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NASA's Single-Pilot Operations Technical Interchange Meeting: Proceedings and Findings

Doreen Comerford
Summer L. Brandt
Joel Lachter
Shu-Chieh Wu
San Jose State University Research Foundation

Richard Mogford
NASA Ames Research Center

Vernol Battiste
San Jose State University Research Foundation

Walter W. Johnson
NASA Ames Research Center

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Executive Summary

Researchers at the National Aeronautics and Space Administration (NASA) Ames Research Center and Langley Research Center are jointly investigating issues associated with potential concepts, or configurations, in which a single pilot might operate under conditions that are currently reserved for a minimum of two pilots. As part of early efforts, **NASA Ames Research Center hosted a technical interchange meeting in order to gain insight from members of the aviation community regarding single-pilot operations (SPO).** The meeting was held on April 10-12, 2012 at NASA Ames Research Center. Professionals in the aviation domain were invited because their areas of expertise were deemed to be directly related to an exploration of SPO. NASA, in selecting prospective participants, attempted to represent various relevant sectors within the aviation domain. Approximately 70 people representing government, academia, and industry attended. A primary focus of this gathering was to consider how tasks and responsibilities might be re-allocated to allow for SPO.

Each day of the three-day meeting had a distinct purpose. On the first day of the meeting, nine invited speakers shared their relevant research and informed opinions regarding the concept of SPO. The second day represented the workshop portion of the technical meeting. Participants were divided into four workgroups of approximately equal size. All workgroups were asked to identify various allocation strategies for responsibilities under SPO. Furthermore, the workgroups were asked to identify barriers, enablers, opportunities and research issues associated with achieving the various allocation strategies they identified. On the third day of the meeting, each of the four workgroup facilitators presented a summary of the concepts discussed on the previous day. In this way, all attendees were exposed to the ideas discussed by each of the four groups and given the opportunity to ask questions, share their feedback, and provide reactions.

An abundant amount of information was gathered from the meeting, and **several steps were taken to convert the information into an organized, comprehensible form.** All presentations, including the summaries of the findings from the workshop component of the meeting, were reviewed by the authors. Thereafter, an abbreviated and an extended account of each presentation were created, and these accounts can be found in the body of this document. These accounts were then used to analyze and organize the findings of the TIM. In order to organize the information, categories and subcategories were derived from common themes throughout the entire meeting. The categories were generated in an attempt to capture the broad issues associated with SPO (e.g., general advantages and disadvantages) and more specific categories that might guide research and development (e.g., specific configurations that might be considered and recommendations for various research and development efforts).

The organized **findings from the meeting** can be found in the body of this document along with accompanying descriptions, commentary, and analyses, where appropriate. In short, meeting participants offered thoughts that were in many forms. They offered thoughts regarding (1) the strengths and weaknesses with a move to SPO, (2) issues and barriers associated with the realization of SPO, (3) configurations that might be considered, (4) issues unique to various configurations, and (5) recommendations for research, development, and design.

As a whole, **attendees seemed to believe that an exploration of SPO feasibility would be beneficial regardless of whether or not single-pilot operations are adopted in the future.** In short, the attendees seemed to agree that almost all components of the current-day national airspace system could reap benefits from such research and development. **Most TIM participants also seemed to believe that SPO is feasible**, and numerous arguments for its feasibility were presented.

In general, the attendees seemed to agree that **the biggest motivator for exploring SPO is the potential cost savings**. However, **attendees were mixed in their opinions as to whether or not SPO would result in cost savings**.

Meeting participants identified **issues and recommendations** in numerous areas. Their detailed thoughts can be found in the body of this paper. Here, a very brief summary is provided for several major topics.

1. **Authority, Control, and Conflict between Agents.** Because a single-pilot cockpit would presumably include relatively more automated systems, it should be noted that human-human conflicts could arise (e.g., pilot-ATC, pilot-remote pilot, etc.), and human-machine conflicts also could arise (e.g., the pilot and the automation are attempting to approach a problem using different methods). When human-machine conflicts arise, the situation could become complicated.

2. **Communications in the NAS.** SPO presumably would change the nature of communications within the NAS. Therefore, new interactions must be addressed (e.g., the relationship between ATC and dispatch) and the bandwidth of communication technologies would be an important consideration.

3. **Development of Requirements and Certification.** Several FAA guidelines, requirements, and assumptions were identified as potential barriers to SPO. Participants suggested that the industry needs direction in the context of requirements and offered several ideas for areas of direction that might be useful. In addition, metrics were addressed in terms of areas in which the industry may be currently lacking (e.g., measures of complexity and risk).

4. **Design of the Aircraft and Ergonomics.** Participants identified the positive and negative effects associated with a cockpit that needs to support only one pilot. They also offered reminders regarding the use of principled human factors design in the development of a single-pilot cockpit.

5. **Enabling Technologies and Decision Support Tools.** Participants offered specific ideas regarding enabling technologies and decision support tools for the single pilot, including such suggestions as automated communications, emergency auto-land, integrated hazard detection systems with decision tools, display and control mirroring for remote personnel, voice synthesis, voice recognition, and a system to monitor automation's performance (analogous to the Flight Operational Quality Assurance system).

6. **Legal Issues (Accountability).** Outside of the pilot and the designer, responsibility for a failure in an automated system could, theoretically, be attributed to any one of many stages in the system's "life." For example, automation failures could be conceived as occurring at the design, manufacturing, installation, maintenance, training, or operations stage.

7. **Mental Workload and Task load under SPO.** Participants consistently expressed concern regarding the single pilot's ability to handle workload under SPO, with particular concern being expressed about off-nominal circumstances.

8. **Pilot Incapacitation and Pilot Availability at Duty Station.** If the pilot must step away from his or her duty station or is incapacitated, the aircraft would be left pilotless under SPO. All participants seemed to agree that this issue is important, but they disagreed as to the degree of its importance in the ability to realize SPO. Participants offered suggestions regarding how pilot incapacitation might be defined, prevented, determined, and managed.

9. **Public and Stakeholders' Reactions to SPO.** Participants presented mixed opinions as to whether they believed the public would accept SPO. However, they seemed to agree that there is potential for negative reactions from all other stakeholders (e.g., unions, insurance companies, and individual pilots). They suggested getting stakeholders involved in the process of examining SPO as early as possible and provided several other suggestions.

10. **Safety of SPO.** Meeting attendees thoughts regarding the safety of SPO were somewhat mixed, with more participants leaning toward a concern regarding safety. Data were presented at the meeting that also were somewhat mixed in terms of the implications regarding the potential safety levels under SPO.
11. **Security in a SPO Environment.** Participants were concerned about a pilot with malicious intent in the SPO environment. The issue of security also was of concern when particular configurations were discussed in which ground-based personnel would inherit the duties of the co-pilot.
12. **Selection and Training for SPO.** Meeting attendees offered reminders that new procedures would require new methods for selection and training. It is likely that these changes would affect numerous parties in the NAS (pilots, ATC, and AOC). In addition, they noted that the apprenticeship-style training of the co-pilot would cease under SPO, and pilots would immediately become captain. Participants offered some strategies to deal with these issues.
13. **SPO in the Context of NextGen.** Although not unanimous, most participants suggested that SPO may be more difficult when considered in the context of NextGen. However, a few points were made suggesting that NextGen might ease some of the burden on single pilots.
14. **Social Aspects of the Single Pilot's Job.** Participants wondered about the effects of being alone in the cockpit. Boredom can lead to fatigue and a lack of attentiveness. In addition, the current peer pressure experienced in dual-crew arrangements may have positive effects. Participants offered a few recommendations such as limiting SPO to short flights, and during times of low workload, allowing the pilot to socialize with other parties in the NAS (e.g., ATC, flight attendants, etc.).
15. **Teamwork and CRM.** Participants noted that the removal of the second pilot could have negative effects (e.g., lack of cross-checking) but simultaneously reduces the need to monitor teamwork. However, the single pilot would, nevertheless, need to develop CRM skills relevant to whatever configuration is ultimately adopted.

Meeting attendees also offered **numerous suggestions for research directions**, with some suggestions being very general and some being very specific. All suggestions can be found within the body of this paper. In short, participants offered guidance regarding theoretical approaches to research and offered several general ideas regarding experiments and simulations. They also suggested that survey research be performed in which the general flying public and all stakeholders are queried regarding SPO. A few suggestions were made for specific locations at which real-world assessments of SPO might be undertaken. In addition, participants identified quite a few literature reviews that should be performed. Finally, several participants suggested the use of modeling in early research efforts and the use of task analyses before task allocations are determined.

Throughout the meeting, participants identified five potential configurations that might allow for the tasks of the second pilot to be performed by other agents in the national airspace system. These configurations are presented in the following list with a brief mention of a few notable points. The interested reader should refer to the body of the document to learn of all issues and recommendations participants shared for each of these configurations.

1. **One pilot on board, who inherits the duties of the second pilot.** This first option was not a particularly popular suggestion. Rather, it was sometimes noted in order to compare it with other configurations.
2. **One pilot on board, with automation replacing the second pilot.** This second option was mentioned much more frequently and seemed to be treated as a much more feasible alternative than the first. The biggest concerns were related to automation issues, because this configuration necessarily would yield an increase in automation. However, automation

issues were not unique to this particular configuration, and automation issues were identified throughout the meeting. Participants shared many recommendations to assist in effective use of automation.

3. **One pilot on board, with a ground-based team member replacing the second pilot.** This third option also was mentioned frequently and seemed to be treated as a feasible alternative. Two options were suggested for the ground-based team member: a remote pilot or a dispatcher. Some concerns were voiced regarding the necessity to have reliable communications but also to ensure communications between the pilot and ground agent are supported with appropriate displays and tools. In addition, defining the job of the ground-based team member was identified as important as were security issues. Again, participants offered several thoughts as to how some of the issues could be addressed.

4. **One pilot on board, with onboard personnel serving as a back-up pilot.** The fourth option was mentioned frequently and seemed to be treated as a feasible option. A few options were suggested for the onboard personnel member who might serve as a backup: commuting pilots, flight attendants, and flight marshals. The major issues identified were related to cockpit access for the back-up pilot, the need for training, and the manner by which the back-up pilot would interact with the system. Scheduling also was of concern in the case of commuting pilots and flight marshals.

5. **One pilot on board, with the support of an intricate, distributed team.** The intricate distributed team was conceived by one of the workgroups. Therefore, due to this circumstance, it was not mentioned frequently. The workgroup suggested that the distributed team might consist of: (1) the single pilot on the flight deck, (2) flight deck automation, (3) a cabin commander, (4) airborne support, (5) a ground support team, including an airport specialist and (6) ground automation. They conceived of the *cabin commander* as someone who could serve to manage in-flight problems within the cabin. Airborne support could be in the form of a *wingman* (or wingmen). A wingman would be a pre-identified pilot in another, nearby flight. This pilot could assist the single pilot by supporting activities such as navigating around weather and turbulence, especially since they would be proximate. The *airport specialist* would be a person located at the airport who could assist the single pilot with questions or problems specifically related to arrival and departure.

