

Toward Single Pilot Operations: Developing a Ground Station

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ABSTRACT

This document describes the second human-in-the-loop study in a series that examines the role of a ground operator in enabling single pilot operations (SPO). The focus of this study was decision-making and communication between a distributed crew (airborne pilot and ground operator). A prototype ground station and tools designed to enhance collaboration were also assessed for further development. Eighteen crews flew challenging, off-nominal scenarios in three configurations: Baseline (current two-pilot operations) and SPO with and without Collaboration Tools. Subjective ratings were largely favorable to SPO; however, there was preference for the Baseline configuration. Crew comments suggest improvements to increase the usability of the collaboration tools.

Keywords

Single pilot operations (SPO), reduced-crew operations, Next Generation Air Transportation System (NextGen), ground station operator, remote pilot support

INTRODUCTION

Currently, large transport aircraft that operate under Part 121 of the Federal Airline Regulations (FARs) are flown by a minimum of two certified commercial transport pilots (FAR 14 CFR 121.385). This number decreased from five in the 1950s to the current levels in the 1980s due to advancements in the design and performance of aviation systems and technologies. For example, Inertial Navigation Systems/Global Positioning Systems (INS/GPS) and Flight Management Systems (FMS) have replaced tasks that were once performed by an onboard navigator.

Transport aircraft builders and operators continue to improve automation, reducing pilot workload and operating costs. Advanced autopilot, and autoland capabilities have replaced manual piloting for the majority of flying today. As a result, pilots spend much of their time monitoring and coordinating systems rather than controlling the aircraft.

In addition, significant progress has been made our ability to remotely fly uninhabited aircraft, known as UASs (Uninhabited Aerial Systems), from manned ground stations. A major challenge to the introduction of civil UASs in the National Airspace System (NAS) is replacing current see-and-avoid procedures (pilot responsibility to visually avoid collision with cooperative and non-cooperative targets) with sense-and-avoid procedures (collision avoidance maintained through additional onboard surveillance data provided to auto-resolution systems). Could new commercial flight deck automation, along with UAS ground-to-air technology, make it feasible to eliminate the First Officer position on transport aircraft, especially if combined with innovative new concepts of operation [1]? There is growing interest in such a move to single pilot operations (SPO) for future transport category aircraft [2, 3].

Single pilot operations are certainly not new. They are standard for nearly all general aviation (GA) aircraft, with a number of aircraft manufacturers currently producing very light jets designed and certified for SPO. These new aircraft are capable of flying at high altitudes and in complex airspace alongside large transport aircraft.

While in many ways SPO may be a viable alternative to conventional two-pilot operations, significant issues with this approach must be addressed before extending it to larger transport aircraft. Aside from the issue of air traveler acceptance, there are at least three main concerns. First, there is the issue of safety: FAR Part 121 multi-pilot operations are extremely safe, far exceeding the safety levels seen in the more generally single piloted GA and Part 135 operations [6]. To what extent is this due to the

redundancy offered by a second pilot, and how can this be replaced? Part 121 operations are also typically more complex, with pilots taking responsibility for managing cabin crew and coordinating with the rest of the airline operations. Can the work covered now by the two pilots be allocated to a single pilot, and if not, how can it be covered? Part 121 aircraft must also fly in a more tightly constrained environment (e.g., controlled airspace, metered arrivals, required navigation performance arrivals and departures) than GA or most Part 135 operations. Again, if the second crew member today is important in order to ensure compliance how will this be addressed with a single pilot? The answers to these questions are still unclear and the focus of the SPO program of research.

Given these motivations and challenges, it is important to carefully select and evaluate viable concepts of operation for SPO. The next section outlines potential approaches to SPO with focus on an approach involving ground support. The remainder of this document describes the second in a series of human-in-the-loop (HITL) studies, a study that examines the role of a ground operator.

