Single Pilot Operations in Domestic Commercial Aviation

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Objective: To provide an overview of concepts of operation for single pilot operations (SPO) and a synthesis of recently published work evaluating these concepts.

Background: Advances in technology have made it possible for a commercial aircraft to be flown by a single pilot under normal conditions, and research is being conducted to examine the feasibility of implementing SPO for commercial aviation.

Method: Context leading up to the consideration of SPO for commercial flight is provided, including the benefits and challenges. Recent studies examining issues relating to automation, operations, and communications in the SPO context are presented.

Results: A number of concepts have been proposed and tested for SPO, and no one concept has been shown to be superior. Single pilots were able to successfully resolve off-nominal scenarios with either the ground-support or cockpit-automation tools examined. However, the technologies developed in support of these concepts are in prototype forms and need further development.

Conclusion: There have been no obvious "show stoppers" for moving toward SPO. However, the current state of research is in its initial stages, and more research is needed to examine other challenges associated with SPO. Moreover, human factors researchers must continue to be involved in the development of the new tools and technologies to support SPO to ensure their effectiveness.

Application: The research issues highlighted in the context of SPO reflect issues that are associated with the process of reducing crew members or providing remote support of operators and, more generally, human interactions with increasingly autonomous systems.

Keywords: aviation, single pilot operations, reduced crew operations, human-autonomy teaming

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HUMAN FACTORS
Vol. 60, No. 6, September 2018, pp. 755–762
DOI: 10.1177/0018720818791372

The role of automation typically is to replace functions performed by humans or provide cognitive support for human operators (Parasuraman, Sheridan, & Wickens, 2008). Increasingly automated systems are taking the place of humans for understanding the system state, projecting the future system state, and deciding on the best approach for meeting system goals. Incorporating such automation has made it possible for a commercial aircraft to be flown by a single pilot under normal conditions, and consideration is being given to implementing single pilot operations (SPO) for commercial aviation. In this article, we provide a brief overview of concepts of operation for SPO, and present a synthesis of recently published work evaluating these concepts.

From the 1950s through the 1980s, crew size on commercial flights fell as technology improved. In the 1950s, the cockpit crew on commercial flights consisted of five members: two pilots, a flight engineer, navigator, and radio operator. Jet engines eliminated the need for in-flight engine adjustments made by engineers, and improvements in navigation electronics and digital radio tuners eliminated the need for navigators and radio operators; all while providing significant gains in capability, performance, and reliability (Fadden, Morton, Taylor, & Lindberg, 2015). Consequently, by the 1980s, the standard crew size for domestic passenger flights was reduced to two: the Captain and First Officer (McLucas & Leaf, 1981). Although the captain is responsible for the flight, s/he and the first officer generally trade tasks to balance their workload.

As automation allows for further workload reductions (Schutte et al., 2007), there is interest in a further reduction in crew size to a single pilot (Deutsch & Pew, 2005; Harris, 2007) for potential cost savings. The flight crew often represents the highest category of direct operating expenses (e.g., 25%) for the airlines (Norman, 2007). Additional savings would also come from the simplification of crew scheduling. SPO can also offset the expected shortage of qualified pilots in the near future based on forecasts of retirements, new FAA regulations increasing the required flight experience for new hires, and changes in the required durations of rest between flights (Carey, Nicas, & Pasztor, 2012). Thus, from a purely economic standpoint, reducing flight-crew expense is a compelling reason for airlines to move toward SPO. However, from a safety point of view, two-member crews offer protection against human errors and rare cases of pilot incapacitation.

In 2012, a technical interchange meeting held at NASA Ames Research Center sparked systematic research into the feasibility of SPO (Comerford et al., 2013). Johnson et al. (2012) identified five global research areas that emerged from the meeting: automation, operations, communications/social interactions, pilot incapacitation, and certification. Recent research on SPO has focused on issues in the first three areas, with emphasis on using remote pilots, automation, or some combination of the two to maintain a manageable workload and to protect against errors.

