareness. These include responsibilities such as routinely updating one another concerning flight status and external factors, anticipation of the situation awareness needs of the other pilot, holding awareness of the physical and mental state of the other pilot, communicating personal problems, and requesting needed information (Garland, Hopkin, & Wise, 1999). Many of these responsibilities are significant with respect to the affective domain of human intelligence. Being able to interpret the other pilot’s body language, demeanor, and overall stress levels is crucial for proper and appropriate communication to take place between pilot crewmembers. With this level of communication between the two, the flight will be more conducive for success.

Liveware-Software

The implementation of CRM principles proved to enhance pilot effectiveness on the flight deck, leading to safer and more efficient flight operations. It ultimately created a relationship within the cockpit based upon trust, respect, and recognition of authority. In essence, the two pilots merged together as one entity made of two shared minds which could perform far greater tasks than if they were separate. So what would happen if this entity were split in half with a machine taking over where a human operator once stood?

Task delegation must first be taken into account. A single pilot taking a predominantly supervisory role with the machine covering a majority of the operational tasks could prove to skew the balance of power on the flight deck. While in current dual-pilot operations the autopilot system is used throughout most of cruising, climbing, and descending flight, this new technology will enable the aircraft to essentially perform all operations completely autonomous from the pilot. This includes takeoffs, landings, and taxi. If the pilot begins to feel as though they are just along for the ride to “chaperone” the system, the intuitiveness of task delegation may begin to become ambiguous. Furthermore, problems such as complacency may begin to affect the pilot community due to lack of flight responsibility on their part. If they are not flying the airplane they may as well just be a passenger.

A seemingly easy fix to this problem would be for the pilot to take commanding authority over the aircraft during various operations whether it be taxi, takeoff, cruise, or landing. With current operations, if a pilot seeks to control the aircraft they simply turn off the autopilot. However, the proposed SPO systems may not allow for deactivation. Automation degradation, or the reduction in the amount of automation authority used to control the flight, can be thought of as a beneficiary to the pilot as optimizing task allocation can quickly fluctuate when flight conditions change (Risukhin, 2001). Given that a machine lacks judgement as a result of prior experiences, incorporating a level of automation degradation can prove to be lifesaving to the pilot who recognizes a situation that the computer does not. Perhaps an AI system could be programmed to “learn” from situations it encounters, but judgement is a dynamic process. As per the Oxford English Dictionary, judgement can be defined as “the formation of a conclusion concerning something, especially following careful consideration or deliberation” (Oxford English Dictionary, 2018). A machine can be programmed to analyze situations, but it is ultimately utilized to fulfill its mission (in this case getting passengers from Point A to Point B). Passenger safety would arguably be another programmable feature, but what happens when passenger safety and mission completion conflict? While more research will need to be completed to answer this question, it currently stands that a pilot with autonomous judgement and *empathy* can best analyze and correct for nonstandard situations that occur in-flight.

Based upon the proposed setup of SPO, this concept of automation degradation appears to work in reverse. With the cognitive human-machine interface interwoven as part of HMT, it is the computer which is analyzing the human, not the other way around. This raises serious concerns about intracockpit authority gradient, or who holds the greater authority and how drastic the difference is. In a dual-pilot operation, it is the captain who should hold a higher authority than the first officer, but it should not be to the point where the captain is an authoritarian figure. Rather, he generally has the final say on situations but will listen attentively and open-mindedly to the first officer’s suggestions. In the case of the cognitive human-machine interface, the pilot has limited say on whether or not they need greater automation. The system will change based upon what it *interprets* the pilot needs (Bassien-Capsa, Lim, Liu, Ramasamy, & Sabatini, 2017).

Looking back at the responsibilities of a two person crew as it relates to the status of the flight, it is each crewmember's duty to assess the physical and mental state of the other pilot and provide assistance where it is needed. While at first glance this may seem identical to the role of the machine, humans can talk to one another. They can communicate what they need done verbally and visually. Monitoring vitals may provide a glimpse at the pilot's ability to handle the situation but it is not the whole picture. The machine lacks empathy whereas a human does not. Furthermore, vital conditions vary from person to person. A singular calibration of this software lacks the ability to discriminate appropriately between individuals of different body types and levels of fitness. It could potentially take over on all tasks for an individual it determines is in a state of distress when they are completely calm and ready to tackle whatever task is before them.