SPO concept of operation

A transition from the current commercial transport two-pilot operations to SPO requires two main considerations: maintaining current safety while maximizing potential benefits. At a high level, any functions currently performed by the First Officer (FO) that are not absorbed by the captain can be handled using either an aircraft-centric approach, an air-ground approach, or a by combination of the two. An aircraft-centric approach attempts to solve the problem primarily by the addition of automation to the flight deck along with new procedures and training for the single pilot. For example, the current autoland system on the B747 aircraft (with its triple redundant autopilots) will land the aircraft and apply the brakes to a full stop on the runway. This type of system could be adapted to land the aircraft in the case of an incapacitated pilot. Additionally, the Emergency Landing Planner (ELP), developed by NASA [5] could provide guidance to which runway would be most suitable in an emergency situation. An air-ground approach seeks to solve the problem by adding ground assets that will support the lone pilot. For example, using technology developed to control unmanned aircraft systems (UASs) a person on the ground to act as FO in times of high workload, or to take over control of the aircraft when the pilot is incapacitated.

Both approaches have their strengths and weaknesses. The aircraft-centric approach would not rely on developing a robust air-ground connection, but on developing advanced automation that is flexible and reliable enough to replace the inherent flexibility of the human problem solver. On the other hand, the air-ground approach requires developing a robust air-ground connection and advanced automation (on the flight deck and on the ground). However, this approach does not require automation to fully replace the human functions and keeps the second flexible human problem

solver in the system. This document explores the air-ground approach, although we expect an intelligent combination of the two approaches will ultimately be necessary to provide a robust system.

An air-ground approach to SPO must have a good benefits case to support it, one benefit being the removal of the cost of one of the pilots. While a person on the ground may still be necessary, this “ground operator” can potentially serve more than one aircraft. As aircraft become more automated, there are typically long periods of time during which there are little piloting tasks and thus the workload can easily be handled by one pilot. An operator on the ground could potentially be allocated to aircraft only during higher workload periods, and could perform other useful work during lower workload periods (such as helping other aircraft or performing dispatch duties).

Another potential benefit of replacing a pilot with enhanced ground support is that the ground could provide specialized support for specific issues. Much as a harbor pilot steers a ship through a particular harbor, a ground operator could be selected based on experience with landing at a particular airport or troubleshooting a particular problem.

To achieve these benefits, our ultimate concept of operations must provide a pool of personnel on the ground servicing the needs of single piloted aircraft. The ground personnel would provide varying levels of service depending on the state of the aircraft or pilot. In nominal conditions, en route aircraft might require little or no assistance from the ground. During heavier workload periods, such as on approach or departure, the ground might come in to reduce workload and crosscheck tasks performed by the pilot on board. In off-nominal situations, such as system failures, severe weather, or pilot incapacitation, the ground personnel could perform some or all of the duties that would typically be performed by the second pilot under current day operations.

Approach

To examine the feasibility of SPO, we are conducting a series of human in the loop (HITL) simulations. Each successive HITL in the series utilizes a more advanced ground station and a more fully evolved concept of operation. This spiral approach is born partially out of necessity (appropriate SPO systems stemming from modifications and refinement to current technology take time to develop) and partially out of a desire to uncover and mitigate potential obstacles a few at a time. This will give us a higher probability of achieving a functional system as opposed to overhauling an entire system at once based on our current knowledge.

SPO 1 – Affects of separation

Our first study examined essential crew decision-making and communication with a comparison of two conditions [4]. In one condition, a two-pilot crew flew off-nominal scenarios while seated next to each other to simulate current day operations. In the other, similar off-nominal scenarios were flown with the FO seated in a separate room

where the right side of the flight deck was recreated. Both pilots were assumed to be operating the same aircraft, but they were invisible to one another for experimental purposes. An ambient microphone allowed the pilots to talk as when seated side-by-side, but they could not view each other or exchange any physical items.

Notably, the results of this study revealed little difference in objective performance between the two conditions. However, most pilots preferred flying together, and they rated the separate condition more poorly for safety of flight, communication and coordination. One area that seemed particularly challenging within the separate condition was simply understanding what the other pilot was doing. Based on video reviews of the pilots' interactions, an analysis found many more incidences of confusion about what the other pilot was doing in the separated condition than in the together condition. With these findings and further feedback from the participants, we developed collaboration tools to help pilots enhance collaboration and become more aware of actions taken by the other pilot for SPO II.