In short, participants identified many issues, raised many questions, and provided numerous recommendations as related to SPO. Much research and development could, and probably should, be performed in order to assess the feasibility of SPO. Participants suggested "scoping the problem." What can be said without bias is the meeting attendees, as a whole, believe that SPO may be feasible and deserves exploration.

Background

1.   Context and Motivation for the Single-Pilot Operations (SPO) Technical Interchange Meeting

1.1.   Background: Why Consider Single-Pilot Operations?

Starting in the 1950s, commercial aviation has been experiencing, what Harris (2007) calls "de-crewing." Historically, a five-person flight crew has been gradually reduced to today's two-person crew. This de-crewing was gradual rather than the result of some radical, one-time change in required crew size. With technological developments, one-by-one, the need for humans to perform three roles, flight engineer, navigator, and radio operator, disappeared. Because technological advancements continue, it is not a surprise that some aviation experts are currently considering further crew reduction. In particular, some are questioning whether a two-person crew continues to be necessary in commercial aviation.

Outside of considering historical trends, current-day circumstances may serve as particular motivators to consider further crew reduction. Current-day airspace is becoming progressively more crowded and the demand for highly skilled pilots is increasing. Therefore, supply and demand may not be at equilibrium. Furthermore, motivation to reduce crew size would be expected if the size of the pilot pool could remain constant but the increasing demand could be met. SPO could produce such an environment. Under SPO, the same amount of pilots theoretically could be dedicated to twice as many flights. The potential increase in revenue may make an exploration of SPO particularly appealing if this reduction in crew size could occur with no change or a positive change in the level of safety. In fact, Harris reports that the historic crew reduction events in commercial aviation have not posed threats to flight safety (Harris, 2007, p. 519).

Evidence suggests that some in the aviation community believe that the concept of SPO warrants serious consideration and exploration. In fact, some researchers began addressing SPO as early as in 2005 (Deutsch & Pew, 2005), and others have since addressed SPO (e.g., Harris, 2007; Norman, 2007). In 2010, a Brazilian aircraft manufacturer (Embraer) announced that it would be planning to provide single-pilot capabilities by approximately 2020 (McCartney, 2010). Not too long after that announcement, an Irish airline (Ryanair) publicly announced that they would like the aviation authorities to grant permission for the airline to use only one pilot per flight (Charette, 2012). These announcements from industry further suggest that some are taking the idea of reduced crew operations quite seriously. Over 70 professionals attended the meeting described within this document, a number that far exceeded the expectation of a small "workshop." Furthermore, ALICIA (All Condition Operations and Innovative Cockpit Infrastructure), a research and development project funded by European Commission, hosted a workshop at HCI Aero 2012, the International Conference on Human-Computer Interaction in Aerospace (ALICIA, 2012). The title of the workshop was "Human Factors for Reduced-Crew Operations." These two events provide further evidence that aviation experts have interest in exploring the potential for further crew reduction in current, two-pilot contexts.

1.2.   NASA's Single-Pilot Operations Research

NASA has decided to examine the long-term feasibility of SPO in traditional two-pilot contexts, such as FAR (Federal Aviation Regulations) Part 121 operations. As an initial step in this endeavor, researchers are working under the Concepts and Technology Development Project, which falls under Airspace Systems Program projects at NASA. Under this program, researchers at both NASA Ames

Research Center and NASA Langley Research Center are jointly investigating issues associated with various, potential configurations for an environment in which a single pilot, or reduced crew, might operate. As part of their early efforts, **researchers at NASA Ames Research Center coordinated and hosted a technical interchange meeting (TIM) in order to gain insight from members of the aviation community regarding the feasibility of, issues associated with, and potential requirements for SPO. This document provides a (1) description of the method, (2) account of the events, and (3) summary of the findings from the TIM.**

2. Approach and Method Used for the SPO Technical Interchange Meeting

2.1. Participants

Professionals in the aviation domain were invited because their areas of expertise were deemed as being directly related to the topic of discussion. The invitation sent to prospective participants can be found in Appendix B. Serving as the hosts of the meeting, NASA personnel attempted to represent various, relevant sectors within the aviation domain when selecting prospective participants. Ultimately, 74 professionals attended NASA's SPO TIM. Attendees represented government, academic, and industry sectors of the aviation domain. Government employees represented those from the host NASA Center: NASA Ames Research Center. However, personnel from other NASA centers also were in attendance (i.e., NASA Dryden Flight Research Center and NASA Langley Research Center) as were representatives from other, relevant government agencies such as the Federal Aviation Administration (FAA). Those from the academic sector represented various institutions of higher education. Industry professionals represented companies specializing in aircraft manufacturing, aviation electronics, commercial airlines, aviation systems, air taxi and charter services, and human factors consultation. A final list of participants, including participant affiliations, can be found in Appendix C.

2.2. Structure of the Technical Interchange Meeting

The agenda distributed to participants can be found in Appendix D. The TIM was held on April 10-12, 2012 at NASA Ames Research Center. The content of the meeting is discussed in Sections 4, 5, and 6 of this document. In terms of structure, the meeting proceeded in a manner consistent with the planned agenda.

On the first day of the meeting, participants were greeted by brief presentations from NASA administrators and lead researchers on the projects devoted to SPO. Thereafter, nine invited speakers shared their relevant research and informed opinions regarding the concept of SPO. These speakers were invited based on their expertise in that they were knowledgeable in topics relevant to the concept of SPO. The keynote speaker, Dr. Thomas Sheridan of the Massachusetts Institute of Technology, was selected based on his well-known expertise in the area of automation (a topic that was considered potentially central to conversations about SPO). In selecting the remaining speakers, meeting organizers attempted to represent perspectives from academia, industry, and government. The number of invited speakers was limited to nine in order to limit formal presentations to one day.

On the second day of the meeting, participants were divided into four workgroups of approximately equal size. An attempt was made to generate groups that were approximately equal in terms of the expertise represented. For example, an attempt was made to distribute pilots evenly amongst the groups. This second day represented the workshop portion of the TIM. Each workgroup was assigned its own room and had different facilitators. Attendees were divided into four groups in order to better facilitate discussions akin with a workshop setting. By dividing the attendees into

smaller groups, chances of everyone speaking on the concept of SPO were increased, and in this way, chances that the workshop findings would represent a wide range of ideas would be increased. Furthermore, finding redundant ideas between workgroups might suggest that a particular idea is of great importance. Despite the separation of the attendees, the instructions provided to each group were identical. The specific instructions and specific findings from the workshop portion of the meeting can be found in Section 6.

On the third day of the meeting, each of the four facilitators presented a summary of the concepts discussed on the previous day. In this way, all attendees were exposed to the ideas discussed by each of the four groups. In the afternoon, interested meeting attendees were invited to take part in optional tours of laboratories located at NASA Ames Research Center.

3.   Approach in Generating these Proceedings and Findings

3.1.   Confidentiality of Recorded Information

Presentations given on the first day of the technical meeting were captured in the form of digital video with accompanying audio. Each presentation ended with a short period devoted to allowing attendees to become involved via discussions, questions, and answers. These discussion periods also were recorded. The second-day discussions from each of the four workshop groups were recorded in audio form only. In addition to the audio recording, each workgroup was assigned a note taker, who attempted to summarize ideas in real time. The third-day presentations given by the workgroup facilitators were recorded in the form of digital video and audio as were the subsequent question-and-answer sessions.

As promised to all presenters and attendees, all information recorded at the TIM has and will remain confidential. The recordings were merely meant to assist in the production of these proceedings. As a result, only the primary author of this document reviewed the digital recordings in order to generate the summaries included in the appropriate sections of this document. The only exception to this rule occurred in the case of the audio recordings of the workgroup sessions. Rather than the primary author, a member of the Flight Deck Display Research Laboratory at NASA Ames Research Center listened to these audio recordings and presented a summary of the audio recordings to the primary author. When summarizing information from the question-and-answer sessions and workgroup discussions, the identities of attendees involved in these discussions has and will remain confidential.

3.2.   Summarizing Presentations of Invited Speakers

In generating the summaries of the first-day presentations, the primary author reviewed the digital recordings and viewed the PowerPoint presentations provided by the speakers. A summary of the presentations and subsequent discussions can be found in Section 5. If presenters were uncomfortable with the inclusion of any information for any reason (e.g., company policies or the like), the authors respected their wishes. Therefore, under such circumstances, portions of the presenters' materials may have been omitted (e.g., slides, extended summaries, etc.). ***Please note that the summaries of the presentations represent the understanding of the material by the authors of this document. The presenters were not necessarily involved in writing or reviewing these summaries.***

3.3.   Summarizing Workshop Discussions

Using the audio recordings, the notes that were taken at the time of the workshop were reviewed and edited, where appropriate. This approach ensured that the final set of notes from the workgroups was accurate and comprehensive. The primary author of these proceedings reviewed this final set of notes when summarizing the findings from the workshop portion of the meeting. In addition, the primary editor reviewed presentations given by the four workgroup facilitators. A summary of the presentations given by workgroup facilitators and subsequent discussions can be found in Section 6. *Please note that the summaries of the facilitators' presentations represent the understanding of the material by the authors of this document. The presenters were not necessarily involved in writing or reviewing these summaries.*

3.4.   Summarizing the Findings of the Entire SPO Technical Interchange Meeting

Because much of the information generated from the meeting is in qualitative form, an attempt was made to impose structure in **organizing the findings**. As previously described, information was reviewed from all presentations at the TIM. That same information was then used to analyze and organize the findings from the TIM. In order to organize the information, categories and subcategories were derived from common themes throughout the entire meeting. These categories are useful in that they allow for a systematic assessment of redundancy (i.e., if an issue is repeatedly presented, it may be of high importance). In addition, the particular categories chosen were ones that might allow the findings to best be presented in a usable form. Specifically, the categories were generated in an attempt to capture the broad issues associated with SPO (e.g., general advantages and disadvantages) and more specific categories that might guide research and development (e.g., recommendations for various research and development efforts and specific configurations that might be considered). The initial organization of the findings can be found in Appendix F. At the start of Appendix F, instructions are provided as to how the information in Appendix F may be understood.

After the initial organization of information was generated, the information was further organized to provide the reader with a more comprehensible version of the findings. Therefore, a large portion of this document is devoted to the presentation of findings. The reader should refer to the "Analysis and Summary of Findings" section of this document, which begins with Section 7 of this document. With the exception of references to the original source of information and specific reference to the frequency with which an idea was mentioned, the "Analysis and Summary of Findings" section of this document provides redundant information with the information found in Appendix F (which, therefore, is redundant with the information found in the accounts of the presentations). In short, the reader should not necessarily have to refer to Appendix F in order to be exposed to all ideas that were communicated at the TIM.

Because the information gathered is in qualitative form, **a few final notes** are necessary in order to ensure the **approach used in analyzing the findings** is clear. These notes are presented in the following list, in no particular order:

1. The authors made no attempt to remain consistent in the level of abstraction used to describe the findings. The authors do not believe it would be appropriate to alter or filter the thoughts presented by TIM attendees. Therefore, some findings are very specific, while other findings are very general. Presumably, both types of information may be helpful given the needs of various readers. If a reader finds that a particular idea shared by a participant is "obvious" (i.e., fundamental or well-known), other readers may not find the same comment to be

"obvious." In addition, such fundamental ideas may be important to document in that they may serve as reminders in efforts to explore SPO.

