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The Training of Operators in Single Pilot Operations: An Initial System Theoretic Consideration

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Single Pilot Operations (SPO) represent a viable concept for commercial aviation in near future. It will require different training regimes to contemporary airliners' pilots because the single-pilot's and remote operator's (including the dispatcher's) responsibilities and accompanying procedures will change, both in air and on ground. This initial system-theoretic analysis of suggestions for training of single-pilot and remote-copilot identified the agreement of job rotation of both. Hence, pilots can still be trained in new single-pilot specific procedures in a special training fleet to includes the apprenticeship-style training in SPO. Advanced new automation tools will be challenging to be included into training. On this basis, skill degradation becomes an issue and must be solved. Nonetheless, the training issue can be early tackled by applying worker competencies' analyses when investigating different concepts in depth early in the design process of SPO.

During the last two decades, research on reducing the crew of an airliner has been hot topic (Lachter, Brandt, Battiste, Matessa, & Johnson, 2017). Different Concept of Operations (ConOps) for commercial Single Pilot Operations (SPO) have been proposed, fragmentarily prototyped and empirically investigated (e.g. Vu, Lachter, Battiste, & Strybel, 2018). This research suggest that SPO seems viable in near to mid-term future. Whilst none of the ConOps was superior to any of the others in any type of human factors research question, system-theoretic analyses excluded, the option of single-pilot without ground-based support. It was shown to be less resilient to safety and security intrusions (Harris, 2018; Revell, Allison, Sears, & Stanton, 2018; Schmid & Korn, 2018; Stanton, Harris, & Starr, 2016). Table 1 (see next page) summarizes the remote operators' most promising and most researched ConOps in SPO, which is most likely to be pursed in future research. In the NASA ConOps, the ground operator is either organized and trained as a hybrid operator, either performing multi-aircraft and dedicated support or as specialist performing one of the high-level functions (Bilimoria, Johnson, & Schutte, 2014). In all other ConOps, no variations in unit structures of the remote copilot have been considered.

The emerging issue of training for transport SPO, and the concomitant changes required, has only been considered marginally in theoretical discussion. It was first discussed regarding certification requirements for such SPO (Harris, 2007; Wilson, Harron, Lyall, Hoffa, & Jones, 2013). Future large transport aircraft employing commercial SPO will be categorized as Part 121 and 125 operations, which currently require a minimum flight crew of two pilots. Hence, as such, SPO are not complient with CFR Part 121 and 125 operations, therefore the regulations would need to be changed or, alternatively, SPO must demonstrate an equivalent level of safety. One challenge is providing new training procedures that fit with the ConOps. The single-pilot as main Pilot Flying (PF) and the remote operater as main Pilot Monitoring (PM), and occasional PF, or even super-dispatcher, would require different and/or additional trainings than is currently the case. Their job would be very different in normal, off-nominal and emergency situations (Wilson et al., 2013). Fallback, or spouse, training has already been considered (see also: Comerford et al., 2013). It refers to non-pilot personnel on-board that receive an abbreviated training sufficient to land the single-piloted aircraft safely in the case of pilot incapacitation. This idea, however, has not been pursued any further.

A technical interchange meeting was coordinated and hosted by NASA to work out the issues and make recommendations for various aspects of SPO that require research (Comerford et al., 2013). New procedures in SPO would require new methods for training because the apprenticeship-style training that is currently employed for current multi-crew operations (MCO) would cease to exist. Pilots could become Captain of a single-piloted aircraft immediately. It is unknown what type and how much training a remote-copilot would need. Skill degradation has to be countered more effectively because of a greater extent of advanced automation tools onboard. Flight length, refering to temporal duration, might become more important and require different training to counter fatigue. Ground personnel also might require different training. For example, an enhanced dispatcher would require additional training to cover their enhanced duties. In summary, the minimum training regulations for each type of SPO-operator would have to be identified, redesigned and certified before they become operational.

Table 1.
The categorization of remote operators in dominant ConOps of SPO.

Remote operator	Functions	ConOps (references)
Super dispatcher	*Multi-aircraft support*: (1) monitoring 30 aircraft, contact to airline operations center; (2) Off-nominal: supporting crew decision-making;	NASA ConOps (Lachter et al., 2017; Matessa, Strybel, Vu, Battiste, & Schnell, 2017; Vu et al., 2018)
Remote copilot	*Dedicated support*: off-nominal and emergency support in pilot functions and/or take over of control in case of need	
Remote copilot	Normal: Flight planning and navigation support; support as PM and of communications with ATC/ATM Off nominal and emergencies: support as PM and/or PF	Support of one aircraft at a time (Revell et al., 2018; Schmid & Korn, 2018; Schmid & Stanton, 2018; Stanton et al., 2016)

Notes. For reasons of space, the most representative references of series of studies are given. Peer-reviewed literature is preferred.

