Reduced Crew / Single Pilot Operations for Commercial Aircraft – Concept of Operations and Technology Needs

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In 2012, NASA began exploring the feasibility of single pilot operations (SPO) in the context of scheduled passenger air carrier operations (i.e., Parts 121 and 125). Technology and automation, especially aircraft automation, have significantly advanced in the 21st century and may be enabling to SPO. However, a move to SPO also has significant challenges. The purpose of this three-year NASA effort was to identify those challenges through workshops, analytic studies, and human-in-the-loop simulations assessing promising concepts and prototype solutions.

While much of the work over the last three years focused on SPO, there were also implications for reduced crew operations (RCO; going to two pilots in operations where three or four are currently required such as long haul flights). Further, much of the work suggested pathways for improving safety and efficiency in current operations. Therefore we use “SPO” or “RCO” according to the context in which the work was done.

Two workshops held on two continents pooled together experts in the US and Europe to discuss the challenges involved in implementing SPO/RCO. A three-day workshop on SPO held at NASA Ames in April 2012 yielded a list of issues including authority and accountability, communication, certification, aircraft design, workload, acceptance by stakeholders and the public, training, NextGen impact, crew resource management (CRM), and safety and security. Participants at the NASA workshop also discussed the feasibility of various potential configurations and distributions of roles and responsibilities between air and ground crew and between human and automation.

To determine whether minimal crew complement can be further reduced, it was important to determine what present day operations involve. To that end, several task analysis studies were conducted. Schutte (2015) enumerated all of the flight deck tasks performed by the Pilot Flying (PF) and the Pilot Monitoring (PM) and identified situations that could negatively impact SPO. Wolter and Gore (2013, 2014) performed a preliminary high-level task analysis of both current day and SPO environments of specific scenarios, with validations provided by interviews with subject matter experts (SMEs). Mosier and Fisher (2014) conducted an extensive literature review on CRM training, practices, and procedures giving considerations to how they might apply (or not) in SPO. Wilson, Harron, Lyall, Hoffa, and Jones (2013) reviewed the current certification requirements and practices for Parts 121, 125, and 135 operations.

After assessing the state of art and practice in automation, air-ground communication and collaboration, and practices like CRM, a solution space was laid out. This space covered a range of aircraft modifications from current flight decks, retrofits, and entirely new designs. Similarly, it covered a range of possible ground support including current air traffic control and dispatch, full time, part-time, and on-demand ground assistance, and remotely flying the aircraft.

Within the solution space several promising concepts were chosen and prototypes and procedures were developed, and four human-in-the-loop (HITL) studies were conducted to assess the effectiveness and further sort out and identify issues. The Single Pilot Operations Observational Study (SPOOS) assessed the ability of a single pilot to fly with no additional assistance. Two pilots flew a full mission simulation together and separately. Not surprisingly, workload and errors were both higher when the pilots flew alone, however, all errors were minor and both pilots rated the workload as manageable.

SPO I compared crew decision-making and communication between crews that were collocated in a single cockpit and crews that were separated. The study utilized high workload off-nominal scenarios requiring diversion decisions. Most pilots preferred flying together, and they rated the separate condition more poorly for safety of flight, communication and coordination, even though little difference in objective performance was found between the two conditions. An analysis of the pilots' interactions found many more incidents involving confusion about what the other pilot was doing in the separate condition than in the together condition. With these findings and further feedback from the participants, collaboration tools were developed to facilitate remote collaboration and help pilots become more aware of actions taken by each other.

In SPO II, we attempted to differentiate the roles of the two pilots, one as the airborne captain, and the other in a ground-based hybrid pilot/dispatch role, performing limited airline dispatch functions and first officer functions in cases of high workload or off-nominal situations. SPO II also implemented and evaluated the collaboration tools developed based on SPO I results. These tools included "CRM indicators," which were touch sensitive LCD panels, as a mechanism for tracking responsibility, actions and acknowledgements. In addition to the CRM indicators, pilots were provided a video feed allowing observation of each other's actions, and shared charts. Feedback on all three tools (CRM indicators, video, and shared charts) was generally positive although pilots had multiple suggestions for improvement. This study utilized even higher workload variants of the scenarios developed for SPO I.

SPO III examined the importance of giving opportunities to a ground operator to acquire situation awareness (SA) prior to being called on to assist an aircraft. In this study, a ground operator acted as a dispatcher, until one of his aircraft had an off-nominal situation, at which point he entered "dedicated assistance," that is he assumed the role of first officer, and handed off his other aircraft. The study employed high workload diversion scenarios similar to those used in SPO II. Results provided no evidence that a ground operator's lack of initial SA when called on for dedicated assistance has any effect on workload or even SA once the ground operator enters dedicated assistance. With appropriate displays, ground operators were able to jump in and provide assistance, even if they had minimal SA prior to getting a request.