2. The authors made no attempt to filter the ideas in terms of the content areas. Although the meeting was hosted by a group that explores human factors issues, some of the information shared at the meeting may serve useful to those outside of the area of aviation human factors.

3. The authors attempted to distinguish ideas in terms of whether they were "issues," "research questions," or "recommendations." In many cases, a mere re-phrasing of a statement would allow an idea to be placed in any one of the aforementioned three categories. For example, consider the following statement: "The duty cycle of the remote pilot needs to be identified." Such a statement may represent an issue (e.g., Can the duty cycle be effectively identified for such a complex job?), a research question (e.g., Research is needed to determine what the remote pilot can handle.), or a recommendation (i.e., Identify the duty cycle for the remote pilot.). The authors attempted to place an idea in the category they believed was consistent with the intent of the participant(s). However, the authors highly recommend that interested readers engage in a thorough review of the findings for this reason.

    a. The authors used one method to assist with the aforementioned challenge. Only those thoughts that specifically mentioned research or a research method were placed in the "Recommendations for Research in the Assessment of SPO Feasibility" section of this document.

4. If the reader refers to Appendix F in order to gather information regarding the frequency with which an idea was relayed, caution should be taken with such information. Two examples should demonstrate why caution is needed in interpreting frequency. First, all attendees were exposed to the presentations of the invited speakers. Therefore, they may have been more likely to repeat the ideas of the presenters than would otherwise have been the case. Second, invited speakers also were members of workgroups, and their ideas may have been represented in two forums (i.e., their presentations and again as a workgroup member).

5. Ideas of invited speakers are necessarily weighted more heavily in the findings. The time devoted to the ideas of each invited speaker was approximately equal to the time devoted to the ideas generated by each workgroup (with each of the four workgroups representing approximately 25% of participants).

Content of the SPO Technical Interchange Meeting

4. Introductory Remarks and Guidance from NASA Administrators and SPO Project Leads

The presentations given during this portion of the meeting were relatively less formal than the presentations given by the invited speakers. Therefore, slides were not used for most of the presentations that are summarized in this section. When slides were used and the presenter provided permission to include the slides in this document, the slides are included in Appendix E. The inclusion of slides is noted in the relevant subsections that follow.

4.1. Dr. Thomas Edwards, Director of Aeronautics, NASA Ames Research Center

Dr. Edwards, Director of Aeronautics at NASA Ames Research Center, spoke briefly in order to welcome attendees to the TIM and to NASA Ames Research Center. Of note, Dr. Edwards did not suggest that the concept of SPO is one that should be adopted or not. Rather, he left the audience to ponder the question, "Is one pilot a logical stepping stone on the way to zero pilots?"

4.2. Dr. Parimal Kopardekar, Project Manager for the Concepts and Technology Development Project, NASA Ames Research Center

Dr. Parimal Kopardekar is the Project Manager and Principal Investigator for the Concepts and Technology Development Project, which falls under NASA's Airspace Systems Program. The research being conducted on SPO falls under the Concepts and Technology Development project. Therefore, Dr. Kopardekar has direct knowledge about the goals of the research. He spoke informally to the audience. Therefore, he did not use presentation slides. However, a summary of his thoughts is provided here.

Dr. Kopardekar began his discussion of SPO suggesting that, "It is a polarizing topic." He introduced Dr. Walter W. Johnson at NASA Ames Research Center and Mr. Paul C. Schutte at NASA Langley Research Center as collaborative, technical leads on the project aimed at exploring SPO. In providing guidance to the attendees, he suggested that the technical interchange meeting be used to explore the issues related to SPO and relayed that it is unclear as to whether SPO is feasible. Instead, he suggested that the feasibility of SPO is an "open question."

He mentioned that cost is one motivating reason to explore SPO. If SPO were ultimately adopted, the cost per passenger or per mile would decrease. Therefore, ticket prices would decrease. This decrease in cost could yield an increase in demand. Such an increase in demand would require the need for more single pilots. Theoretically, then, a move to SPO would yield an increase in revenue, an increase in the number of travelers served, and an unchanged demand for pilots. In addition to cost, motivation to explore SPO should be high in that SPO may be realized any time one pilot, of a two-person crew, becomes incapacitated.

Given his remarks, Dr. Kopardekar provided more specific guidance to the meeting attendees. He asked that attendees spend the three days considering the range of issues that might arise under SPO. He offered a few examples of such issues: automation, operations, and human-system integration issues. However, he asked that the attendees spend their time at the meeting determining the issues. In addition, he asked that attendees assist in identifying research issues that need exploration in determining the feasibility of SPO.

4.3. Mr. Mark G. Ballin, Serving to Represent the SPO Research Project Technical Lead at NASA Langley Research Center (Mr. Paul Schutte).

Mr. Mark G. Ballin served to represent the technical lead at NASA Langley Research Center, Mr. Paul Schutte. Mr. Schutte was unable to attend the meeting in person but was able to "attend" the meeting remotely. Mr. Ballin spoke informally to the audience. Therefore, he did not use presentation slides. However, a summary of his thoughts is provided here.

Mr. Ballin dedicated most of his talk to providing thought-provoking questions and ideas. He began by arguing that, in 100 years, airplanes may be fully automated much like elevators are today. Such an argument may not seem unreasonable when history is considered. He suggested that, with technological advances, airplanes are getting progressively safer and easier to operate. Historically, it could be argued that, from a human operator's perspective, the aircraft's greatest level of complexity was immediately prior to introduction of turbo jets. Since the 1950s, we have reduced crew size and added a lot of technology on both the flight deck and on the ground. In fact, a navigator used to be a necessary role on a crew, but historically, the navigator was the first crew member to be removed. In addition, he reminded the audience that we used to have flight engineers, but the jet age removed the need for this particular crew member.

Mr. Ballin provided evidence to support the notion that airplanes may be fully automated in 100 years. Specifically, he reminded the audience that we already are experimenting with fully automated cars that can share our highways with us. In addition, he suggested that younger generations do not share some of the relatively older generation's "hang-ups" about technology. This generational difference may increase the likelihood that future aircraft will be fully automated.

Mr. Ballin subsequently suggested that our speculations about aircraft automation in 100 years may not be too diverse, relatively speaking. However, he asked the audience, "What about 5, 10, or 50 years from now?" He suggested that the speculations about the level of aircraft automation may be diverse when considering shorter time horizons. He asked, in these shorter time horizons, "Do we still need two pilots? Any pilots?"

Because aircraft are one of the most complex systems devised by humankind, Mr. Ballin suggested that we need to ask ourselves whether moving to SPO is feasible or not. After all, he reminds the audience that some FAR Part 135 operations already are approved for single-pilot operations. However, to include SPO in FAR Part 121 operations, he asked audience members to consider whether it is a good idea or not. He emphasized that we, as a community, need to ensure there are benefits in moving from current-day, two-person crews to a single-pilot approach. Specifically, in moving to SPO, some issues we should consider include: (1) a new concept of operations, (2) the required, enabling technologies, (3) the legal and policy requirements, and (4) a feasible approval process for SPO. He closed his presentation by suggesting that we can only understand the necessary research and development efforts after we have considered the aforementioned four issues.

4.4.   Dr. Walter W. Johnson, SPO Research Project Technical Lead at NASA Ames Research Center

Dr. Walter W. Johnson, the technical lead at NASA Ames Research Center, served as host to the entire meeting and spoke intermittently during the three-day meeting (e.g., serving to introduce speakers and giving general instructions regarding breaks and the like). However, as one of the technical leads, he also spoke to the audience during the introductory phase of the meeting in order to provide his own thoughts and general guidance. Dr. Johnson's presentation slides can be found in Appendix E.

Dr. Johnson presented the audience with the ***official goal of the meeting***. *He stated that the goal was to **"develop a set of critical research issues that can be used to inform the planning for a 2-5 year research effort examining the feasibility of a move from two-pilot to single-pilot flight decks."** He asked the meeting attendees to consider two paths, while considering a potential move to SPO: flight deck automation and ground-based support. Dr. Johnson elaborated on each of these paths. Specifically, in terms of flight deck automation, he asked the audience to consider a future flight deck with very intelligent automation that can effectively replace the functions of the first officer. Furthermore, he reminded the audience that, in the future, we will be relying more extensively on air-ground collaboration. Therefore, he asked the audience to imagine a case in which many of the first officer functions are handled remotely (from the ground). He reminded the audience that these two potential paths to SPO are not necessarily exclusive, and they do not necessarily represent an exhaustive list of possibilities.

In considering the potential configurations for SPO, Dr. Johnson ***asked the attendees to consider a NextGen (Next Generation Air Traffic System) time frame (i.e., 20 to 30 years from the present time)*** when sharing thoughts. Given this time frame, Dr. Johnson offered some thoughts in terms of what might be expected of the national airspace system (NAS) at that time. Specifically, he

suggested that a NextGen airspace might include: (1) the use of trajectory-based operations, (2) improvements in predicted weather for the flight deck, (3) the use of flight deck managed spacing, (4) delegation of separation management, (5) the use of DataComm, which allows for the exchange of full flight plans between the air and the ground, (6) high degrees of air-ground integration in general, (7) availability of optimized profile descents, (8) relatively greater use of UASs, or unmanned aerial systems, and (9) general advances in automation/technology.

Dr. Johnson suggested that attendees should expect arguments on "both sides of the issue." In fact, he suggested to audience members that the use of UASs should be prompting us to consider, not only the impact of removing pilots from the flight deck, but the value of leaving a pilot on the flight deck. In the case of SPO, removing the first officer from the flight deck should generate questions regarding the potential problems that might arise under such operations. Dr. Johnson provided a sampling of the potential problems that might surface under SPO. Specifically, SPO might yield: (1) a perceived or actual reduction in safety, (2) increased pilot workload, and/or (3) a reduced ability to handle off-nominal events. Despite such potential problems, an exploration of SPO might have benefits. Specifically, Dr. Johnson suggested that exploring SPO might yield advances in automation and improved air-ground collaboration with both air traffic control (ATC) and dispatch. If SPO is not ultimately adopted, some of the aforementioned advances might yield benefits for the two-person crew configuration. If SPO ultimately is adopted, the NAS might reap the aforementioned benefits in the nearer future, while moving along the path to ultimately adopting SPO.

In closing, Dr. Johnson suggested to attendees that they spend time considering the requirements associated with a move to SPO. Specifically, he suggested considering the "smarter," more advanced automation that would be required. In addition, he asked participants to consider the necessary improvements in coordination/collaboration that would be required. In considering such collaboration issues, Dr. Johnson asked that attendees consider coordination between people and automation, and in both cases, proximal and remote placements of these components (humans and automation) should be considered.