The present system-theoretic approach aims to provide a first theoretic (re)view on the issue of training in SPO. No study has properly investigated the training issues for commercial SPO to the best of the authors' and Vu et al.'s (2018) knowledge. In this systematic analysis, possible upcoming issues in training design are identified and considered from a system-theoretic approach. Using the System-Theoretic Accident Model and Process (STAMP; Leveson, 2004) it is possible to identify potential hazards and resulting risks from the training of remote-operators in SPO. This study examplifies how STAMP can be used predictively to assess the single hazards around one component of the hierarchical control structure in system operations (Grant, Salmon, Stevens, Goode, & Read, 2018; Leveson, 2015; Revell et al., 2018). The use of the method in a predicitive context has been less dominant in literature. Nonetheless, its potential should be considered in how it can provide structured hazard analysis early in the design process because concomitant adaptions of regulations to SPO on each level will be required anyways.

Method: System-Theoretic Accident Model and Process (STAMP)

The System-Theoretic Accident Model and Process (STAMP) views as interrelated components that are kept in a state of dynamic balance by feedback loops of information and control (Leveson, 2004). The feedback loops stretch from the top of a control hierarchy of a supranational level via national and organizational level to the lowest levels where the operating process, including its operators, are located. Across this hierarchy, the three primary components of STAMP take effect: the safety constraints, hierarchical safety control structures, and process models (Leveson, 2011, 2017). The safety constraints are design principles, processes, as well as regulatory, legal, insurance, cultural, and other social control. Safe operations emerge from enforcing appropriate constraints on the system's behaviour and from an adaption of them to changes across the time. Incidents and accidents are viewed as an inadequate enforcement of the safety constraints on the behaviour at each level of a sociotechnical system. In this sense, safety is viewed as a control problem rather than a component reliability problem.

The safety constraints are displayed in a safety control structure across each level of a hierarchy from regulators on the top down to the across all levels to the operating process (Leveson, 2017). Such hierarchical control structures can be constructed for both system development and system operations. Both contain the control loops between and across all system components that are currently in place in development and operations. As part of them, actuators implement control actions and sensors provide feedback about the state of the given process. Controllers initiating both can be human or machines. In doing so, they enforce the safety constraints.

These control processes operate between all components that are connected with each other in feedback loops. The third major component of STAMP are these process models. The related hazard analysis of System-Process Process Analysis (STPA) technique predicts how the behavioural safety constraints can be, or were, violated in a incident or accident scenario (Leveson, 2011). Four types of Unsafe Control Actions (UCAs) can occurr: (1) A control action is not provided, (2) A UCA is provided, (3) A control action is applied too early/late, and (4) A control action is applied for a too short/long time. Afterwards, the analysists determine how the potenatially hazard control actions could occurr. In our application, STPA is not carried out because we do not investigate a specific incident or accident scenario.

In contrast, we consider the function allocations for remote operators and the single-pilot in SPO that have been proposed in research until now to the best of the authors' knowledge. They have been summarized previously in the introduction. In doing so, this analysis investigates a specific change of the hierarchical safety control structure at a limited scope defined by the research question of the training issue in SPO.

In the present part of a study, we focused on the control loops that are involved in the remote operators' training, which will have to change to adapt to commercial SPO. The whole hierarchical control structure for commercial MCO and SPO is described and presented in Schmid, Vollrath, and Stanton (2018) and Schmid and Stanton (2018). The results were reviewed and validated by a commercial pilot in two half-day sessions (28; male, CPL, frozen ATPL, 1,400 of 1,800 hrs. were undertaken in a B737-800). Based on that, we took the control loops and investigated them further regarding what would have have to change in the remote operators' and single pilot's training when SPO is introduced in future. We also included all considerations of the training issues in SPO that have been raised previously during in the course of research on commercial SPO.