CONCEPTS OF OPERATION FOR SPO

One outcome of the 2012 meeting was the identification of alternative concepts of operation for SPO. The concepts range from ground operators providing support for in-flight-critical operations to cockpit-based technologies that would perform specified tasks to reduce overall workload (Comerford et al., 2013). Questions regarding which tasks to assign to human operators versus automation naturally arose. Task analysis and cognitive task analysis are often used in human factors to identify roles and responsibilities of different operators, and these types of analyses were recommended for SPO (Boy, 2014). Wolter and Gore (2015) used task analyses to generate scenarios that could serve as use cases in research, as these scenarios should result in observed differences with respect to pilot workload, safety, and efficiency under different SPO concepts.

In addition to task analyses, several studies used interviews with pilots to examine how interpersonal relationships affect flight deck operations in SPO (Cummings, Stimpson, & Clamann, 2016). Co-pilots do more than share workload; they are integrally involved in current procedures regarding situation awareness and decision making, and (less formally) help relieve boredom and manage stress. Replicating aspects of these relationships are important for SPO (Mosier & Fischer, 2014). These issues have been examined in research studies reviewed in this article.

GROUND-BASED OPERATIONAL CONCEPTS

One concept that was proposed for SPO is to have the First Officer be located remotely and be able to support the onboard Captain when requested. Remote piloting is not a new concept and has been successful for Unmanned Aerial Systems (UAS; Merlin, 2009). Communication and coordination among different UAS crews have also been studied (e.g., Cooke, Gorman, Duran, & Taylor, 2007). However, UAS teams have very different goals, and the UAS pilots do not have to worry about onboard passengers. Thus, although research relating to UAS remote piloting and teaming can be used to inform SPO concepts, there are numerous issues around communication and coordination between the two pilots in the SPO context that must be examined.

Lachter, Battiste, et al. (2014) examined the challenges produced by physically separating the flight crew. Pilots flew low-fidelity desktop simulators of a two-crew transport cockpit in scenarios that required them to divert from their original flight plan. The displays and controls were positioned such that a crew could operate them as a single flight deck or as two separated flight decks. The crew flew scenarios with the pilots located together or separately. Although pilots preferred face-to-face interactions, there was no impact of the separation on subjective workload or ultimate decisions regarding the flight. However, when the two pilots were separated, the lack of access to nonverbal cues and actions negatively impacted communications between pilots and their awareness of what the other pilot was doing. For example, pilots showed confusion regarding their roles (e.g., who was the pilot flying?) and whether actions were completed (e.g., did the other pilot enter the commands?). These findings suggest that nonverbal communications are an important aspect of crew coordination and must be maintained or replaced to promote good awareness and crew resource management (CRM) when pilots are separated.

Locating a first officer on the ground makes sense economically only if the ground pilot is performing other tasks when workload is low, perhaps taking on dispatcher roles and providing first-officer services only when requested (Bilimoria, Johnson, & Schutte, 2014; Lachter, Brandt, Battiste, Matessa, & Johnson, 2017). Lachter, Brandt, et al. (2014) examined the operational issues associated with the ground-operator concept by comparing performance of air transport pilots assuming that role in comparison to the current-day first-officer role. As a ground operator, the pilot performed limited airline dispatch functions (uplink reroutes for weather avoidance or turbulence) under normal operations, and first-officer functions when requested by the captain. The captain flew scenarios and encountered problems that required the aircraft to divert. The second pilot was either in the cockpit with the captain as the first officer (current-day condition) or on the ground serving as the ground operator (single-pilot condition). If requested by the captain in the single-pilot condition, the ground operator provided dedicated assistance typically performed by a first officer using simulated flight deck controls on a ground station, while attempting to continue performing the assigned dispatch tasks. To address the CRM issues identified with remote crews found by Lachter, Battiste, et al. (2014), two single-pilot conditions were tested, one with no collaboration tools and another with a series of collaboration tools designed to improve CRM. These tools included CRM indicators (panels that indicated who was responsible for various tasks such as Mode Control Panel manipulations, Control Display Unit inputs, and Air Traffic Control communications), video of the cockpit/ground station, shared flight deck displays, and charts.