5.   Account of Presentations from Invited Speakers

Sections 2.1 and 2.2 describe the manner in which the invited speakers were selected. In terms of **instructions to invited speakers**, they were asked to give short (20-25 minute) presentations focusing on the challenges of moving from traditional dual-pilot flight decks to SPO. The keynote speaker was an exception in terms of the aforementioned guidance; one hour (including the question-and-answer session) was devoted to the presentation given by Dr. Tom Sheridan. All speakers, including the keynote speaker, were asked to share their visions of how a SPO environment might operate in 20 years from the time of the workshop. Furthermore, invited speakers were told that these presentations were meant to give other attendees a glimpse into how each invited speaker envisions the challenges and opportunities associated with a move to SPO. Specifically, the invited speakers were told that the presentations were meant to assist in stimulating subsequent discussions, in which all meeting attendees would attempt to identify and describe salient operational and research issues that might be associated with a move to SPO. All invited speakers were told that their presentations would be followed by a short question-and-answer session during which time they would have the opportunity to interact with the other meeting participants.

This entire section (i.e., Section 5) contains a summary of the presentations given by the invited speakers. The list of invited speakers can be found on the meeting agenda (See Appendix D). Two versions of each summary are included. **For each presentation, an abbreviated account is presented** and serves a function similar to an abstract in a peer-reviewed journal. **An extended**

account of the presentation also is included, which provides a more comprehensive description of the thoughts relayed by the speaker. The extended account also includes a summary of the discussions that followed each presentation. These discussions occurred during a time that was set aside for audience members to pose questions or share thoughts with the presenter. When the presenter provided permission to include the slides in this document, the slides are included in Appendix E. The inclusion of slides is noted in the relevant subsections that follow.

5.1. Human-Automation Interaction in Single-Pilot Carrier Operation, *Dr. Thomas B. Sheridan* (Keynote Speaker), *Massachusetts Institute of Technology*

The slides used by Dr. Sheridan can be found in Appendix E.

5.1.1. Abbreviated Account of Dr. Thomas B. Sheridan's Presentation

Dr. Thomas B. Sheridan's keynote presentation provided a theoretical framework for the meeting. In particular, Dr. Sheridan highlighted a number of distinctions and issues concerning the apportionment of tasks between the pilot and other agents. He began by noting a number of challenges: (1) Adding the tasks of the pilot not flying to those of the pilot flying increases workload, but offloading them to a ground agent could result in various communication issues, (2) A pilot can become incapacitated, or worse, can have malevolent intent, and (3) To the extent you use ground-based resources or automation to reduce the workload issues noted earlier, the risk due to failure of the automation or communications channels increases. Dr. Sheridan then addressed the issue of control. Control can either be shared between the pilot and a second agent (either a ground-based agent or flight deck automation) or can be traded between them (where one agent has control at any given time). Control can be passed between agents in either a cooperative manner (e.g., pilot turns on the autopilot) or a non-cooperative manner (e.g., automation takes over for apparently incapacitated pilot). Dr. Sheridan also noted the difficulty in getting computers and humans to cooperate. In particular, when the goals of the pilot and automation differ, there will be conflict. Therefore, it is important for both the automation and human to give feedback and for the computer to have a good model of the pilot's intentions. While it is generally thought that the pilot must have ultimate responsibility for the flight, Dr. Sheridan thought there are many tasks that the pilot may not be able to effectively perform. For example, human response times can be quite long for even simple tasks, so rapid emergency responses should probably be automated. In addition, humans are not very good at vigilance tasks, so humans probably should not be given critical monitoring tasks. Dr. Sheridan argued that *authority* should only be given when the pilot has the ability, *control* should only be given when the pilot has authority, and *responsibility* should only be given when the pilot has control. Finally, Dr. Sheridan discussed "levels of automation." Specifically, he discussed his long-standing observation that tasks do not need to be assigned to automation in an all-or-none manner but can be classified into many levels depending on the degree to which the human operator is involved in the decision making.

5.1.2. Extended Account of Dr. Thomas B. Sheridan's Presentation

Dr. Thomas B. Sheridan opened his keynote presentation by making reference to a current event in which a pilot on a major airline (JetBlue) apparently experienced a psychological breakdown. He suggested that such events lead one to question how this situation would have been handled had the second pilot not been available to identify and assist in allowing the flight to proceed safely. Therefore, Dr. Sheridan suggested that, although a move to SPO *can* be accomplished from a technological standpoint, the question is whether or not it *should* be realized. Following

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these opening remarks, Dr. Sheridan proceeded to present arguments both for and against the concept of SPO.

Dr. Sheridan suggested that **several issues can be used to argue against the move to SPO**, and these issues should be considered. He presented three such issues to serve as examples. *First*, he suggested that the use of a single, onboard pilot might not be acceptable to the general, flying public. Members of the general, flying public may find it important that anyone controlling the airplane is on board the airplane. In this way, the onboard person controlling the airplane also has his or her life on the line. As part of the public reaction, we must also imagine the reactions of the media and Congress when first considering SPO. *Second*, Dr. Sheridan raised the question as to whether or not the aviation community may be putting too much faith in automation. He reminded the audience that, when automation fails, it can sometimes be catastrophic. However, unlike automation, humans can be innovative and have the ability to recover from unusual mishaps. *Finally*, Dr. Sheridan discussed cost savings. Presumably, a move from a two-person crew to a single pilot might be motivated by cost savings. However, in practice, the industry must consider whether or not cost savings will be realized or if the industry will simply be moving people from the air to the ground.

Dr. Sheridan also presented arguments that represent **potential advantages in adopting SPO**. *First*, he reminded the audience that General Aviation (GA) pilots have flown as single pilots for a long time, with some general aircraft certified for up to 19 passengers. *Second*, he reminded the audience of the well-known emergency landing of US Airways Flight 1549, in which Captain Sullenberger successfully landed an airplane on the Hudson River after the engines shut down. Captain Sullenberger reportedly communicated to his colleague that he would be taking control of the airplane, and he single-handedly completed the landing. Such a case reminds us that, under emergency circumstances, single pilots with ample experience and training are more than able to handle flight. *Third*, Dr. Sheridan relayed that Embraer is in the process of designing aircraft for the 2020-2025 timeframe with SPO as part of the design. This effort suggests that some experts in the aviation community fully expect SPO to be realized. *Finally*, in contrast to his previous statement regarding the general public's lack of acceptance, Dr. Sheridan suggested that the general public very well may "warm up" to the idea of SPO. He used the tram at SFO (San Francisco International Airport) to demonstrate a real-world public reaction to automated transportation. The tram at SFO does not have an onboard operator, yet the public seems quite willing to utilize the tram as a means of transportation at the airport.

Whether or not SPO are adopted, Dr. Sheridan spent most of the remainder of his allotted time discussing the **challenges posed by the notion of SPO** and suggested that these challenges need to be addressed in considering the feasibility of SPO. The first two points reviewed in the following paragraphs place relatively more emphasis on technologies, and the points mentioned thereafter focus more on the entire human-machine system. The fifth through eighth point primarily focus on the issue of task allocations within SPO.

First, Dr. Sheridan suggested that industry must consider the issues related to **automation failures**. If automation failures occur on the flight deck, the industry must consider how the pilot might proceed. The onboard pilot might need to revert back to manual control. Dr. Sheridan also suggested that SPO might include designs in which automated systems are configured in "levels." In the case of automation failure, such levels might allow the pilot to "step down" a level in the automation. This action would remove the failing higher-level of automation while maintaining some assistance from automation. Similarly, the procedures associated with any ground-based automation failures must be identified.

If the pilot-not-flying is replaced by a human on the ground, Dr. Sheridan discussed a *second* set of challenges: **issues with communication systems**. Specifically, the quality of the communication channel will be important (i.e., the quality of the information that reaches the second set of eyes and ears on the ground). In addition, mechanisms must be employed to address the situation in which there is a failure in the communication system. Redundant and non-overlapping channels of communication probably are needed to avoid complete failures in the communication system. Dr. Sheridan shared that the UAS community currently is dealing with communication problems. In particular, the time lag in communication is creating issues, and these time delays are a result of the time it takes the communication signals to travel to the satellites and back. There is no reason to believe that similar issues would not affect two pilots cooperating remotely (i.e., with one on the ground and one in the air).

The *third* major issue he addressed was that of **workload**. He addressed the potential increase in workload for the single, remaining pilot. If the routine tasks of the pilot-not-flying are transferred to the pilot-flying, the pilot-flying obviously would experience increased workload. Therefore, Dr. Sheridan advises that the industry must carefully examine the tasks of the pilot-not-flying. Thereafter, the aviation community can ask how, or if, those tasks can be allocated. He reminded the audience that human response times tend to follow a lognormal distribution. In short, to accommodate the response time of most people (say, with 99% confidence), the time window allotted must be much longer than the average response time for a given task.

The *fourth* challenge Dr. Sheridan discussed was that, **for the single pilot, the social context in SPO is quite a bit different** than in the two-person cockpit of today. In contrast to the workload issues previously mentioned, the issue of boredom also arises. He reminded the audience that, under normal circumstances, flying can be boring. When two pilots are flying, they often engage in casual conversation during "down time." Human factors research shows a link between boredom and inattention (or lack of vigilance). Therefore, SPO might require a change in the expectations regarding social interactions with other parties. For example, unlike today, the single pilots might be encouraged to engage in more frequent casual conversations with ground personnel than they are today. Other alternatives might be to allow more conversations with onboard personnel, or perhaps SPO should be limited to relatively shorter flights.

Fifth, when a system includes two or more active agents, Dr. Sheridan reminded the audience that **cooperation issues** must be considered seriously, because either a cooperative or a conflict state might arise. When a cooperative state exists, the issues are less complicated than when there is disagreement between agents (e.g., the pilot in the air vs. the pilot on the ground or the pilot in the air vs. automation). When a cooperative state exists, the agents agree regarding actions that should be taken by each agent. He suggested that such instances include relatively benign circumstances, as in the case of a pilot-flying who leaves the cockpit to use the restroom. In this case, control might be given to the automation or the pilot on the ground, and the pilot-flying might even issue the command to assign control to another agent. However, even under these relatively benign circumstances, the agent that gains control must be clearly defined under SPO. When conflict exists between the agents, the issue of control becomes more complicated and needs to be explored. A method must be developed that allows for the identification of a conflict state, especially conflict between a human agent and automation. After the conflict is identified, the method of managing the conflict also must be identified.

A *sixth*, and related issue, was addressed: **communication between the human and the automation.** If the single pilot will collaborate with the automation in a manner similar to that of a second pilot, they must be continually giving feedback to one another to stay synchronized, as would

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the first officer and co-pilot. When two people are involved, much of the feedback happens naturally with spoken and body language. The challenge in SPO would be to ensure this natural flow of feedback is maintained. A major challenge is how to measure and model the intentions and adaptive behavior of the human so that the computer can "understand" the human. Providing the pilot with information about the automation's intentions is less difficult (relatively speaking), because the automation's intentions can be displayed or communicated in some manner. Perhaps pilots will be required to communicate their intentions more actively than they do today.

Dr. Sheridan suggested a *seventh* challenge in that researchers will need to i**dentify whether tasks will be traded or shared** in the SPO environment **and** to consider **levels of automation**. An allocation in which tasks are traded is one in which one agent or another is performing the task, whereas the sharing of tasks occurs when two or more agents are sharing the responsibility of performing the task. Identification of sharing or trading allocation probably will not be constant across tasks. Therefore, an additional challenge exists in deciding which tasks should be shared and which should be traded. This distinction is somewhat related to, but different than, the notion that automation should be conceived in levels. Dr. Sheridan reminded the audience that automation should not always be treated as an all-or-none state. Instead, there is a large range in the roles that automation can fill. For example, automation can serve to provide recommendations, and on the other end, automation can take control of a situation. He warned against overreliance on automation and shared that we often believe automation is more capable than it may be in reality.