SPO II – Current study

SPO I served to give us a basic understanding of pilot communications and the challenges that might arise as a result of physically separating members of a flight crew. SPO II put these findings to use in a more operationally relevant environment. In SPO I, pilots flew low fidelity aircraft that could be split into two flight decks that allowed for a straightforward examination of the difficulties of communicating task-relevant information without confounding influences created by different physical environments. In SPO II, one pilot flew in a high-fidelity full motion simulator while the other pilot flew in a prototype ground operator station that incorporated aspects of an airline dispatch station. Thus, the ground based and flight deck based pilots had access to somewhat different information and used equipment with somewhat different capabilities.

SPO I revealed that while control manipulations can be acknowledged non-verbally in two-pilot operations, acknowledgement may be forgotten or require extensive radio use in SPO. Additionally, there is risk of lack of situation awareness (SA) when pilots are physically separated, such as uncertainty about roles and responsibilities (e.g., Do you have the plane or do I?) uncertainty about control manipulation (e.g., Are you entering the altitude?) and uncertainty about completed actions (e.g., Did you put that in the box?). In SPO II, a suite of tools was introduced and empirically tested for usefulness and flight performance to address these CRM challenges when crews were no longer collocated.

Objectives

SPO II had two objectives:

1. To compare decision-making and communications between pilots in a current day configuration with those in an SPO environment.

2. To develop and evaluate a prototype ground operator station. In particular, to test the effectiveness of a suite of tools designed to overcome coordination problems found in SPO I when pilots were separated.

METHOD

Participants

The participants were 36 airline pilots with ATP certification under 14 CFR Part 121 and with CRM experience through their employers. Seventy-eight percent of the crews consisted of pilots from different airlines. The majority (78%) reported over 10,000 hours of experience as a line pilot (none less than 3,000). All were active duty, except five retired pilots (average length of retirement was seven months, range of two to 16 months). One two-pilot crew was tested per day.

Experimental design

The study utilized a Position (2) x Crew Configuration (3) mixed factorial design. The levels of the within-subject factor, Crew Configuration, were Baseline (both pilots on flight deck), and two single pilot configurations where there was a pilot on the flight deck and a pilot at the ground station. The two SPO configurations, in turn, were SPO with No Collaboration Tools (NCT), and SPO with Collaboration Tools (CT). The levels of the between-subject factor, Position, were Captain, who was the onboard pilot in command in all Crew Configuration conditions, and second pilot, who was the First Officer (FO) in the Baseline configuration, and the Ground Operator (GO) in the SPO configuration. Each crew was exposed to two scenarios in each condition. Each scenario lasted approximately 20 minutes.

The Baseline configuration was representative of current day operations with both participants operating on the flight deck. In both SPO configurations, the pilot who served as Captain in Baseline remained on the flight deck while the FO was transferred to our prototype ground station. A hot audio link between the flight deck and ground station was provided for voice communication. In all configurations, both operators had push-to-talk voice communication with ATC and both were provided approach plates and charts on an Electronic Flight Bag (EFB).

Aircraft simulator

The Advanced Concepts Flight Simulator (ACFS) located in the Crew-Vehicle Systems Research Facility (CVSRF) at NASA Ames Research Center was used for the aircraft simulator. The ACFS is a high-fidelity cab mounted on a six-degree-of-freedom synergistic motion system and employs optional advanced flight systems. For this simulation, the ACFS was modeled after a Boeing 737-900.

Ground station

For the SPO configurations, the ground station merged a simplified dispatcher station with remote flying tools. As such, it consisted of two conceptually separate areas. The right side of the station had a large traffic map similar to the displays typically seen in many dispatcher stations. This display was based on the MACS Display System

Replacement (DSR) and incorporated the advanced aircraft rerouting tools from that system [7]. This system was augmented with the ELP, which could provide a current list of the best runways for emergency landing and automated rerouting advice.

The left side of the ground station mirrored essential controls and instrumentation presented on the ACFS flight deck, with the exception of the side sticks and some aircraft systems controls, which were not used in this study. This implementation provided ground operator access to ACFS autoflight systems through a GUI Mode Control Panel (MCP) and access to the ACFS Flight Management System (FMS) through a GUI Control Display Unit (CDU). Secondary flight controls (landing gear, flaps, speed brakes) and secondary flight displays (aircraft synoptic and controls) were presented in GUI format as well. Instrumentation and information displays included: a primary flight display (PFD), a navigation display (ND), an Engine Indication and Crew Alerting System (EICAS) display, and video feed showing out-the-window view seen from the aircraft.