The outcome of the aforementioned effort is a set of potential concepts of operations that could enable both SPO and RCO – with further development and research and a plan for this research and development.

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Outline

- What is RC/SPO
- Findings of Initial SPO Technical Interchange Meeting
- Research Summary

What is SPO?

- Only one pilot (captain) in cockpit of commercial aircraft that currently require a two-person crew
- Captain is assisted by advanced cockpit automation and new ground operators with support tools
- Removing first officer cuts cockpit crew cost by ~50%; secondary benefits from better crew connection integrity
- Savings will be offset by costs of new automation/tools and additional ground personnel to maintain safety

Desired **Attributes of SPO**

- At least as safe as current Part 121 commercial operations that currently require two pilots and flight dispatcher
- Negligible additional burden on air traffic service provider
- Technologically feasible
- Operationally viable
- Economically beneficial

SPO Technical Interchange Meeting (TIM)

- **Goal**
  - Develop a set of critical research issues that can be used to inform the planning for a research effort examining the feasibility of a move from two-pilot to single-pilot flight decks
- **Location**
  - NASA Ames Research Center, April 10-12, 2012
  - 70 Attendees divided between government, academia and industry
- **Structure**
  - One day of invited talks and 1 day of intensive discussions in break out groups
- **Output**
  - Proceedings and Summary (NASA/CP—2013–216513)

SPO TIM Findings

Majority View: Industry is moving toward single pilot operation. There were two dominant concepts:

- **Flight Deck Automation:** A flight deck with very intelligent automation that can effectively replace the functions of the First Officer.

- **Ground-Based Support:** An air-ground collaboration, with many of the First Officer functions being handled remotely.

SPO TIM Findings – General Issues

- **Automation**
  - Legal – can automation be responsible (limits of autonomy)?
  - Potential for Degraded Situation Awareness
  - Skill Degradation
  - Should ask what single pilots can do without more automation

- **Operational Issues**
  - Will future single pilots be able to manage the workload when and if significant new responsibilities are shifted to flight decks?
    - NextGen
    - SESAR
    - TBO

SPO TIM Findings – General Issues (continued)

- **Pilot Incapacitation** – *When, how, and if to take over command of aircraft from the pilot*
  - Frequently mentioned issue and perhaps the most controversial
    - Some participants thought this would make single pilot operation infeasible
    - Some participants thought it was overemphasized
  - Majority believed it was extremely important but could be addressed through
    - Real-time pilot physiological health monitoring
    - More frequent / more sophisticated medical examinations
  - Mental incapacitation identified as particular challenge

SPO TIM Findings – General Issues (continued)

- **Communications and Social Issues**
  - Effects of boredom, especially with increased automation (lower workload), affecting situational awareness
  - Lack of peer pressure from second pilot to “stay on the ball”