Results: The Control Loops of Training in Single Pilot Operations (SPO)

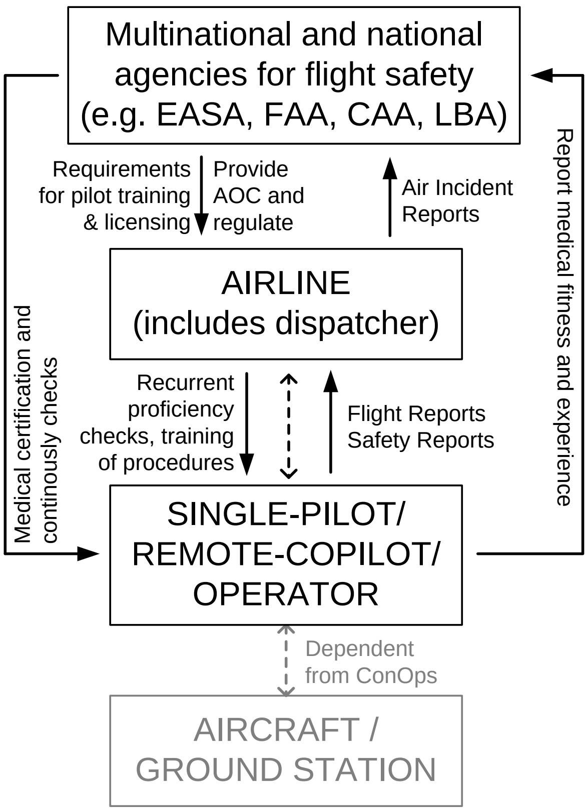

Figure 1. Detail of the hierarchical control structure of SPO for training.

Figure 1 shows the part of the hierarchical control structure of SPO which is relevant for training. The medical certification including checks and the mandatory report of medical fitness will remain. The same accounts for the duty to report any incidents and accidents to the respective upper level controller. In contrast, the procedures, training, and proficiency checks will change to match the requirements for pilot training and licensing that will have to be updated.

First suggestions have already been made how the training of the single-pilot could be approached (Comerford et al., 2013). The apprenticeship-style training could be redesigned in an alternate arrangement of a second pilot observing a single-pilot during operations before he transits to own SPO duties. Operating a special training fleet for SPO pilots complements this idea of the dual trainer concept of military jets (Schmid & Korn, 2017). A fleet would be flown by two pilots that is already equipped with SPO' technology and automation tools. In general, SPO will be introduced after MCO which is why first experience will need to be gained in MCO before switching to SPO. Nonetheless, this concept would serve pure SPO because the Captain of the trainer's fleet aircraft can still be undertaken by an experienced single-pilot.

On ground, the dedicated support or the remote-copilot's functions would essentially require the same skills as those of a conventional pilot (Matessa et al., 2017; Schmid & Korn, 2017). Here, the last quoted ConOps proposes that the single-pilot's and remote-pilot's job can be performed in job rotation to keep skills of each position fresh. Hence, the concepts of training suggested above would include the training of a remote-pilot in depth due to the job rotation in SPO. Finally, the super-dispatcher's job has been already discussed (Matessa et al., 2017). Their job could either performed by a commercial pilot or an enhanced dispatcher. Both of them would require an additional training in performing super-dispatch functions for using the advanced automation tools.

Discussion

In summary, the present paper has identified a dominant concept of training in SPO: the single-pilot's and remote-copilot's job should be performed through job rotations (Matessa et al., 2017) with a trainer fleet concept to tackle the main training issues (Schmid & Korn, 2017). Combining new advanced automation technology with the design of user interfaces gives designers more freedom regarding the whole setup of the single-pilot cockpit and the remote-operator's Ground Station (GS). Here, the future new operating procedures coupled with advanced new automation tools are challenges to be included into training. Nonetheless, the job rotation of both positions ease the training burden by educating each pilot in both jobs to keep the knowledge of the system current. The training will have to be tailored to the new single-piloted aircraft, including the GS, which will differ from contemporary aircraft models. Skill degradation might become an issue, depending on how automation is used. Hence, the result of the present study provides a basis to foster the analysis of worker competencies and start investigating training issues of different ConOps of SPO in place.

Possible changes in training, and later concomitant regulations, are a precondition for system operations that often appear later in the design process, but it is worth considering them much earlier on if SPO is to be successful. The additional costs of training personnel has not been included in any benefits and cost models of SPO until now (Graham, Hopkins, Loeber, & Trivedi, 2014; Malik & Gollnick, 2016; Norman, 2007). New costs, including the infrastructure, can affect the cost-benefit practicability of the SPO concept. Nonetheless, the training issue will become relevant in practice when a distinct ConOps, including advanced automation and the data-link technology, are mature enough. In general, establishing a training regime for SPO operators seems viable as SPO itself.

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