Conceptually, the aircraft displays and controls on the left side of the ground operator station could connect to any aircraft “owned” by the ground operator. However, in this simulation it was “hard wired” to the ACFS.

Collaboration tools

As described above, the SPO I study revealed a number of problems related to the loss of non-verbal communication. Some problems were related to flying the plane with an unseen pilot and were categorized as role uncertainty, manipulation uncertainty, and action uncertainty. These three categories can also be thought to involve future actions dictated by roles, current actions being performed by the other pilot, and past actions performed by the other pilot. Other problems were categorized as information gathering and decision-making.

In SPO II, solutions to these problems were designed and evaluated (see Table 1). To address problems with flying the plane with an unseen pilot, CRM indicators were developed to replace the non-verbal communication resulting from viewing a crewmember’s hand manipulate controls when pilots were side by side. Also, a video feed was installed to regain some ability to communicate nonverbally. To address problems with information gathering, a capability to share charts was added. To

address problems with decision-making, a capability to share the ground weather and route display was added. These solutions were available to the operators on both the flight deck and ground station for the CT configuration.

Video. The video feed allowed participants to view each other during the scenarios. Cameras and monitors were placed to the side of each station so that the perspective seen was roughly that which would be seen had both pilots been seated in the flight deck. Using this video feed, pilots could see if the other pilot was manipulating controls or roughly where the other pilot was looking (e.g., MCP, CDU, checklist, etc.).

Shared charts and displays. In this configuration, approach plates and charts could be viewed on the EFB in one of two modes: shared in which both crewmembers shared one display and would see the chart as the other manipulated it, and independent, in which each crewmember could independently manipulate their own charts. Using this view, one pilot could bring up an airport chart for the other or point out where a waypoint was located. Additionally, the ground station plan view traffic map could be viewed by the flight deck allowing a shared view of proposed routes, traffic and weather.

CRM indicators. Finally, six CRM indicators were a series of LCD displays that provided a mechanism for tracking responsibility, actions and acknowledgements.

On the flight deck, the indicators were implemented with touch-sensitive LED panels. The heading, speed, and altitude indicators were located below the corresponding controls on the MCP, and the Pilot Flying indicator was located to the left of the MCP. The CDU indicator was located above the Captain’s CDU, and the radio indicator was located above the FO’s CDU (see Figure 1). On the ground station, the indicators were grouped in a single window of a touch-enabled monitor (see Figure 2).

To mitigate potential confusions of roles and responsibilities in high workload environments, the text of the CRM indicators was color-coded green on the displays belonging to the pilot responsible for the task and white for the other pilot. The Pilot Flying indicator either read “PF” (in green) for the pilot flying and “PNF” (in white) for the pilot not flying. When “PF” was displayed, the text of the MCP indicators (“SPD” “HDG” and “ALT”) was green, and the text of the “CDU” and “ATC” became white. Pressing the Pilot Flying indicator switched colors and signified a switch in roles. MCP actions were displayed on the corresponding indicators with symbols (e.g., up or down arrows indicating changes in MCP speeds) and gave audio annunciations (e.g., “speed” enunciated speed changes). Once the action resulted in a stable value, that value was displayed in the indicator (e.g., “250”). Acknowledgements to MCP actions were made by pressing the corresponding CRM indicator. CDU actions were displayed as “...” on the indicator and gave the audio annunciation of “CDU”.

Table 1. SPO I problems and SPO II solutions

SPO I Problem	SPO II Solution
Role uncertainty	Pilot Flying CRM indicator
Manipulation uncertainty	Action indicator, Video feed
Action uncertainty	Acknowledgement buttons (part of the CRM indicators), Video feed
Information gathering	Shared charts
Decision making	Shared plan view