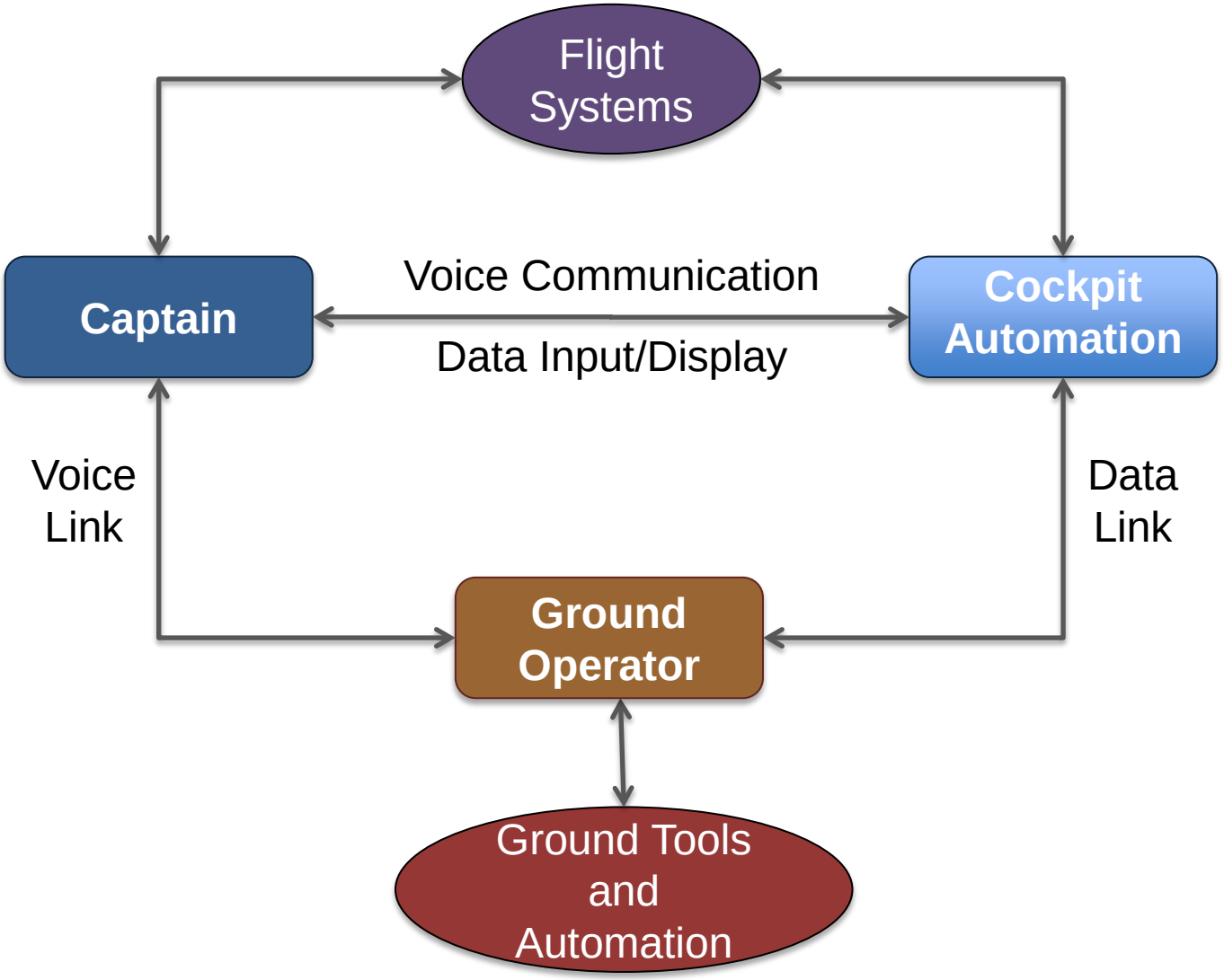
- **Certification / Approval of SPO for air carrier operations**
  - Evaluating complex hardware/software
  - Showing equivalent levels of safety with new operational concepts

Concept of Operations

What replaces the second pilot?

- Flight deck automation
  - Paul Schutte, NASA Langley
- Ground personnel
  - Walter Johnson, NASA Ames
- Ultimately both approaches are needed.
- Combined con-ops

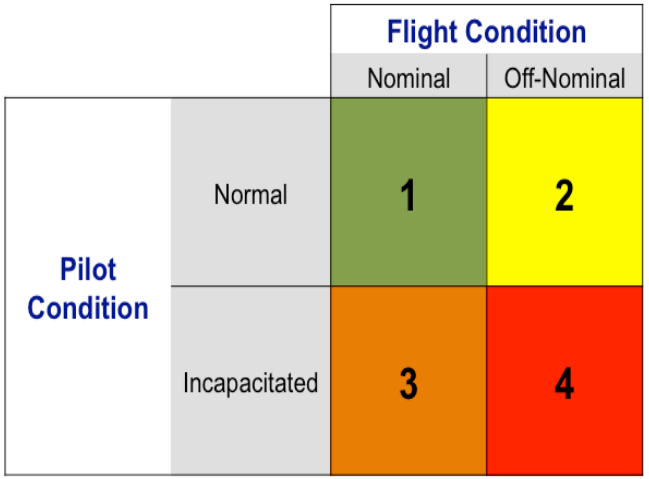
Concept of Operations
Principal Agents in SPO



Concept of Operations
Function Allocation for SPO Agents

- Captain (unless incapacitated) is in command of the flight

- Cockpit Automation
  - Supports all SPO conditions
  - Provides piloting monitoring support needed for nominal operations
  - Interacts with Captain and/or Ground Operator, as needed
  - Able to autonomously land aircraft when pilot incapacitated and link lost



- Ground Operator & Automation
  - Dispatch for multiple aircraft (Conditions 1, 2, 3, 4)
  - Basic piloting monitoring support for multiple nominal aircraft (Condition 1)
  - Dedicated piloting support for one off-nominal aircraft (Cond. 2, 3, 4)

Air-Ground Options Space

	Nominal Operations	Off-Nominal Operations
Pilot Healthy	**1** Captain is in command, assisted by Cockpit Automation Ground Operator monitors and supports multiple aircraft assisted by Ground Automation	**2** Captain is in command, assisted by Cockpit Automation Ground Operator provides 1-on-1 support as remote First Officer
Pilot Incapacitated	**3** Cockpit Automation executes control commands Ground Operator assumes command and is responsible for flight safety	**4** Cockpit Automation executes control commands Ground Operator assumes command and is responsible for flight safety unless lost link