Lachter, Brandt, et al. (2014) found that the pilot crews were able to perform the diversion task safely in the current-day and single-pilot conditions. However, the current-day condition was rated higher than the single-pilot conditions in terms of safety, ability to coordinate and make decisions, and awareness. The lower ratings for the single-pilot conditions could be due to the novelty of the concept and the unfamiliarity with the new ground operations. For single-pilot conditions, pilots rated safety, ease of coordination and communication, and their decision-making ability to be better in the condition with the collaboration tools. More important, though, Lachter et al. found that almost no aircraft assigned to the ground operator received dispatch services after the captain requested dedicated assistance. In debriefing sessions, pilots serving as ground operators commented that dispatch tasks left their awareness once they became involved with first-officer duties. Thus, the results of the study argue that ground operators could provide first-officer support in SPO, but the ground operators should not perform other tasks while providing dedicated assistance to a flight.

If acting as a first officer prevents an operator from performing other duties, ground support must be split into two modes, one in which a ground operator supports many routine (nominal) aircraft and another in which a ground operator acts in a more dedicated manner to an off-nominal aircraft needing more extensive support. Brandt, Lachter, Battiste, and Johnson (2015) examined the transitions between these modes. They compared a hybrid (dispatch + dedicated assistance) role of the ground operator to a specialist (only dedicated assistance) role. These two roles differ critically in whether the nominal aircraft are handed off when an off-nominal aircraft requires dedicated assistance (hybrid), or whether the off-nominal aircraft is handed off to a dedicated ground pilot (specialist). In the former case, the ground operator would have prior interactions with the aircraft before dedicated assistance is requested, which could affect situation awareness. Brandt et al. found that both hybrid and specialist ground operators performed equally well in supporting the single pilot in the off-nominal situations examined. Pilot feedback suggested that this was the case because information for most off-nominal events was provided on the ground station displays (cockpit situation display, CRM tools, video feed, etc.) and through direct interactions with the onboard pilot. Based on these findings, Battiste et al. (2018) suggested that the decision of how dedicated assistance should be provided could be left to air carriers based on their analyses of cost-benefit ratios.

Another specialist, ground-based operational concept that has been examined is called the Harbor Pilot. A harbor pilot is a ground pilot who specializes in a specific airport, assisting single-piloted aircraft during the, taxi, arrival, and departure phases of flight. A harbor pilot, with more detailed knowledge of the traffic flow, weather, and other procedures within the specific terminal area airspace, could more easily anticipate the needs of the crew and air traffic control. Koltz et al. (2015) showed that the concept is workable in that the workload was rated to be low, and the pilots indicated that they would be able to assist between 4-6 aircraft successively under nominal conditions.

COCKPIT-BASED OPERATIONAL CONCEPTS

The ground-based operational concepts discussed above make extensive use of automation that, at a minimum, monitors the aircraft and performs the error-checking functions of the second pilot. In the cockpit, the automation needs to be developed so that a single pilot can fly the aircraft without the aid of a second human operator. Much is known about the benefits and pitfalls of human interaction with automation (e.g., Parasuraman et al., 2008). Automation can reduce workload but may force the operator to monitor the automation, leading to problems associated with vigilance (Warm, Matthews, & Finomore, 2017) and decreased situation awareness (Endsley, 2018; Vu et al., 2012), among others. Cockpit-based operational concepts must overcome these pitfalls.

Cummings et al. (2016) suggested that problems associated with automation could be mitigated by incorporating good functional requirements in the design. For SPO, they argue that these requirements include the ability for automation to process natural language, intuit when to interrupt the pilot based on context, perform independent monitoring of aircraft state, provide verbal and visual indicators about when it is performing tasks or is thinking, take over for the pilot when needed, engage in self-diagnosis, and fail gracefully. Shively et al. (2017) highlighted the notion of human-autonomy teaming (HAT) in the context of reduced-crew operations, where automation and human operators work together to solve problems. HAT represents a significant shift from the view that automation is a simple replacement for human functions to a view where the automation acts as an agent, and serves as a team member with the pilot.