Procedure and task

Each day consisted of approximately three hours of training, six 20 minute experimental scenarios, and a 90-minute debrief session in which additional feedback was gathered. Participants were provided with pre-flight briefing materials before each scenario (similar to current-day flight operations) which included relevant ATIS, charts and approach plates for airports in the region, and a flight plan, weather briefing, and maintenance briefing. Participants reviewed these materials prior to each scenario while sitting together in the Baseline configuration or sitting separately (with an audio link) in the SPO configurations. Scenarios were developed to maximize crew interaction and decision-making under difficult circumstances. Building off of SPO I scenarios, multiple diversion scenarios were constructed, all containing weather and systems challenges requiring the crews to divert to an airport other than their scheduled destination. For example, one scenario began with the aircraft low on fuel on descent into Denver. At 30 seconds into the scenario, ATC informed the flight deck that there has been a microburst at DEN and to expect holding. At 90 seconds, they were given holding instructions and an expect further clearance time of 10 minutes. (Since they only had fuel for 5 minutes, they were expected to divert to Cheyenne, their filed alternate, at this time.) At 5 minutes, they received a warning that their aft cargo door was open. And at 9 minutes 30 seconds, their weather radar failed (requiring them to coordinate with ATC to avoid a small weather cell). These scenarios were designed in trios that required the crews to make similar types of decisions (e.g., in one trio aircraft were arrivals on descent and were forced to divert due to an airport closure). Scenarios were run in the same order for each crew; however, crews saw these scenarios in different configurations. For example, the first scenario was presented to the first crew in the Baseline configuration, but the second crew in the NCT configuration.

Roles and responsibilities for SPO II

In Baseline, the participant assigned the role of the Captain occupied the left seat of the ACFS. For CT and NCT configurations, the Captain remained on the flight deck as single pilot and the FO moved to the ground station to



Figure 1. Flight deck in SPO with Collaboration Tools configuration, with EFB tablet displaying shared plan view on the left and CRM indicators on the right. The video feed is on an EFB out of view on the far right of the cockpit.

assume the duties of the GO. Under off-nominal situations, high workload, or important decision-making points, the Captain was to request “dedicated assistance” from the GO. The GO served two distinct roles: airline dispatch for several company aircraft and remote FO for the Captain. In the first role, the GO was tasked with a simple, non-essential (but cost-saving) re-routing assignment for the company aircraft for which he or she was providing dispatch services. This task required the traffic map display and was used as a benchmark for the ground pilot’s ability to multitask without requiring coordination between multiple ground operators.

When the Captain requested dedicated assistance, the GO switched roles and became the FO for the Captain requesting assistance. Since the GO’s ground station was linked directly to the aircraft’s autoflight systems and secondary flight controls and presented similar displays to those on the flight deck, the Captain could ask the GO to assume any role a traditional FO would assume in a conventional two-pilot crew. In addition, as time permitted, the GO was told to continue performing the dispatch rerouting task on other aircraft. The GO remained FO of the aircraft that requested dedicated assistance until assistance was no longer needed at which point the GO would discontinue dedicated assistance in coordination with the Captain.

In the Baseline configuration, dispatch service was provided by a confederate researcher, and consisted of just the primary diversion option given by the ELP. This was meant to emulate the limited service provided by today’s dispatch and to equate the information available to the pilots across the three conditions. In all conditions, ATC service was provided by a confederate.

Dependent variables

A large quantity of data was gathered on each flight, including aircraft state information (recorded at ten hertz), video recordings, and audio recordings. This paper will focus on subjective data from two questionnaires. After each scenario, pilots completed a brief (11-question) post-trial questionnaire. This focused on pilots’ perceptions and cognitive processes related to that specific flight, such as workload and decision-making. After all flights, the pilots completed an extensive post-simulation questionnaire in which they were asked to give additional feedback. This



Figure 2. Ground station in SPO with the Collaboration Tools configuration, with video feed on the left and CRM indicators on the right.

included comments and critiques about their experiences of flight safety, workload, communication, crew coordination, and decision-making processes.

RESULTS

Subjective ratings were submitted to mixed-factorial analysis of variance (ANOVA) with Position (Captain, FO/GO) as the between-subject factor and Crew Configuration (Baseline, NCT, CT) as the within subject factor. Sidak post-hoc analyses were then run to reveal the nature of significant effects.

Post-trial ratings

At the end of each trial, pilots were asked to rate 11 items on a 9-point likert-type scale (specific anchors varying by item) relating to safety, workload, ability to make decisions, coordination, awareness and communication. Significant main effects were found for configuration in five of the 11 ratings (plus two with marginal significance). No effects were found by position. In all cases, NCT and CT ratings did not significantly differ; however, SPO ratings often differed from Baseline.