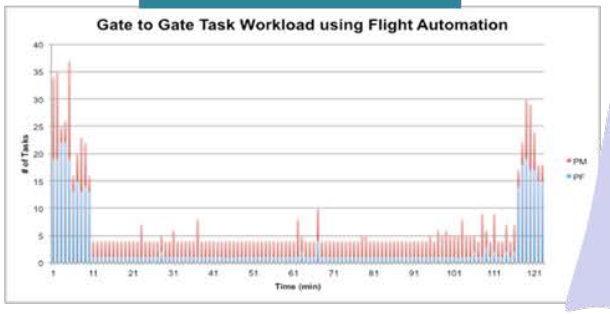
Summary of Research

Characteristics of Impaired Pilots

Emergency Landing Planner

Prototype Ground Station with CRM Tools

Functional Analysis



2015 - 2020

R&D on Increasingly Autonomous Systems

April 2015 — Concept of Operations

July 2014 — Prototype Ground Station ConOps Simulation Evaluation

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Identified Characteristics of Impaired Pilots

August 2013 — Prototype Ground Station Simulation Evaluation *(with CRM tools)*

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Part 121 SPO Feasibility Assessment – Simulation Eval. *(feasible but requires enhanced support at choke points)*

August 2012 — Non Co-Located Pilot Simulation Evaluation *(identified impact to CRM)*

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Part 121 SPO Feasibility Assessment – Functional Analysis *(choke points: terminal area, non-normals, preflight, checklists) (identified tasks for pilot, cockpit automation, ground support)*

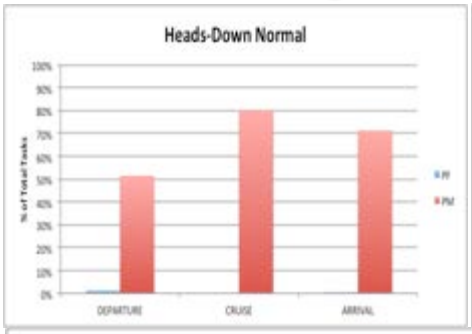
April 2012 — SPO Technical Interchange Meeting *(70 attendees between government, academia and industry)*

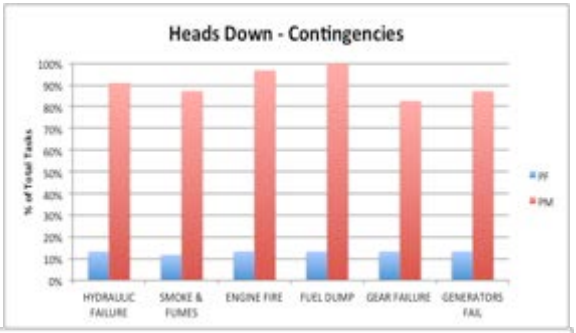
Flight Deck Studies

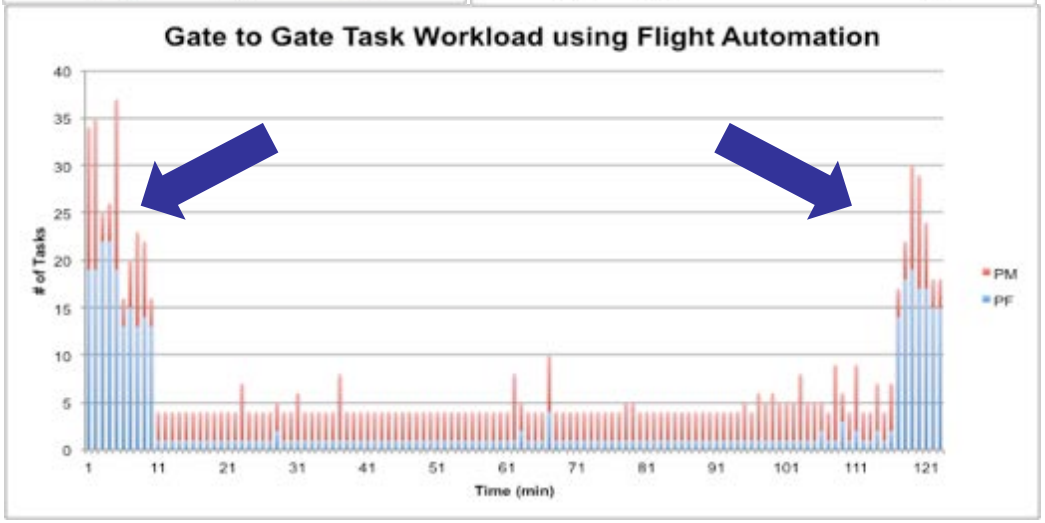
- **Task Analysis**
- **Simulation of SPO on Current Day Cockpit**
- **Monitoring the Pilot**