Shively et al. (2017) indicated that the following qualities of the agent must be met to overcome problems associated with automation in reduced-crew operations. First, the human operator must understand the intent and reasoning of the agent and determine the factors used by the agent in arriving at a solution or recommendation. At the same time, the agent must understand the preferences, attitudes, and states of the human team member. Second, fast and bidirectional communication must take place between the human and agent so that there is shared knowledge of each member's role and responsibilities, and negotiations can take place from both sides to reach optimal decisions. Third, the system should be operator directed. Humans should be setting the goals and priorities, and also (to avoid confusion) the modes of interaction with the automation.

The HAT concept was evaluated with a tablet-based rerouting and divert system (the Autonomous Constrained Flight Planner; ACFP) that was installed in the cockpit of a high-fidelity simulator (see Cover, Reichlen, Matessa, & Schnell, 2018; Matessa et al., 2018; Strybel et al., 2018). In the study, air transport pilots flew simulated scenarios in SPO where they encountered off-nominal situations (e.g., weather, medical emergency), requiring them to make divert decisions. The captain could request information from either the dispatcher or the ACFP in all conditions. In half of the scenarios, the ACFP was enhanced based on tenets of good HAT (Shively et al., 2017), resulting in a more transparent and interactive interface with the automation (see Table 1). Key features of the enhanced ACFP included:

- "Plays"—preprogrammed lists of actions for resolving a specific off-nominal event such as

TABLE 1: Characteristics of the ACFP in a Study of Human Automation Teaming (HAT)

Critical Components	HAT (Enhanced ACFP)	No-HAT
Plays (preprogrammed lists/ actions for specific events)	Pilot selects a play based on off-nominal alert	Pilot selects a play based on off-nominal alert
ACFP recommendations (4 alternative destinations)	Interactive ACFP • Shows the factors used in recommendations • Pilot can adjust weights of the factors using sliders • ACFP creates new recommendations; allows iterative interactions	No ACFP interaction
Checklists	Electronic checklists: automation performs some tasks on the list and checks the list	Paper-based checklists

cabin fire, cargo door open, medical emergency. The plays also contained information regarding responsibility so that, as part of the play, each action would be assigned to either the pilot or to automation to perform.

- Transparency regarding the factors (e.g., fuel, estimated time of arrival, medical/maintenance facilities at airport) used by the automation in the selection of recommended airports. The initial weightings of these factors were determined by the play, but an interface was available for the pilot to adjust the weighting of these factors.
- Electronic checklists.

The pilot would initiate the automation by selecting a specific play on the ACFP. The ACFP then brings up the electronic checklist for the specific play that includes the listing of actions to be performed by each team member, the order of the actions, and the status of each action. Although performance differed based on the difficulty of the scenarios, all pilots were able to perform the diversion tasks successfully with both types of automation. Pilots indicated that they preferred the enhanced version of the ACFP and indicated that the HAT condition improved efficiency, information integration, keeping up with important tasks, and workload (Cover et al., 2018). However, use of the enhanced tools did not affect the pilots' decision-making time or change their levels of situation awareness (Strybel et al., 2018). It should be noted that the HAT functions of the ACFP were in prototype form; therefore, more developed versions of the tool are likely to yield additional benefits.

FEASIBILITY OF THE SINGLE PILOT CONCEPT AND FUTURE RESEARCH NEEDS

A variety of operational concepts have been developed for SPO. Although no single concept has been shown to be superior, the studies reviewed here show no real "show stoppers" in moving toward SPO. In the simulation studies reviewed, single pilots were able to successfully resolve off-nominal scenarios with either ground support or cockpit automation tools. Although the results of these studies are promising, they represent only the first steps in the research needed to evaluate the feasibility of the SPO concept. Moreover, all concepts and recent demonstrations for SPO thus far rely on the development of advanced autonomous tools that perform many of the functions currently performed by the pilots. Yet, development of these tools has only begun. Thus, there is a need for continued development of new technology to support SPO.