Safety and workload

There was a significant main effect for the safety of flight rating, $F(2, 68) = 5.58, p < .01$. Pilots rated Baseline ($M = 7.70$) as safer than NCT ($M = 6.89$) and CT ($M = 6.83$). Workload ratings, however, did not differ by configuration. Both the average workload and peak workload were rated similarly across Baseline ($M = 6.47$ and $M = 7.42$), NCT ($M = 6.60$ and $M = 7.53$) and CT ($M = 6.69$ and $M = 7.72$).

Coordination and decision-making

Configuration significantly effected the crew's ratings of their ability to make decisions ($F(2, 68) = 3.49, p = .04$) as well as the difficulty coordination concerning diversions ($F(2, 68) = 4.38, p = .02$). However, comparisons revealed only marginal differences between Baseline ($M = 7.14$ and $M = 7.35$) and NCT ($M = 6.56$ and $M = 6.85, p = .069$ and $p = .053$, respectively). Between Baseline and CT, no difference was found in the decision-making rating ($M = 6.50$), but there was a marginal difference for difficulty coordinating ($M = 6.63, p = .056$).

Awareness

Agreement with the statement "I was aware of what the other pilot was doing most of the time" was good, but differed significantly as a function of configuration ($F(2,68) = 23.81, p < .001$). Baseline ($M = 8.26$) was rated higher than either NCT or CT ($M = 6.88, M = 6.86$) with both post-hoc contrasts significant ($p < .001$). Similarly, pilots rated the other crewmember's awareness of developing conditions as good: Baseline ($M = 7.58$), CT ($M = 6.99$), and NCT ($M = 7.28$), with an overall significant main effect of configuration ($F(2, 68) = 3.52, p = .04$). Of these, only the post-hoc contrast between Baseline and CT approached significance ($p = .051$). Finally, when asked to rate their own awareness of developing conditions during the flight, they gave moderately high ratings for all configurations: Baseline ($M = 7.28$), NCT ($M = 6.75$), and

CT ($M = 6.83$). However there was no significant effect of configuration for this rating.

Communication

Lastly, pilots was rated their communication as similarly effective across configurations: Communication with the other crewmember: Baseline ($M = 7.71$), NCT ($M = 7.24$), and CT ($M = 7.15$); Communication about the approach plates: Baseline ($M = 7.73$), NCT ($M = 7.14$), and CT ($M = 7.23$); Communication concerning weather: Baseline ($M = 7.74$), NCT ($M = 7.24$), and CT ($M = 7.40$). Analysis of the impact of configuration on general effectiveness of communication with the other pilot, and with the other pilot about the approach plates, were both marginally significant ($p = .06$). Relevant Sidak post-hoc pairwise comparisons were not significant.

Post-simulation ratings and comments

Upon completion of the simulation, participants were asked to rate and comment on a number of questions regarding various aspects of their experience in the simulation.

SPO feasibility

Pilots were asked to rate on a 9-point scale (1: Completely Infeasible – 5: Partial Feasible – 9: Completely Feasible) how feasible they believed single pilot operations would be in 10 years. Pilots rated this item after the initial briefing just prior to training and again at the end of the simulation. Interestingly, pilots rated SPO as less feasible at the end of the day ($M = 4.31$) compared to their initial response ($M = 4.78; F(1, 34) = 5.16, p = .03$). The lower ratings may be due, in part, to our specific concept of operation and the challenging off-nominal events presented in the simulated flights.

SPO collaboration tools

Pilots also rated, again on a 9-point scale, the individual tools provided in the CT configuration scale (1: Not Useful – 5: Somewhat Useful – 9: Very Useful). Pilots rated the shared charts ($M = 6.11, SD = 2.66$), shared plan view of air traffic and weather ($M = 6.56, SD = 2.41$) and CRM indicators ($M = 6.14, SD = 2.18$) all somewhat useful. However, the video screen showing the other pilot was not rated as useful ($M = 4.44, SD = 2.65$). Given that pilots rated non-verbal communication with the other pilot as important ($M = 6.92, SD = 2.52$), we had hoped that video could help provide this form of communication.