Finally, in regards to challenges, Dr. Sheridan offered some general advice regarding **when the human should be in control (vs. automation)**. Specifically, he suggested that humans should not necessarily always be in a position of control. In particular, he suggested that humans should *not* be in control when: (1) the human is inattentive, (2) there is little time to respond, and (3) the human is lacking the knowledge to manage the situation. As a general rule, four conditional states should be considered: (1) ability, (2) authority, (3) control, and (4) responsibility. Dr. Sheridan suggests that the human should not have authority if he or she does not have ability, the human should not have control if he or she does not have authority, and the human should not have responsibility if he or she does not have control.

Dr. Sheridan's presentation was devoted to three, additional topics. First, Dr. Sheridan discussed some of the potential roles of other humans (i.e., besides the single pilot) in a SPO environment. Thereafter, he addressed the need to address changes in legal responsibilities that may be necessary. Finally, Dr. Sheridan offered some thoughts regarding the research that might be undertaken in exploring SPO. Each of these topics is discussed in the following paragraphs.

In discussing the **roles of humans (other than the single pilot)**, Dr. Sheridan began by addressing a second pilot that may be located on the ground. He told the audience that some have postulated that a second pilot on the ground may serve to assist approximately five single pilots in the air. He further stated that this number is probably necessary if the industry is searching for cost savings with this particular arrangement (i.e., one pilot in the air and one on the ground). However, at times when particular aircraft need special attention (e.g., landing, off nominal conditions, etc.) the number of aircraft that the ground pilot assists may have to vary. Therefore, he suggests that there may need to be some sort of flexibility in the arrangement for the pool of ground pilots. Dr. Sheridan posed the question as to whether or not the ground pilot's tasks would be combined with that of a regular controller. He suggested that the ground pilot's tasks should probably remain separate from the regular controller's tasks but suggested that we need to consider how these two roles will be integrated, if at all. He also considered other personnel that may be on board the aircraft. For example, he considered flight attendants and flight marshals. He presented the possibility that, if

something dire occurred, it might be possible to have these other, onboard personnel interact with automation or ground personnel.

Dr. Sheridan addressed the **relation between authority and responsibility under SPO**. He defined authority as being related to the manner in which control is enabled and responsibility as being related to accountability in the case of failure. He suggested that this relation is complicated because, in modern organization, both authority and responsibility tend to be shared vertically (i.e., more than one "level" of the organization is involved). He used the Three-Mile Island investigation as an example. In that case, he relayed that "fingers pointed" first at the operators, then at the trainers, and finally at management. He reminded the audience that human users can become dependent upon automation and decision support tools. In such a case, he asked who it was that should be held responsible and suggested that it is difficult to pinpoint a specific locus of human input. With automation use in a potentially dire-outcome situation, responsibility could be conceived as occurring at the design, manufacturing, installation, maintenance, training, or operations stage. In light of these complications, he suggested that we need to develop an "automation policy" to guide design, operation, and management of highly automated systems

Dr. Sheridan discussed several **research efforts that might be undertaken in evaluating SPO**. First, he suggested that the related work conducted by DARPA (Defense Advanced Research Projects Agency) be reviewed. Second, he suggested that some of the models of pilot behavior be examined. He particularly recommended the relatively newer models, which take the cognitive components of the piloting task into account. He mentioned the following works: ACT-R (Johnson-Laird et al.), Air Midas (Corker et al.), D-OMAR (Deutsch & Pew), and the challenges of model credibility with increasing complexity and pace of change (Foyle & Hooey). (The previous examples were provided by a speaker. Therefore, the references are not included in the reference section of this document.)

In terms of experimental simulations, Dr. Sheridan suggested that some researchers might consider incorporating some of his recent work into their research. Interested researchers can refer to his recent publication (Sheridan & Inagaki, 2012). (The full reference can be found in the reference section of this document.) In short, his recent work provides a theoretical framework in which the automation-human machine relation can be examined. His work, for example, includes a comparison of the action that could be taken by the user given the current situation (needed action, allowed action, or inappropriate action) with the judgment made by the automation (recognition as to whether the human acted or not). For example, in the automotive domain, the category of "needed action" would represent a situation in which automatic braking could be employed because the human did not act when he or she should have acted. The category of "inappropriate action" would represent a situation in which automatic lane change prevention could be employed, when the human attempts a lane change but would collide with another automobile if the lane change were accomplished. The work further analyzes situations in terms of whether the automation gives a warning or intervenes and allows for the assessment of the probability that automation will prevent accidents, present unnecessary warnings or interventions, or present an inappropriate warning or intervention.

On a broad level, Dr. Sheridan offered his thoughts regarding **the approach that might or should be used in researching SPO**. Specifically, he expects that research should have successively more challenging platforms and might proceed in this order: (1) use of fast-time models, (2) human-in-the-loop simulations, (3) flight trials with SPO-certified, GA, passenger jets, (4) trials by express mail carriers, and (5) trials by short-distance passenger carriers.

During the **question-and-answer session** following Dr. Sheridan's presentation, a few noteworthy discussions occurred. In short, *one* audience member suggested that, rather than discussing roles and responsibilities of automation and the pilot, what we are really doing is giving the authority to the designer when automation is involved. The audience member further relayed that the designer must make assumptions and forecasts about what conditions exist in flight, and many accidents and incidents have been a result of the designer making the "wrong call." However, in these cases, the pilot was held responsible. Dr. Sheridan agreed with the audience member in saying that we are giving more responsibility to designers. He suggested that it is not unknowns that are the problem, but the unknown unknowns that are problematic. He suggested that experiments might be directed at making some of these unknown unknowns merely unknowns. A *second* audience member suggested that, as compared to fighter aircraft or rotorcraft, commercial flight is a more constrained environment and wondered whether we might have a better chance of being successful with intent inferencing for FAR Part 121 operations. Dr. Sheridan seemed to believe that the term "constrained" would have to be better defined and was not necessarily certain he agreed with the idea that one environment is more or less constrained than the other. He stated that he was interested that the audience member believes the military environment is less constrained.

5.2. Modeling the Work of the Flight Deck, *Dr. Amy Pritchett*, *Georgia Institute of Technology*

The slides used by Dr. Pritchett can be found in Appendix E.

5.2.1. Abbreviated Account of Dr. Pritchett's Presentation

Dr. Amy Pritchett, from Georgia Institute of Technology, spoke from the perspective of modeling the workflow of the flight deck as a means to gain insights into the possibility of SPO. She approached the question of how work should be distributed between human agents and automation by first modeling the task work then extending the modeling to include teamwork. Using arrival and approach operations as an example, Pritchett presented detailed analysis of task work and teamwork required to complete these operations, and how the work can be divided between pilots and automation, ranging from full automation to mostly manual control on the part of the pilot. To determine what level of automation is most suitable in a given operational context, Dr. Pritchett advocated the use of a host of functional allocation metrics that included workload, interruptive automation, considerations for boundary conditions, and predictability of the humans' work environment, noting that design concepts that score well on one metric may score poorly on others.

5.2.2. Extended Account of Dr. Pritchett's Presentation

Dr. Amy Pritchett, from Georgia Institute of Technology, performs research that examines function allocations when automation is used, and her previous research has been in the context of aviation. Therefore, during her presentation, she spoke from the perspective of modeling the workflow of the flight deck as a means to gain insights into the possibility of SPO.

When considering function allocations, Dr. Pritchett suggested that **several perspectives may be relevant**: a (1) technology-centered, (2) human-centered, (3) team-oriented, and (4) work-oriented perspective. In using a technology-centered perspective, the questions focus on how automation should be designed. In using this perspective, autonomy is often appreciated or emphasized. When using a human-centered perspective, the focus tends to be on asking how the technology can be used to best support human needs and how the human is impacted when automation is introduced. The team-oriented perspective has its roots in management science, and this perspective emphasizes

manners in which effective teams can be formed. Interestingly, in using this perspective, the concept of "autonomy" is somewhat unique. Specifically, autonomy is defined as the extent to which an agent does not need to be supervised. The "intelligence" of the agent is not necessarily of central focus. Instead, for example, a successful autonomous agent could be one that sweeps floors. It is considered successfully autonomous if it is able to report to the supervisor in the event that it needs assistance. The work-oriented perspective emphasizes the manner in which the human-automated team can improve mission performance, and the dynamic nature of the work is emphasized.

Dr. Pritchett began, what might be considered the "core" of her presentation, by asking **why we should have more team members**. (The two answers she reviewed, and the related points, were central to her presentation, and she revisited these points at the close of her presentation to emphasize these points again.) She discussed the division and redundancy of task work as an answer to the question regarding the value of teams. *First*, she reminded the audience that an increase in team members allows for a distribution of task work, with different team members completing different tasks. However, she emphasized the point that, when team members are added, teamwork becomes a new part of work. Therefore, the total volume of work (to get the job done) increases, despite the fact that the number of tasks per team member may decrease. *Second*, additional team members increase redundancy on task work. Specifically, in some cases, team members may perform the same tasks in order to allow for error checking. However, for this second point, Dr. Pritchett emphasized the notion that human teammates may make similar mistakes.

After making the aforementioned central points, Dr. Pritchett approached the question of **how work should be distributed between human agents and automation** by presenting the approach she uses in her work. In general, she **shared the manner in which she models tasks** in her work and demonstrated the effects of first modeling the task work then extending the modeling to include teamwork. Dr. Pritchett presented an example of the detailed analysis of the task work and teamwork that she has performed in her research. She used her work on arrival and approach operations as an example and explained to the audience that such detailed analysis is made possible because much structure already exists for the task (e.g., approach plates, etc.). Using this example, she demonstrated how work can be represented at different levels of abstraction (i.e., mission goals at the highest level and temporal functions at the lowest level). She noted that such a representation captures the work that needs to be performed regardless of how many team members are working on the problem.

Dr. Pritchett also presented a more conceptual model that one might consider in modeling task work. Specifically, the process of completing task work might be conceptualized as an agent interacting with the environment. In this conceptual model, the environment requires action from the agent, and the agent seeks information from the environment. She notes that, when a team member is added to the conceptual model, the work of the teammates cannot be modeled separately. One team member becomes a part of the environment for the other team member.

Returning to the model of arrival and approach operations represented at various levels of abstraction, Dr. Pritchett demonstrated how the work can be divided between pilots and automation, ranging from full automation to mostly manual control on the part of the pilot. This series of demonstrations allowed for a visualization of the tasks required and the manner in which they would be differentially distributed depending on the circumstances (e.g., teamwork vs. full automation). The related graphics can be found in the Appendix (Pritchett's slides 8 -15). Dr. Pritchett noted that, in order to "run" a simulation based on her modeling techniques, she first creates the work model with detailed actions inserted (e.g., "Need to set autopilot targets"). This information is then

submitted to an agent model, which allows the researcher to know which agent performed which task and when it was completed.