Another serious questions that will have to be asked is whether or not pilots are willing to expose their vital information to this machine. While studies are yet to be conducted on this particular front, it is likely that at least some portion of the pilot population would not be comfortable strapping these software probes onto their body. It could be perceived as a violation of privacy and a force which could serve to create more stress than would be present without it. If pilots rejected to expose their vitals would the automation still be able to function? How would this impact task delegation and flight deck authority? Ethically speaking, VPA could prove to be exceedingly difficult to fully implement.

Livewire-Environment

Implementation of SPO technology will also carry its fair share of new environmental considerations for the pilot, most notably with the ground operator. While interaction with individuals on the flight deck will be minimized with installation of the Virtual Pilot Assistance system, there will still exist a human interaction element. This comes in the external form of a ground crew or ground operator. This would truly be a new and unique element of communication and interaction as all prior forms of external person-to-person contact would be with air traffic control, other aircraft, or the airline dispatcher, all of whom have no physical control over the aircraft. By introducing an isolated human that can take control over the aircraft from an undisclosed operation center new concerns are created.

In their “Roadmap” to the integration of civil unmanned aircraft systems into the National Airspace System, the FAA has identified certain areas of emphasis pertaining to human factors. These concerns include trust levels between the ground operator and pilot in the aircraft, effective human-automation interaction via the ground station, definition of roles and responsibilities, and airspace users’ and providers’ qualification and training, to name a few (Federal Aviation Administration, 2013). Perhaps one of the more pressing issues concerns when the ground operator would have authorization to take control of the aircraft. While the system is designed to transfer control over to the ground operator upon pilot incapacitation, the system code could potentially be written to allow external override abilities in the event of hijacking or immediate need for outside intervention. This creates an entirely new spectrum for intracockpit authority gradient as now the pilot must exercise a role of authority with a machine and an individual perhaps hundreds of miles away (refer to Appendix B). In this case, it may be that the pilot does not hold the greatest authority. Perhaps they even hold the least.

Security concerns are also present with this type of setup. The aircraft are connected to the ground operator via Datalink software, which is a high-speed and real time indicator of aircraft location and performance specifications (Bassien-Capsa, Lim, Liu, Ramasamy, & Sabatini, 2017). If this software is subject to hacking and cyber-attacks, it could open the door for a new level of terrorism. While this particular issue is beyond the scope of this paper, it does introduce serious concerns that will require heavy and continuous testing to ensure that such events are unlikely to occur.

Conclusion

Single-pilot operations bring a unique prospect to the aviation industry, especially for airlines that are desperately in need of countering the effects of the pilot shortage. While functionality-wise the proposed system implementation that would accommodate SPO is more than capable of handling this task, the human factors impact would be too compromising to the safety and authority gradient of the flight. While in the technical tasks it provides for less of a demand on the part of the pilot, the psychological repercussions make way for greater levels of ambiguity and uncertainty. If the pilot does not know where the true authority lies while conducting the flight, this makes way for a breakdown in trust. Without trust, the cohesive bond between man and man, or man and machine, is shattered. The level of performance thus deteriorates and flight safety and efficiency suffer. If this technology is ever to be implemented, it would require the conservation of this sturdy and effective, yet ever so fragile trust.