SPO Part 121 Feasibility Assessment using Task Analysis

- **Approach**
  - Develop a full task analysis
  - Allocate tasks based on factors *(PF or PM, heads up or heads down, …)*
  - Identify *'choke points'* and challenging areas for SPO







- **Results**
  - PF generally has continuous, heads up, aviate and navigate tasks
  - PM generally has discrete, heads down, communicate or systems tasks
  - Choke points exist in terminal area, non-normals, preflight and checklists
  - Aviate, navigate, communicate, heads up tasks best suited for pilot
  - Aviate, navigate, systems continuous tasks best suited for onboard automation
  - Navigate, communicate, systems, discrete tasks best suited for ground support

SPO Feasibility Assessment
Current Flight Decks

- **Approach**
  - Have current 'glass cockpit' pilots fly full mission flights by themselves using current automation
  - Observe for signs of stress, amount of heads up and heads down time
  - Question subjects on their experience

- **Results**
  - Subjects were able to fly gate to gate missions
  - Only errors were missed call signs
  - Stress levels were higher than in duel crew operations
  - Subjects felt that they could not have done SPO in bad weather, complicated or unknown airports, any non-normals, or without automation
  - Subjects also missed second pilot in terminal operations
  - Subjects felt less confident with no cross checking or back up

Monitoring the Pilot

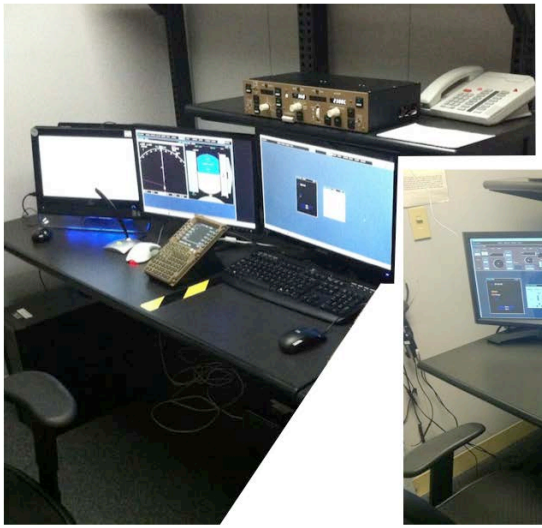
- With a single pilot in the flight deck, the automation will have to monitor, not only the pilot's health, but also the pilot's actions and responses.
- Two human in the loop studies were conducted to assess our ability to monitor the human
- One study looked at the ability to use steady state visually evoked potentials (EEG) to detect if the pilot was actually processing information versus looking-but-not-seeing
  - 60 subjects
  - Results of SSVEP were not easy to interpret but showed some promise
- Second study looked at pilot performance (both behavioral and neurophysiological) when impaired (due to induced hypoxia)
  - Test ongoing - 15 of 25 subjects to date
  - Reduced Oxygen Breathing Device (ROBD2)

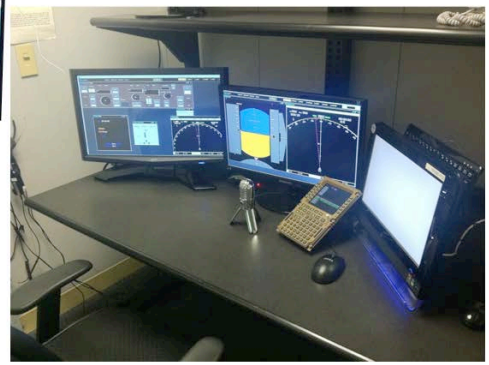
Air-Ground Studies

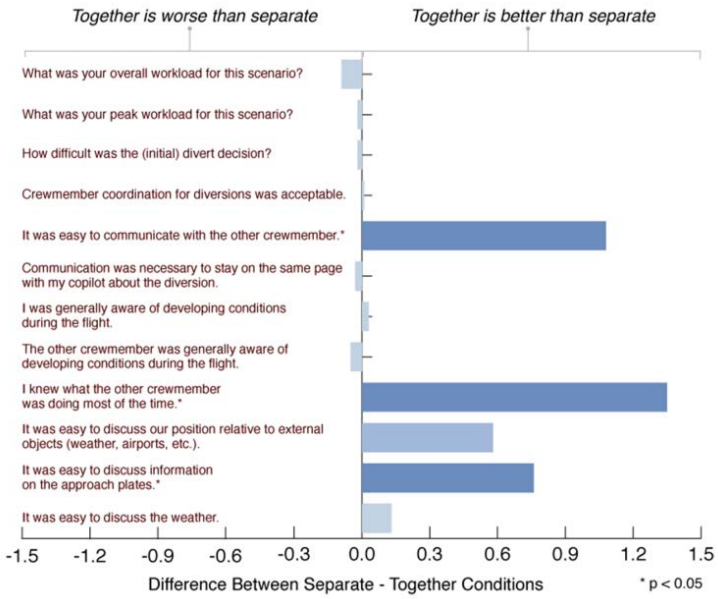
- **SPO I: Split Flight Deck Study**
- **SPO II: Developing a Ground Station for Dedicated Support**
- **SPO III: Evaluating Ground Operator Concepts for Dedicated Support**
- ***SPO IV: Developing a Ground Station for Super-Dispatch Support***