Additional obstacles beyond the scope of this article will play a critical role in determining the eventual design of SPO, all of which require additional human factors research and support. Thus, a research agenda for moving forward with SPO should include continuing research on ground-based and cockpit-based concepts for SPO and the technologies required to implement those concepts (e.g., CRM and HAT tools described earlier), as well as new research on pilot incapacitation and SPO certification. Although estimates of pilot incapacitation are low (e.g., annual rate of 40 cases, Evans & Radcliffe, 2012; 1 out of 34,000 flights, Australian Transport Safety Bureau, 2016), solutions for remote or automated piloting of the aircraft in cases of pilot incapacitation must be found. Several solutions for detecting pilot incapacitation have been proposed (e.g., Liu, Gardi, Ramasamy, Lim, & Sabatini, 2016), including methods for determining whether the pilot is alert (i.e., making appropriate inputs and decisions), and is capable of maintaining command of the aircraft. If the pilot is deemed incapable, the system must take command and control of the aircraft and make the strategic and tactical decisions necessary to safely navigate the aircraft to an acceptable destination. Thus, there is a need for research on the effectiveness of these systems as well as the development of procedures handling cases of pilot incapacitation. Operational certification challenges for SPO have been documented (Wilson, Harron, Lyall, Hoffa, & Jones, 2013) and will need to be examined in future studies. Wilson et al. (2013) recommend the use of a task force to evaluate the evidence in support of or against single pilot operations. This would help gain stakeholder and public acceptance. Human factors researchers can play a critical role in contributing to the evidence base.

The findings from the research highlighted in this article have several implications for the design of tools in support of SPO, such as CRM and HAT, and for training operators on their use. As aforementioned in the Ground-based Operational Concepts section, a suite of tools was developed to assist the onboard captain (e.g., Lachter, Brandt, et al., 2014; Matessa et al., 2018; Strybel et al., 2017). The tools were designed based on interviews with pilots about functional components, and they incorporated recommendations for good automation and CRM (e.g., Cummings et al., 2016; Mosier & Fischer, 2014; Parasuraman et al., 2008) and HAT (Shively et al., 2017). A common theme with the new tools was that pilots were positive about their potential. However, the novelty of the tools and prototype nature of their implementation restricted their effectiveness (Cover et al., 2018; Strybel et al., 2018). Thus, future research needs to focus on training operators on the use of the tool before they can be properly evaluated in an operational environment. We are not aware of any study that has examined training issues for SPO, and it is likely that joint and remote training with SPO will be necessary for the development of CRM effective air-ground crews (see Mosier & Fischer, 2014). Thus, there is also a need for research on how to train pilots on the new roles and with the new technologies for successful implementation of SPO.

Many of the issues surrounding the training of operators with new technology generalize to other systems that rely on increasingly automated tools, such as those being implemented in semiautonomous and autonomous vehicles. Like the single pilot, the driver of an autonomous vehicle needs to understand the functions of the automation and the roles and responsibilities of the driver versus automation. The driver and automation need to be aware of “who” is in control of the vehicle at any point in time. The driver will also need to be able to extract information from the automation and interact with it in an effective manner to achieve larger goals or to respond to off-nominal situations (e.g., traffic accidents, lane closures, emergencies). Finally, in the evaluation of the new technologies for implementation in autonomous vehicles, it is also important to ensure the drivers have a good understanding of the tools that are being implemented in the vehicle before they are evaluated on the road.

ACKNOWLEDGMENTS

This research was supported in part by NASA cooperative agreement #NNA14AB39C “Single Pilot Understanding through Distributed Simulation (SPUDS),” R. J. Shively, Technical Monitor.

KEY POINTS

- There is interest in SPO for commercial flight due to the potential cost savings and expected shortages of qualified air crews.
- Multiple SPO concepts of operation were shown to be promising, but more research is needed to

examine additional barriers and challenges to SPO.

- New technology must be developed to support SPO concepts, and human factors researchers need to continue to take part in the iterative design and evaluation of the technology and concepts.

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Date received: March 31, 2018
Date accepted: July 4, 2018