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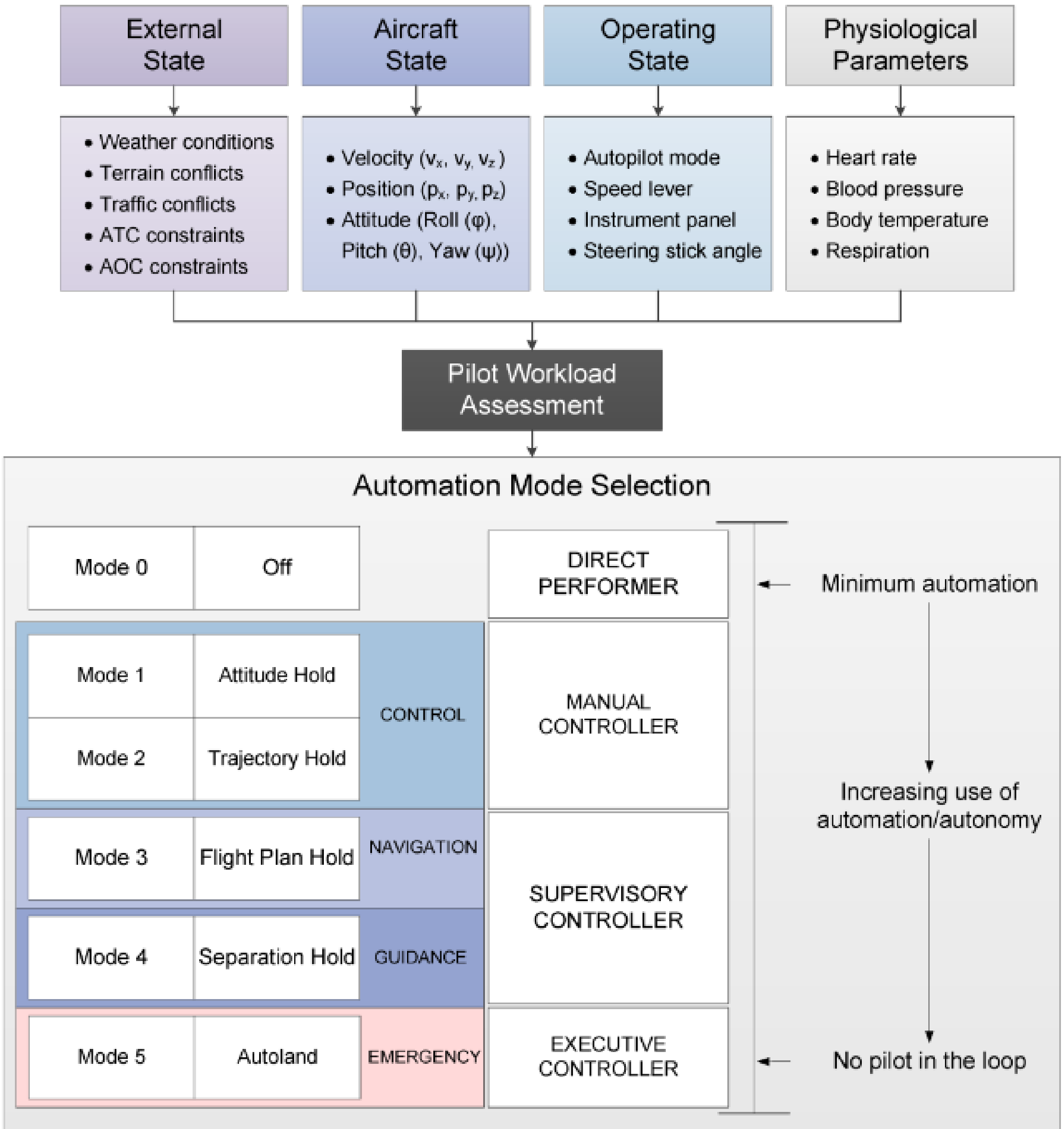
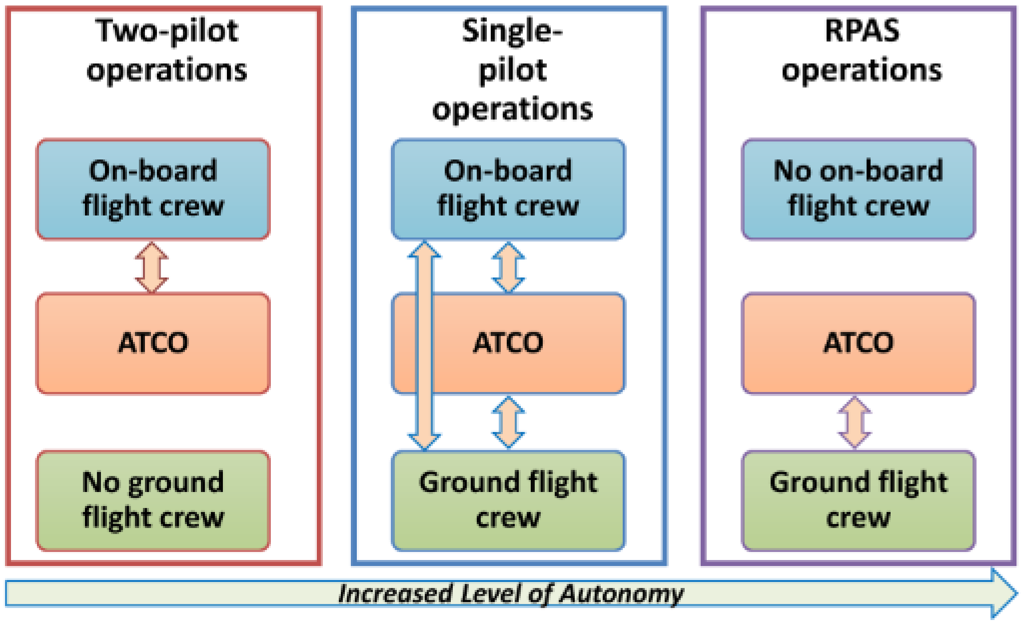
Appendix A