SPO I: Split Flight Deck Study

- **Goal**
  - Evaluate impact of crew separation on flight performance and crew workload, SA, and communications
- **Approach**
  - HITL evaluation of ATP pilots flying difficult off nominal scenarios requiring diversions and when sitting
    - Side-by-side
    - In separate rooms with open mic
  - Evaluate dependent measures *(workload, observed confusion, ratings of communication and decision making, etc)*
- **Results**
  - No evidence that separation affects flight performance
  - Risk factors related to Crew Resource Management (CRM)
    - Reduced awareness of pilot actions
    - Specific communication issues
  - Suggested mitigations
    - Video
    - Acknowledgement indicators
    - Shared data views







SPO II: Ground Station / Flight Deck Design for CRM

- **Goal**
  - Evaluate ground station /flight deck design incorporating CRM mitigations addressing problems seen in SPO I
- **Approach**
  - HITL Evaluation of dedicated (one-on-one First Officer) ground support for
    - SPO with CRM tools,
    - SPO without CRM tools,

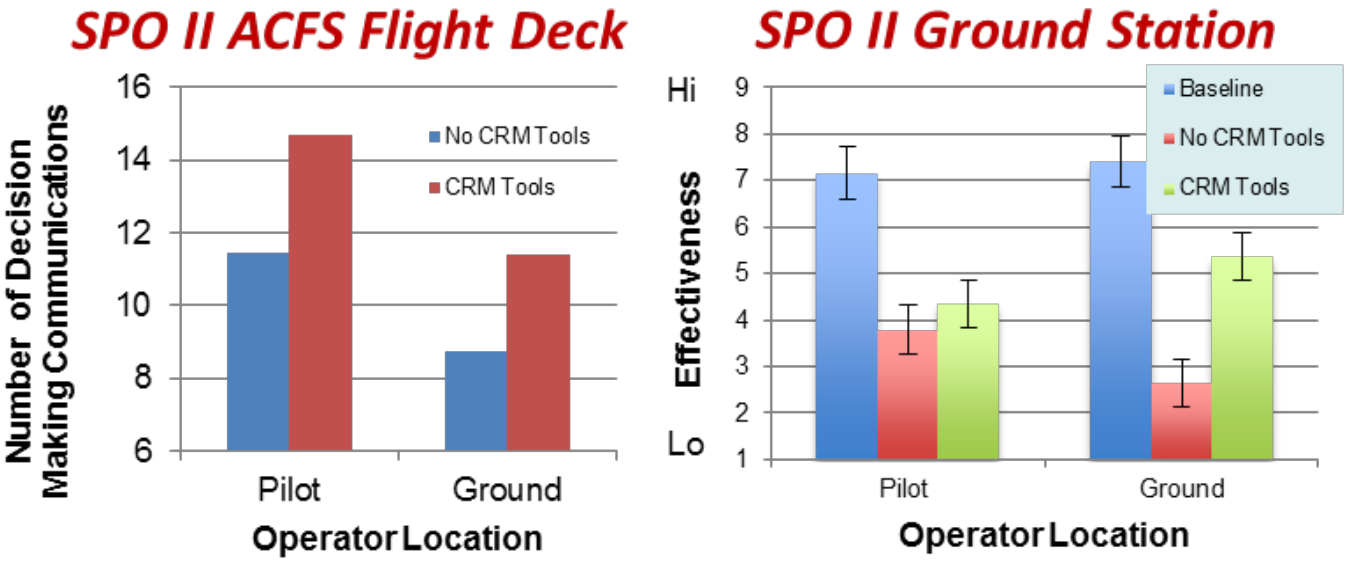
    and
    - Traditional 2 pilot flight operation

    during off nominal approach and arrival scenarios requiring diversions

CRM Tools

- CRM Indicators
- Shared charts and displays
- Shared Plan View Traffic, Weather, & Rerouting Display
- Video – views of other operator
- Out the Window display (limited field of regard)