Dr. Pritchett's modeling techniques produce output based on various metrics, which she chooses based on findings in the literature. To determine what level of automation is most suitable in a given operational context, Dr. Pritchett uses a host of functional allocation metrics that included workload, interruptive automation, considerations for boundary conditions, and predictability of the humans' work environment, among others. Dr. Pritchett presented an example of the output from one of her simulations. She relayed that it was important to note that the highly automated function allocations performed very well on some metrics and not so well on others. In short, this demonstration highlighted the notion that successful function allocation is dependent on the particular task.

During the **question-and-answer session** following Dr. Pritchett's presentation, a few noteworthy points were made. *First*, one audience member asked if Dr. Pritchett thought there was something we could do to train pilots in the softer skill sets to encourage more consistent challenges between crew members. Such challenges might decrease the likelihood of confirmation errors and the like. Dr. Pritchett agreed and suggested that, even under such circumstances, we need to be sure we are not assuming the crew is engaging in cross-checking. Instead, the use of such "challenges" and cross-checking should be made to be more systematic and active, such that it is known that the crew is engaging in such behaviors. Another audience member confirmed that such a process is being successfully implemented by several airlines, and it appears to be working well. Dr. Pritchett added that Captain Sullenberger, who successfully landed the airplane on the Hudson River (see Dr. Sheridan's discussion of this emergency landing), also engaged in a last-minute query of the co-pilot. He said "What am I forgetting?" Such a statement suggests that expert pilots often do engage in cross-checking and allow room for challenges. *Second*, an audience member asked for clarification of Dr. Pritchett's use of workload in her modeling research. Dr. Pritchett clarified that workload is defined as the number of actions performed. She recognized a current weakness in her approach is that this definition of workload does not include perceived effort. However, their current approach does include an analysis to ensure the tasks are at the same level of granularity. *Third*, an audience member asked whether or not her work has included an examination of the type of errors (e.g., verification errors). Dr. Pritchett noted the importance of such an examination. However, her current work has modeled the flight crew as one group. She has not yet examined errors happening as part of communications within the crew. *Finally*, an audience member suggested that we not limit our consideration of verification errors to human agents, when designers can engage in the same type of errors. In the past, we have had common mode errors across systems (i.e., different systems were using the same piece of data, but the piece of data was invalid or the incorrect piece of data). Dr. Pritchett agreed and mentioned one particular study that might validate such a statement. Specifically, one study found that programmers trained in the same undergraduate program make similar errors and often cannot find the errors of programmers who graduated from the same academic program.

5.3. Single-Pilot Operation: Motivation, Issues, Architectures, and Con-Ops, *Dr. R. John Hansman, Massachusetts Institute of Technology (MIT) International Center for Air Transportation*

The slides used by Dr. Hansman can be found in Appendix E.

5.3.1. Abbreviated Account of Dr. Hansman's Presentation

Dr. John Hansman, from the Massachusetts Institute of Technology (MIT) International Center for Air Transportation, noted the decreasing air carrier crew trends over the history of commercial aviation. He reminded the audience that the air carrier has gone from a five-person crew prior to the1950s (a captain, first officer, flight engineer, navigator, and radio operator) to the two-person crew that began in the 1980s and continues through today. He thought SPO was possible but its deployment must be supported by a sound, reliable (i.e., safe and redundant) architecture. Dr. Hansman noted the type of redundancy architecture offered by a two-person crew and advanced possible ideas to maintain such redundancy in SPO. For example, the redundancy in judgment normally offered by a second pilot could be complemented by having a virtual co-pilot on the ground, likely served by a dispatcher equipped with enhanced real-time information. The physical redundancy offered by a second pilot could be complemented by trained flight attendants or embedding the functions of remotely-piloted vehicles into cockpit design so a ground-based backup can take over when necessary.

5.3.2. Extended Account of Dr. Hansman's Presentation

Dr. John Hansman, from the Massachusetts Institute of Technology (MIT) International Center for Air Transportation, began by inferring he believes the use of SPO is feasible. In fact, he offered the hypothesis that nominal flight operations, in particular, can be reliably managed by a single pilot with current or near-term systems. He used the B-787, Piper Mirage, and F-22 as examples of aircraft that already can be flown under SPO.

Dr. Hansman proceeded by presenting **arguments for the use of SPO under various operating rules**. In terms of *air carrier operations (FAR Part 121)*, Dr. Hansman suggested that SPO would be beneficial in terms of both cost and flexibility. Specifically, cost would be reduced, not only in terms of labor, but also in terms of training and accommodations for personnel. Flexibility would be increased in terms of scheduling pilots, and the pilot pool would be functionally increased without an absolute increase in the number of pilots. In terms of *business and personal aviation (FAR Part 91)*, safety, flexibility, and savings could be increased. Dr. Hansman reminded the audience that SPO already exists in this category, but any research and development might only enhance these operations.

After presenting these general arguments, Dr. Hansman **elaborated on cost issues by presenting data**. In terms of US air carrier operations, he presented 2010 data suggesting labor costs are approximately 25% of total costs. Interestingly, this percentage is in great contrast with China, where airlines' labor costs were about 3% in the early 2000s (when US costs also were around 25%). However, he also presented data showing that US air carrier labor costs have shown a downward trend. This downward trend may not necessarily be advantageous. As labor costs go down, some report that personnel satisfaction is decreasing. Such a circumstance leads one to ponder whether the quality of flight crews will go unchanged. The implication might be that a decrease in labor costs due to SPO might not have a negative impact in the same way recent labor cost reductions have.

Like other presenters before him, Dr. Hansman found it important to address the notion of reducing aircrew size by presenting a **historical account of air carrier crew trends**. Beginning with a description of the 5-person crew (captain, first officer, flight engineer, navigator, radio operator), he noted that advances in technology and general simplification of systems led to reductions in crew size. Beginning in the 1950s, radio operators were no longer needed, by the 1970s, the role of the navigator was being eliminated, and by the 1980s, we saw the flight engineer's job begin to

disappear. For perspective, he reminded the audience that we are now questioning whether the first officer's role is needed any longer, and that poses the question as to whether or not we will eventually be asking the same question about the captain's role.

In order to further address **concerns about safety under reduced crew operations**, Dr. Hansman presented statistical data from Boeing. The data illustrated that accident rates from 3-person crews were higher than accident rates observed today, under two-person crew operations. Such data suggest that a reduction in crew size does not necessarily yield a reduction in safety. In fact, he shared additional data from Boeing, and when describing the data, he stated that the USA is at a remarkable level of safety for commercial aviation with about 0.2 accidents per one million departures, and worldwide the rates are only slightly higher (i.e., at approximately 1 to 3 accidents per one million departures). Dr. Hansman also addressed safety in GA. He presented two studies. One study was performed by Bennett and Schwirzke and analyzed 25 years of GA flight data for approaches. This data showed that, for GA, accidents occurred seven times out of every 100,000 approaches. Interestingly, the data showed that the rates were not much different when the plane was flown with one or two pilots. However, he did note that the data were limited only to the approach phase of flight and caution should be taken before drawing overall conclusions. He further noted that the data indicate that single-pilot operations were much worse than dual-pilot operations when instrument flight rules were being used at night. He also presented data from a study performed by the AOPA Air Safety Foundation. Covering the years 1983 through 1999, the results of the study showed that 61 single-engine, daytime accidents occurred with two pilots on board. On the other hand, 1,170 single-engine, daytime accidents occurred with one pilot.

As with any change in aviation, **certification issues** must be considered. Dr. Hansman presented the audience with a brief overview of the certification process and reminded them that risk analysis is a part of any certification process. When performing such an analysis, the consequence and probability of an event must be addressed. For example, for a catastrophic event (consequence), the probability of its occurrence must be extremely improbable. The definitions associated with the categories of probabilities (e.g., ranging from frequent to extremely improbable) vary, but one typical definition of extremely improbable is a probability (per unit of exposure) of 10E-9.

Dr. Hansman also addressed the **issues of reliability in equipment and technology.** He reminded the audience that there must be an attempt at identifying all of the possible failures. Furthermore, the system must be "fail safe, fail operational." In other words, the system must continue to be safe even in the event of a failure, and if possible, you want to ensure the overall system continues to be operational in light of a failure in one component of the system (i.e., to ensure you do not have to land immediately under some sort of "nominal failure"). He also emphasized the degree of redundancy that is required in systems that are deemed to be safe. He reminded the audience that many components require dual redundancy, while some components require as much as triple redundancy (e.g., if two sensors provide conflicting information, a third is needed to determine which value is valid).

To mirror the issues of reliability in equipment and technology, Dr. Hansman also addressed **the need for redundancy in the human components of the system**. Specifically, he emphasized the need for physical and judgment redundancies. He explained that the need for physical redundancy is primarily a result of the idea that pilot incapacitation may occur. Like several of the speakers that preceded him, he exemplified this reality by referencing the current event in which a pilot on a major airline (JetBlue) apparently experienced a psychological breakdown. Furthermore, he presented FAA data that suggests pilot incapacitation occurs approximately once per month. He emphasized

that these data imply it is not a problem that can be ignored. In terms of judgment redundancy, he reminded the audience that a second pilot serves to cross-check the judgments made by the captain.

Under SPO, of course, physical and judgment redundancy could no longer be offered by a second pilot. However, Dr. Hansman offered some suggestions as to **how human redundancy may be accomplished under SPO**. *First*, in terms of physical redundancy, he suggested that flight attendants could be trained to serve as a back-up pilot of sorts. This particular concept brings the post-9/11 locked cockpit doors to the forefront. If onboard personnel will provide more assistance to the pilot than today, accessibility to the cockpit must be considered. *Second*, he discussed a related, but more general, alternative. Specifically, he addressed the notion of having humans who have little or no training serve to operate the aircraft under dire circumstances. With this discussion, he reviewed a digital autopilot with a recovery function (i.e., the Avidyne DFC 90) from the GA domain. This particular autopilot offers numerous functions. However, what is notable is that the interface contains one button labeled "straight and level." This intuitive button serves to accomplish what might be expected: to bring the aircraft to a straight-and-level state. He, therefore, suggests that the aircraft could have these simplified types of functions available to allow for several options when considering a backup for an incapacitated pilot. *Third*, he discussed the idea that the airplane might have an automated backup (i.e., the airplane would be able to fly itself). Dr. Hansman gave an example of a vehicle that already exists (i.e., the Aurora Centaur OPA), and it is categorized as an "optionally piloted vehicle" (OPA). *Fourth*, he suggested a ground-based backup as an option in the face of pilot incapacitation. Specifically, such an aircraft would be flown as a remotely piloted vehicle. However, this alternative would put pressure on communication standards. Specifically, terrorism would need to be considered if an aircraft could be flown from the ground. In this case, a ground-based "pilot" could cause harm to passengers while posing no risk to himself or herself. In terms of judgment redundancy, Dr. Hansman shared a *fifth* suggestion. Specifically, he suggested that the role of a virtual co-pilot could be served by enhanced dispatch services. This possibility might be feasible with communication and surveillance systems that support real-time interaction over most of the world. The challenges would be in terms of having adequate bandwidth in the equipment but also in terms of the human resources within the dispatcher. Today, a dispatcher can handle approximately 20 flights under normal circumstances, but this number decreases rapidly when some non-normal state occurs (e.g., a winter snow storm).