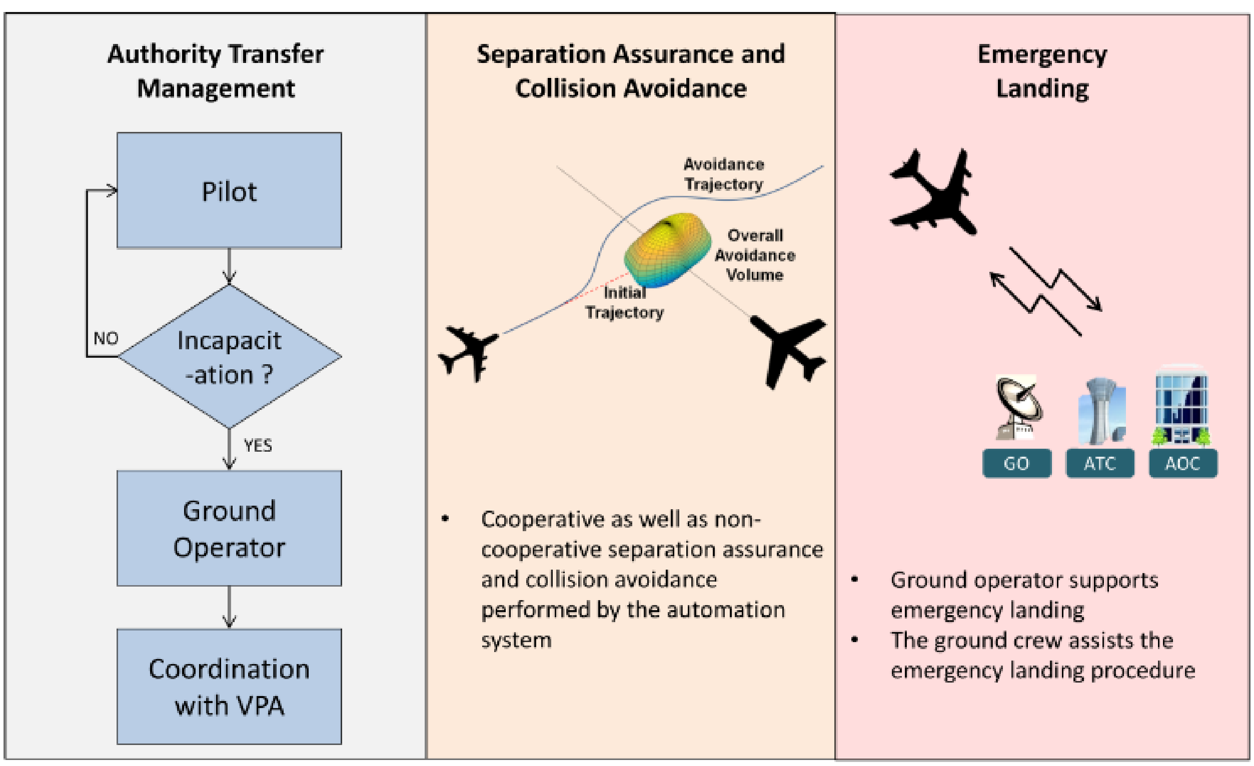


VPA Functional Allocation Scheme

Appendix B



Aircraft Configuration Communication Scheme



Ground Operator Control/Incapacitation Procedure