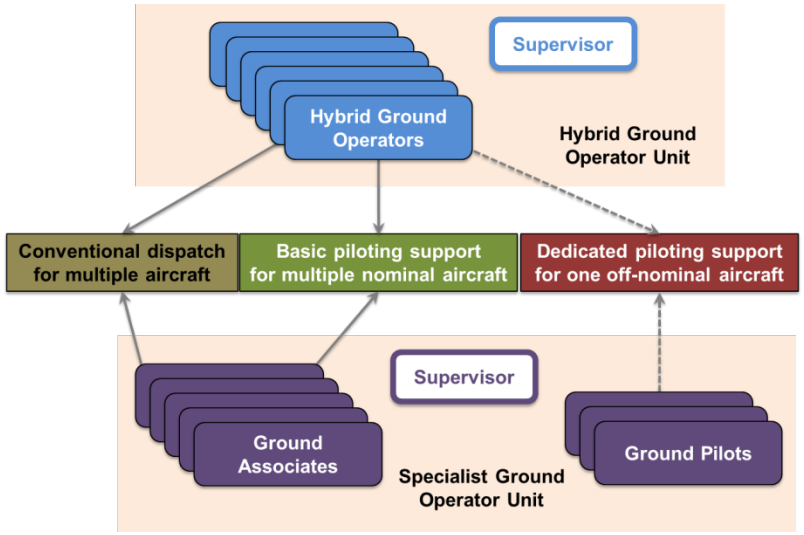
SPO II Results



- Pilots preferred baseline condition (flying together), but all flights managed successfully
- Favorable/positive ratings of newly developed CRM ground station tools
- Communications analysis showed more communications when CRM tools provided
- Pilots agreed that the concept, while not what they like, appears feasible
- When using collaboration tools more content was exchanged, and at a greater rate. This was a particularly reliable finding for acknowledgements.

SPO III: Ground Operator ConOps

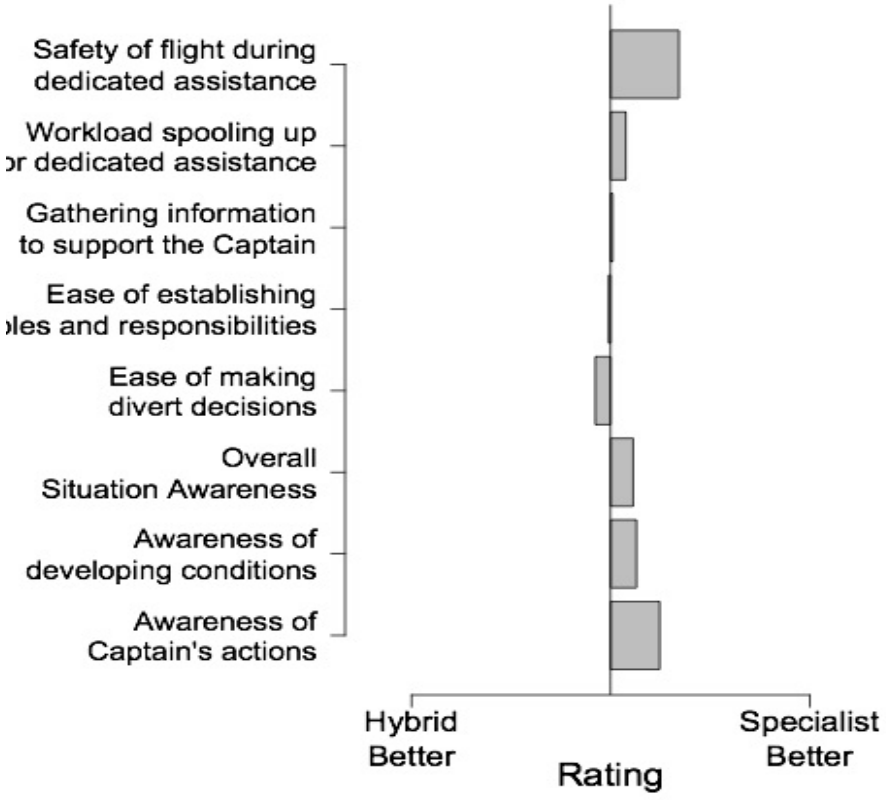
- **Goal**
  - Evaluate SA implications of two ground operator ConOps
    - **Specialist**: A *super dispatcher* monitors multiple SPO aircraft and hands off any aircraft needing dedicated assistance to a *specialist* who is trained to function as a First Officer (low initial SA)
    - **Hybrid**: A *super dispatcher/specialist* monitors multiple SPO aircraft and provides dedicated assistance when needed while handing off the remaining aircraft to other super dispatchers (high initial SA)