Dr. Hansman highlighted **potential advancements in GA that might be spawned from the work on FAR Part 121 SPO**. His ideas were very similar to those he discussed in terms of the manner in which FAR Part 121 human redundancies can be accomplished without a second pilot. One notable exception was that, when discussing GA, he mentioned cost as a limiting factor for some of the aforementioned alternatives (e.g., the ground-based backup or enhanced dispatch services).

In closing, Dr. Hansman reviewed a few final issues that might serve as **challenges in the realization of SPO**. *First*, he mentioned that the communications and control architectures must be developed to ensure integrity and security, if people on the ground will be more actively involved in flight decisions and/or controls. The issue of communication loss is one that should be examined carefully. *In addition*, he mentioned single-pilot boredom and public acceptance as ones that need to be addressed. *Third*, he questioned whether the complexity of the proposed NextGen procedures offset the potential benefits of SPO. In closing, he presented a *fourth* challenge in dealing with non-normal operations. Specifically, he seemed to believe that SPO is feasible under normal conditions, but the challenges will arise when something out of the ordinary occurs.

During the **question-and-answer session** following Dr. Hansman's presentation, audience members made several notable comments. *First*, one audience member suggested that all labeling within the

cockpit may need to be re-visited if untrained people will be serving as backups. The audience member suggested that the "straight-and-level" button shown during the presentation was a great example of the manner in which the cockpit would need to be re-designed. A *second* audience member suggested that, with the loss of the second pilot, the idea of apprentice training is lost. Under SPO, a pilot would become "captain" immediately rather than going through the learning process that occurs in serving as a first officer.

5.4.   Defining Research Issues for Single-Pilot Operations in Transport Aircraft: Why Should We Care About Crew Resource Management (CRM)?, *Captain Robert Koteskey, San Jose State University Research Foundation*

The slides used by Captain Robert Koteskey can be found in Appendix E.

5.4.1.   *Abbreviated Account of Captain Robert Koteskey's Presentation*

Captain Robert Koteskey, a professional pilot who also serves as a researcher for the NASA Ames Flight Deck Display Research Lab as part of the San Jose State University Research Foundation, discussed the role of Crew Resource Management (CRM) in SPO. Similar to speakers that came before him, he noted the decrease in crew size for transport aircraft during the last fifty years. Thereafter, he presented a summary of CRM and its effect on transport operations since the 1970s. The presentation reviewed the evolution of CRM and then covered the basic team and human-oriented skill standards for which professional air carrier pilots are currently trained. The skills that are taught include: decision making, adaptability/flexibility, mission analysis, monitoring and correcting, communication, leadership, assertiveness, situation awareness, and threat and error management. Captain Koteskey argued that the techniques used in CRM are still applicable when the other crew members are remote or non-human. A model of flight crew performance was presented, and the need for CRM concepts to be included and addressed in any SPO implementation was stressed.

5.4.2.   *Extended Account of Captain Rob Koteskey's Presentation*

Captain Robert Koteskey, a professional pilot who also serves as a researcher for the NASA Ames Flight Deck Display Research Lab as part of the San Jose State University Research Foundation, discussed the role of Crew Resource Management (CRM) in SPO, with the goal of providing insight for the following day's workshop discussions. Similar to speakers that came before him, Captain Koteskey addressed the **history of crew size**. He noted that, in the beginning, aircraft worked under SPO and asked audiences to bring historical figures to mind in recalling this fact (i.e., Charles Lindbergh and Amelia Earhart). In the 1950s, the transport aircraft could no longer be controlled by single pilots, and pilots suddenly needed to adjust to a large crew size and working on a team (a pilot, co-pilot, navigator, radio operator, and flight engineer). In the modern era, technology led to a progressive reduction in crew size. Captain Koteskey asked the audience to consider what happened to the jobs of the navigator, radio operator, and flight engineer. To answer the question and emphasize his point, he highlighted pieces of technology on an image of a modern cockpit and stated that their jobs are now done by these pieces of technology. With today's advanced technologies available, Captain Koteskey asked the audience to consider why SPO is not being used now, since one pilot can fly the airplane (e.g., if the co-pilot leaves the cockpit). However, he noted that flying single-handedly is not necessarily possible today if something goes wrong. Therefore, in order to adopt SPO, he argued that it may seem counterintuitive but we must explore issues related to CRM.

Before he was able to present the specific rationale regarding the importance of CRM under SPO, Captain Koteskey presented a **notional, graphic description of CRM and technology effects**. The slides related to this discussion can be found in the Appendix (Koteskey's slides 17 – 32). His conceptual graph plotted the number of events that require action from the pilot(s) against the difficulty associated with handling the event. Captain Koteskey populated the graph with notional data such that it might represent the reality of the 1930s. His graph relayed a state of affairs in which there were many events that required action from the pilot, with many of those events being difficult. Thereafter, and in the context of the same notional graph, Captain Koteskey presented the notion of a risk threshold. Given the concepts presented on the x and y axis, Captain Koteskey suggested that the risk threshold of any crew might be conceived as a negatively sloped straight line. (However, he reminded the audience that this illustration is merely notional, and his choice of a straight line was merely based on intuition for the sake of conversation.) Using this model, he suggested that circumstances to the right of the threshold line (i.e., the upper, right-hand corner of the chart) might be conceived as a circumstance with accident or incident potential, while circumstances to the left of the threshold line (i.e., the lower, left-hand corner of the graph) might be conceived as conditions that are conducive to safe flight. He then relayed that the notional threshold should be considered moveable and dynamic. Specifically, while maintaining the same slope, the notional threshold line could vary in terms of where it intersects with the x axis. In illustrating the movement of the threshold line, Captain Koteskey made two important points. First, the location of the threshold line can vary between crews or across time within one crew. In other words, some crews may be better at handling many, difficult tasks, whereas other crews may simply not have as much skill. However, one crew may vary in terms of its threshold across time. For example, a crew with a high threshold may, after time spent on an extended flight, have a lower threshold than when they began.

Captain Koteskey then pulled together the notional data representing pilots from the 1930s and the notion of a threshold. In short, the illustration emphasized that, in the 1930s, there was much potential for an accident or incident, given that much of the notional data fell in the area representing risk. He further illustrated the effect that technology had on the relation between events and thresholds. Specifically, he suggested that technology has decreased the frequency of situations in which there are many events occurring that are of high difficulty. He argued that weather radar, reliable air traffic control services, and automation, for example, have been responsible for this change. Therefore, in modern day, most (but not all) circumstances are such that they are below the threshold for accident and incident potential. He then used the graph to illustrate that, under SPO, our goal would be similar in wanting to keep the events such that they remain under the threshold of risk, which suggests that CRM is relevant to SPO.

After reviewing this notional model, Captain Koteskey discussed CRM explicitly by focusing on the **history of CRM**. He relayed that CRM emerged because, in the 1970s, technology became quite impressive, such that crew errors became a safety emphasis. He relayed that crews presumably were not getting worse in their judgments, but the technology became so effective that the crew-related errors became more apparent. At that time, research was conducted that suggested the airline pilots of the 1970s and 1980s, hired and trained based on old SPO values (i.e., rugged individuals), needed new training on how to successfully operate in human teams in order to improve crew performance and safety. However, when the training was initially offered, he relayed that there was much "push back" from the pilots, who considered the seminar training to be, a sort of, "charm school." Now, CRM has become widely accepted as part of the necessary skills for piloting, and the CRM skills are seamlessly integrated into standard training programs for pilots. Captain Koteskey ended this portion of his presentation with a review of various success stories that presumably were a result of good CRM skills.

Captain Koteskey then reviewed CRM in terms of a formal **definition and current-day approach to training of CRM skills**. He noted the CRM initially was an acronym for "cockpit resource management" but has since been changed to "crew resource management." In terms of its meaning, effective CRM means effective use of *all* available resources (information, equipment, and people) to achieve safe and efficient flight operations. He further noted that these resources are both internal and external to the aircraft (e.g., onboard personnel, dispatch, air traffic control, National Weather Service, flight automation, etc.). As an example he mentioned that, before a pilot pushes back, the pilot must contact numerous personnel that serve as extensions to the two-person cockpit team (e.g., maintenance, lead flight attendant, etc.). In CRM training today, the skills that are taught include: decision making, adaptability/flexibility, mission analysis, monitoring and correcting, communication, leadership, assertiveness, situation awareness, and threat/error management. These skills are meant to be applied in interactions with all resources, within and outside the cockpit.

Captain Koteskey argued that the techniques used in **CRM would be applicable under SPO**. He shared that CRM research and training has embraced the philosophy that a web of teams is involved in the ability to manage an airline flight safely (in planning, flying, and recovering), and as a result, this area of research and training should provide rich insight in the planning of SPO. When CRM concepts are ignored, Captain Koteskey suggested that we might limit ourselves to considering only aircraft control tasks (e.g., power control, flight control, and navigation). However, Captain Koteskey continued by presenting a graphic illustration of all the areas that would be omitted if the full range of CRM-related tasks were not considered (e.g., communications and decisions tasks, team formation and management tasks, etc.). He asked attendees to consider all the CRM-related tasks during the workshop portion of the meeting. For example, we might ask the questions as to how we can ensure that automation, which may replace a human, will have good CRM skills. In closing, Captain Koteskey stated his belief that we should: (1) retain safety benefits reaped from CRM while designing for SPO, (2) use CRM concepts to define the duties and responsibilities of, not only the pilot but, the web of teams and automation that will exist in SPO, and (3) enable a single pilot to adequately coordinate with all resources to produce sound decisions at high levels of performance and safety.

During the **question-and-answer session** following Captain Koteskey's presentation, audience members asked a few questions. *First*, one audience member asked if there are tasks that cannot be captured by a task-oriented approach to automation. Captain Koteskey responded with a "yes." He used an example as an elaboration. He gave the instance when the co-pilot is running through the checklist with the pilot. However, if the pilot is distracted by some event on the runway, the co-pilot instinctively pauses in the review of the checklist. Furthermore, the co-pilot instinctively knows (without anyone verbalizing it) that the cause for distraction has been resolved, and the co-pilot would resume the review of the checklist at an appropriate time. In this instance, the two pilots are sharing (experiencing) the same environment. A purely task-oriented approach to automation would not capture the need to pause the review of the checklist, nor would it capture the notion that there is an appropriate time to resume review of the checklist. In short, a task-oriented approach to automation may miss concepts such as prioritization and urgency. A *second* audience member asked if CRM can provide automation requirements and criteria. Captain Koteskey suggested that the body of research on CRM, which dates back to the 1960s and 1970s, and the training of today can be used to guide requirements and criteria.

5.5.   Establishing Advanced AOC Systems for Single-Pilot Operations, *Ms. Leigh-lu Prasse, San Francisco ARINC*

The slides used by Ms. Leigh-lu Prasse can be found in Appendix E.