Comparison of configurations

Pilots were asked to rate each of the configurations along seven dimensions such as safety and ease communication. Significant main effects of configuration for all seven groupings, with Baseline rated significantly "better" than either SPO configuration on all seven dimensions and CT rated significantly better than NCT on six of the seven. No main effects were found for position.

In the ratings of safety ratings there was a significant overall effect ($F(2,68) = 45.42, p < .001$), with Baseline ($M = 8.58$) rated higher than either SPO configuration, and CT ($M = 6.78$) rated higher than NCT ($M = 5.89$; all comparisons, $p < .01$). A similar effect was found for

workload ($F(2, 68) = 27.99, p < .001$), with Baseline ($M = 5.19$) less than NCT ($M = 6.86$) and CT ($M = 6.56$; both $p < .001$). The difference between CT and NCT was not significant.

Pilots made three ratings of ease of communication (verbal, non-verbal, and overall). Again, for each of these there was a significant effect of configuration ($F(2, 68) = 26.68, p < .001$; $F(2, 66) = 50.23, p < .001$; $F(2, 68) = 34.47, p < .001$, respectively). In each of the three, there were significant differences between all pairs of configurations (all with $p < .01$): pilots rated communication as more effective in Baseline ($M = 8.33, M = 7.31, \text{ and } M = 8.28$, respectively) than in CT ($M = 7.19, M = 4.89, M = 6.72$) and in CT than in NCT ($M = 6.53, M = 3.29, \text{ and } M = 6.08$). In the case of non-verbal communication, an interaction was found between position and crew configuration ($F(2, 66) = 3.45, p = .04$; see Figure 3). Non-verbal communication was rated the least effective by the GO in NCT.

There were significant effects on ease of both crew coordination ($F(2, 68) = 50.24$ and $p < .001$), and decision-making ($F(2, 68) = 50.24, p < .001$). Pilots rated both coordination and decision-making easier in Baseline ($M = 8.33$ and $M = 8.39$) than in CT ($M = 6.44$ and $M = 7.19$, respectively), and easier in CT than in NCT ($M = 5.58$ and $M = 6.14$) (all with $p < .001$).

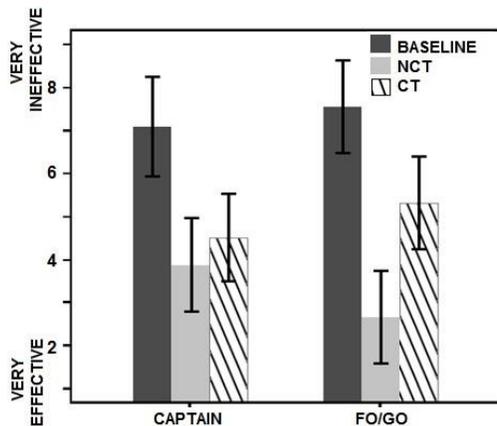


Figure 3. Non-verbal communication effectiveness by position and configuration with standard error bars

DISCUSSION

Comparisons of the SPO and Baseline configurations

Our first objective in SPO II was to examine distributed decision-making and communication between the crew under our current SPO concept of operation. The current day configuration of both pilots together (Baseline), was consistently rated more favorably than either SPO configuration. On most post-trial and post-simulation ratings, Baseline was rated significantly better, while neither SPO configuration was rated better than Baseline on any. This was not entirely unexpected given that all our pilots had flown thousands of hours in this configuration. When compared to SPO I [3] which featured a similar contrast between separate and side-by-side seating, there is some evidence that pilots were even more poorly disposed

to SPO in SPO II. In particular, post-trial ratings of decision-making, crew coordination and situation awareness were all nearly identical in SPO I, but differed significantly (or at least marginally so) in SPO II. There were several differences between the studies that might have resulted in such a difference. Workload was higher in SPO II, the fidelity of the simulation was higher and the post-trial questions were worded slightly differently, any of which might have resulted in exposing differences that were not found in SPO I. A more interesting possibility is that the role of the “First Officer” was different in the two studies. In SPO I, the FO had exactly the same role as in current day operations; pilots were told to think of the FO as being on the same flight deck, but invisible so that all communications must be verbal. In SPO II, the “First Officer” was on the ground performing a hybrid dispatcher/pilot role. This may have engendered a variety of communication (since the two pilots were not in the same situation) and trust issues (since the ground pilot didn’t have “skin in the game”). While these data certainly do not prove that a change in roles opens up such issues, we should take them as a warning and investigate in future studies.