SPO III: Ground Operator Results

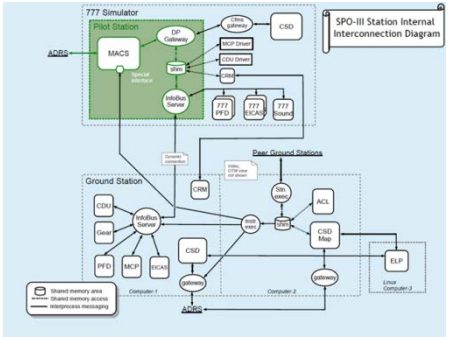
- **Approach**
  - HITL evaluation of performance, workload, and acceptability during dedicated (one-on-one First Officer) ground support for
    - Specialist ConOps
    - Hybrid ConOps

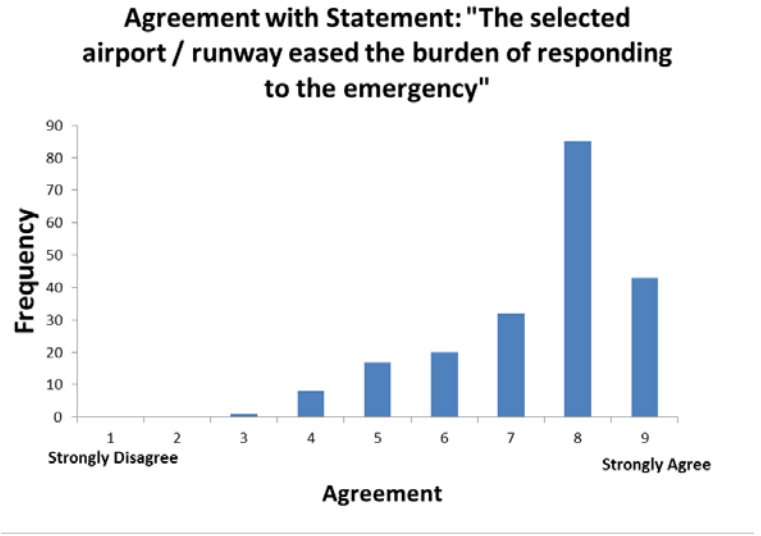
    using off nominal approach and arrival scenarios requiring diversions
- **Results**
  - No meaningful differences detected between the two concepts indicating that initial SA was not a critical factor

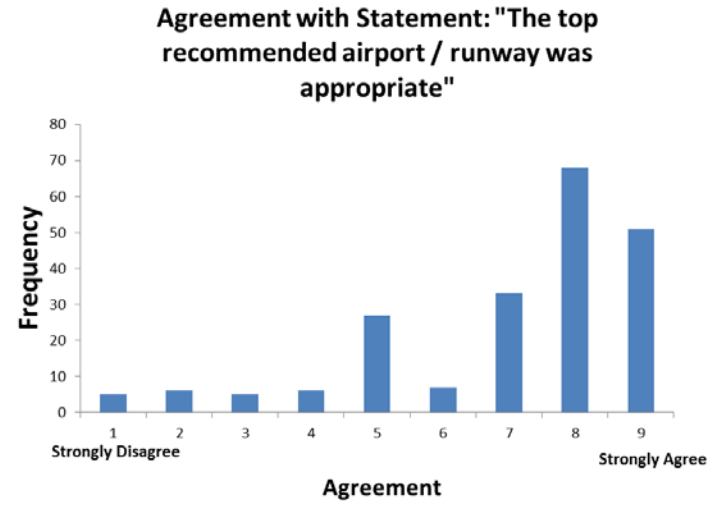


SPO III: Landing Planner Evaluation

- **Goal**
  - Adapt and evaluate a ground station implementation of NASA's Emergency Landing Planner (ELP)
- **Approach**
  - Present diversion options ranked according to the ELP's calculated risk metric
    - Consider all runways within range (150 miles)
    - Construct "obstacles" for weather & terrain
    - Search for paths to each runway
    - Evaluate risk of each path
    - Present ordered list
  - Gather data on whether pilots agreed with the ELP's top choice, and whether they found it useful
- **Results**
  - Pilots nearly unanimously liked having the tool
  - Most pilots wanted to be shown more about why and how it made the choices that it did







SPO IV: Automated Pilot Monitors

This study is planned to run in early 2016 and will examine

- Aircraft system and flight conformance monitoring automation that will allow a ground based operator/“Super Dispatcher” to simultaneously oversee multiple single-piloted aircraft

- An enhanced Landing Planner that will incorporate better transparency and allow automated evaluations of arbitrary airports and routes selected and designed by a ground operator or a pilot.

Thank You

Questions?