While clear differences were found between the Baseline and the two SPO configurations, this should not be taken as a rejection of the SPO concept. The SPO configurations generally received positive ratings, just not as positive as Baseline. Communication with each other, communication about approach plates, and communication concerning weather were easy and effective in all configurations. Ratings of coordination with each other concerning diversions, awareness about developing conditions, and actions of the other pilot were good.

SPO ground station prototype and collaboration technologies

The second objective was to develop and evaluate a prototype ground station with collaboration technologies to aid communication with the flight deck pilot. These collaboration tools (described in the Methods section) were designed to overcome confusions and lack of SA found when pilots were separated in SPO I.

Ratings of the collaboration tools tell two divergent stories. With the post-trial questionnaire, no advantage was found for the collaboration tools. This is disappointing since the collaboration tools were created to overcome problems with separating pilots found on a similar questionnaire in SPO I. On the post-simulation questionnaire however, the pilots consistently rated the Collaboration Tools configuration better than the No Collaboration Tools, and rated all the tools (aside from the video feed) as being at least somewhat useful. We believe the reason for this divergence is that pilots answer more generally with regard to the concept on the post-simulation questionnaire, whereas they were focused on their specific experience in the preceding scenario on the post-trial questionnaire. In comments, many pilots complained about specific aspects of the implementation of the tools. It is possible that their

post-simulation ratings reflect the potential for these tools more than the actual implementation that the post-trial questionnaire may reflect.

Most pilots found the shared displays useful, commenting, for example: *“this increased overall awareness greatly,”* and *“in a high workload environment, it was very useful to have one person pull up the chart while the other tends to other tasks (division of labor).”* However, many also complained about the interface, commenting, for example *“the interface was clunky,”* and *“this was useful, but VERY difficult to manipulate with fingers.”* This issue is likely to be due to the (touch screen) EFB interface for viewing the charts on the airside, which simply mirrored the mouse driven ground-side display. A true touch interface may have helped considerably instead of the desktop interface used.

Similarly, most pilots found the CRM indicators useful, commenting, *“It is important to know who is in control of the A/C, so this is a necessary component.”* However, many pilots indicated that they required practice, e.g., *“Good tool, hard to get familiar with in time allowed.”* This suggests that, with more training they may have been rated higher. Pilots also complained about the frequency of some annunciations, e.g., *“[The CDU annunciations]... I don't know if that was really helpful, you know, 'CDU, CDU' ...if she's not yapping because the speed breaks are being left on or the altitude's changed, why would she yap about the CDU?”*

Finally, pilots generally gave the video lower ratings than the other tools. Captains complained that the layout of the ground station was unfamiliar, so simply looking at what the Ground Operator was doing was not highly informative. Also, unlike pilots seated together on a flight deck, neither of the video displays was truly within peripheral vision. While, the video display at the ground station could be sampled simply by a glance, the small size and location of the video display on the flight deck required the pilot to turn his head to see it. Finally, while pilots may use vision to quickly examine the other crew-member's face and body language in order to gather information about the other's anticipated actions, decision-making certainty, workload, etc., in this study there were other methods of gaining this information in a potentially more direct fashion (i.e., shared displays, information indicators, voice communication). Relative to these other methods, the video feed may have not been the most effective method to gain this information. This is further suggested by the pilots' written comments: *“not really used that much,”* *“[it was] a distraction,”* and *“paying attention peripherally to the other pilot was not possible.”*

CONCLUSION

Overall, SPO II demonstrated that separating a two-pilot crew is feasible within the parameters and concepts we designed and tested, with all flights' urgent and challenging situations handled in a relatively successful manner (no

aviation accidents). On average, results showed a moderately favorable rating in all three configurations, although pilots rated SPO flights less favorably than conventional flights with both pilots onboard.

Both comments and ratings suggest a need for further refinement of the ground station and collaboration tools with valuable advice to make those adjustments. Modifications to the CRM indicator design and adjustments to the annunciation triggers, removal of the video feed (or with an option to turn it off) as well as development of a native touch interface for the shared charts may improve the collaboration tools effectiveness in a distributed environment such as single pilot operations.

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