5.5.1. Abbreviated Account of Ms. Leigh-lu Prasse's Presentation

Ms. Leigh-lu Prasse of ARINC discussed the development of Aircraft Communications Addressing and Reporting System (ACARS) and its importance in providing reliable and rapid communication. She relayed that, as other speakers had suggested, communication and surveillance will likely play a key role in our ability to move to SPO. She thought current-day, performance-based operations such as Required Total System Performance (RTSP) could be applied to an advanced dispatcher as it incorporates required performance for communications, navigation, and surveillance. In her vision, the job of the dispatcher could become a combination of a dispatcher, ATC, and copilot. Serving as controller, the dispatcher would require direct communication and surveillance with the pilot. In addition, the dispatcher would need a "big picture" of the airspace and aircraft in his/her control and would need a direct link to the position of aircraft. As copilot, the dispatcher could support decision making, monitor for non-standard or marginal weather at relevant airports (destination and alternate), and provide pertinent information to the pilot on board. An advanced dispatcher certification process would need to be developed, possibly one that would include in-depth knowledge of aircraft and IT systems. Dispatchers would also need to be provided technology, such as Automatic Dependent Surveillance-Broadcast (ADS-B), which is currently available to ATC. An advanced Airline Operations Center (AOC) may help enable SPO and save in crew costs.

5.5.2. Extended Account of Ms. Leigh-lu Prasse's Presentation

Ms. Leigh-lu Prasse of ARINC began by briefly introducing the audience to **ARINC**. In terms of its **history**, ARINC is now in its 83rd year of operation and was started by the airlines in 1929 to provide communications for the industry. The SFO (San Francisco) ARINC location at which Ms. Prasse is employed provides communications for the Pacific region (e.g., voice services for aircraft in FAA-controlled oceanic airspace and aeronautical operational control communications for aircraft operators in international airspace). Ms. Prasse stated that, over the last 18 years, she has been able to witness the integration of automation in oceanic sector ATC.

Ms. Prasse proceeded to describe **ARINC's development and implementation of ACARS**. ACARS was one of ARINC's most notable innovations. It was originally named the "ARINC Communications Addressing and Reporting System," but was renamed in the 1990s to the label used today: "the Aircraft Communications Addressing and Reporting System." The system was developed by ARINC as a solution for saturated voice channels and to expand system capacity for ATC. However, following test phases and trials in 1967, the FAA decided that "general-purpose data link had no near-term ATC applications," and efforts directed at ACARS were diminished. She reported that the test trials happen to coincide with the B737 two-person certification process that was conducted in 1967. Piedmont, known in the industry as forward-thinking and innovative (e.g., they were the first to use TCAS, the traffic collision avoidance system), was exploring ways in which they could realize savings by operating the B737 with a two-person crew. The FAA would not certify Piedmont for two-person operations unless the airline demonstrated continuous "reliable and rapid communications" in FAR 121.99. Therefore, Piedmont asked ARINC if they could have a designated network that would enable them to monitor specific VHF frequencies on which their aircraft could receive calls from dispatch. ARINC, having just certified ACARS, persuaded Piedmont that ACARS would be a communications solution in addition to the network. The initial application of ACARS automated the four phases of flight. The airlines soon found that a host of other operational activities performed by VHF voice communications could be digitally automated. Therefore, pre-departure information, the actual weight and balance calculations for take-off, fuel status, weather updates, new flight plans, engine performance parameters, and virtually any type of operational communication could now be sent to the small printer in the cockpit. Within the first

year (by the end of 1979), Piedmont's original 13 ACARS sites quickly grew to 134 ground stations with 4 airline customers, 415 aircraft ACARS-equipped, and 6 more airlines signed up. Today, ACARS is implemented world-wide and integrated not only into commercial aviation, but it serves as a means of communication for ATC as well. In short, ARINC's ACARS and Piedmont's target for a two-man crew had a revolutionary impact on aviation; ACARS was instrumental in solidifying a two-man crew and was inadvertently a precursor to the digital age of automation and communications. Ms. Prasse believes that the evolution of ACARS shows us the importance of communications for commercial, military, and ATC operations today. Requirements for SPO may lead us in the same direction for the AOC. Specifically, she suggests that, in addition to integrated aircraft automation capabilities, the industry also will need to examine the necessary communications and surveillance required to advance the standard crew size from two to one.

In the research and development directed toward SPO, Ms. Prasse reminded the audience that there are many types of air carrier operations to examine: (1) aircraft automated systems and performance, (2) flight operations and pilot requirements, (3) the maintenance operations control center, and (4) the AOC. She relayed to the audience that **her presentation would take a narrow approach to SPO with a focus on AOC and the dispatcher.** In using this approach, she applied criteria already established today in air traffic management performance-based standards.

Ms. Prasse reminded the audience that **requirements associated with the general approval process** must be considered when reflecting on the concept of SPO. She shared that, historically, an evaluation of equipment and human limitations has guided regulations, but performance-based standards provide flexibility for new technologies to be implemented. These performance-based standards are effective because they provide a structured, analytical approach and method. She presented one such example: RTSP. RTSP is a set of performance-based standards that pertain to air traffic management and includes all functions (i.e., communications, navigation, and surveillance in air traffic management). The International Civil Aviation Organization uses RTSP as an operational concept for global air traffic management (ATM). Ultimately, because performance-based standards are used as separation minimums to safely control air traffic, she suggests that the same performance-based standards could be applied to AOC requirements in approval of SPO. Specifically, Ms. Prasse suggested that an analogous set of requirements for SPO might be developed, which we might call "Required SPO Systems and Performance" (RSSP). She suggested that RSSP could be a solution for managing the capabilities and performance of SPO and will establish operational, safety, and performance requirements world-wide. Furthermore, Ms. Prasse suggested that the criteria to establish the standards required for SPO would need to be developed, and the industry would want to consider SPO as it operates within a whole system (from the air carrier to air traffic control). As examples, she presented the following areas that might be considered in relation to RSSP: technology, procedures, organizational factors, human factors, and security.

Before considering the certification process, the particular configuration of interest must be identified. Ms. Prasse suggested **two possible configurations for SPO operations**: the use of (1) UAS technology with remotely piloted operations to back-up SPO and (2) an advanced AOC with*out* a remotely piloted back-up UAS. Ms. Prasse proceeded to discuss each of these possibilities in turn.

When addressing the first option, use of **UAS technology as a back-up to the single pilot,** she reminded the audience that the technology already exists in order to allow for this particular configuration. In particular, she reminded the audience of two currently existing categories that may be relevant. A UAS is one that the FAA considers to include all the complex systems associated with

an unmanned aerial vehicle (UAV), such as the ground stations involved in the process. A second, related system is the optionally piloted aircraft (OPA), which can be flown with or without a pilot on board. OPA is the FAA term for an aircraft that is being controlled from the ground even when there may be a pilot on board. In short, with these technologies already being used, commercial flights eventually can be fully autonomous and fly a programmed profile from one location to another with the single pilot as the primary monitor. These advanced automated aircraft could be "armed" on departure to be operated remotely or from a pre-programmed profile in the event of pilot incapacitation. In the event of loss of communications, the flight would respond as programmed (e.g., to continue to the destination, land at nearest airport, or return to the departure point). She suggested that this option is not only feasible, but it would be the safest option to pursue.

In contrast to the advantages she shared, Ms. Prasse relayed **several questions (or issues) that arise when pondering the use of UAS technology as a back-up to the single pilot:**

1. How can pilot incapacitation be determined in order to establish that the single pilot is no longer in control?
2. For how many flights would the remote pilot be responsible?
3. For how many hours should a remote pilot be on duty?
4. Would the dispatcher monitor the flight and then alert an on-duty remote pilot when needed?
5. What are the single-pilot, duty requirements? Would they be something akin to a 2 X 2 X 8 rule, such that SPO would be restricted to two-engine aircraft with two take-offs and landings and under 8 hours flight time?
6. Would SPO flights be mixed with a dispatcher's other fights in the airline's system?

Finally, Ms. Prasse emphasized one final issue, in particular. She suggested that, although the UAS technology might be the safest, this configuration would have the highest cost.

Ms. Prasse continued her discussion by addressing the second, potential option in detail. When addressing the **use of an advanced AOC with*out* a remotely piloted back-up**, she shared that she believed this option to be feasible. However, she suggested that this configuration would require a highly automated AOC, integrated with the aircraft systems through advanced mediums. In such a system, she relayed that three-way communication would be necessary; dispatch must be able to communicate with the pilot and controller in the same "loop." The dispatcher's communication with the pilot would have to be in the form of direct links (e.g., primarily with digital data messaging, voice, or streaming video through the electronic flight bag). Dispatch must have real-time aircraft situational displays. In addition, technologies such as the ADS-B would need to be enabled for the dispatcher, such that the dispatcher can receive the same signal as the controller. The dispatcher must have direct communications with air traffic control via the same data link modes the aircraft uses in order to support a single pilot in the same way a co-pilot would, enabling the pilot to focus on flying the plane. The dispatcher must be able to interrogate the aircraft systems for real-time flight planning predictions (with 4-D trajectory information) and receive enhanced weather from onboard avionics. Surveillance ability would be necessary to establish situation awareness with regard to the particular aircraft in order for the dispatcher to have real-time knowledge of the plane's location and all performance factors associated with it. Although the dispatcher would not be separating traffic as a controller would, they would have a new level of responsibility in supporting a single pilot. The job of the dispatcher would become more of a combination of what are currently tasks associated with the dispatcher, controller, and co-pilot. Instead of separate data conduits, the advanced AOC system would need to be integrated into a single display in order to support the higher level of responsibility associated with the job of the dispatcher. She presented Ocean21, developed by Lockheed for the ocean sectors, as an example of such an integrated workstation.

Ms. Prasse continued by addressing some considerations in attempting to certify the specific SPO configuration in which **an advanced AOC is used with*out* a remotely piloted back-up**. Specifically, she suggested that *controller-dispatcher data link communications and dispatcher-pilot data link communications would need to be certified*. She shared that performance-based communications are based on the International Civil Aviation Organization material on required communications performance, which considers communication process time, continuity, availability, and integrity among other criteria. Currently, the dispatcher does communicate through company data link systems to flights but not with required communications performance standards. SPO should have the same standards already established by performance-based communications and surveillance as used by ATC for controlling traffic. If a flight can send a message to a controller directly, there is no reason why a dispatcher should not be able to do the same. Ms. Prasse also discussed the reality that there would be a need to address *advanced AOC dispatcher certifications*. Specifically, she relayed that there would need to be a special dispatcher certification for SPO operations, such as a type-rating. This certification would need to include in-depth knowledge of the aircraft and information-technology systems. She mentioned that this type of certification would have an impact on two federal aviation regulations in particular. She suggested that this SPO configuration would take FAR 121.533, covering joint responsibility with the captain, "to the next level." In addition, FAR 121.465 would need to be amended. In particular, a SPO dispatcher might be limited to a maximum of 8 hours on duty (instead of 10 hours) within a 24 hr period with no more than 5 consecutive days (instead of 7 days).

Ms. Prasse ended her presentation by reviewing her major points. In closing, she reminded the audience that single-pilot operations are not new. However, what is new is the application of SPO to commercial aviation and large jet transport that will interface within the NAS. She suggested that SPO may possibly be a stepping-stone to commercial UAS. The FAA currently is requesting public input on selection for six UAS test sites to collect data for a safe civilian UAS integration into the NAS.

Several audience members became involved during the **question-and-answer session** following Ms. Prasse's presentation. These discussions are summarized here. *First*, an audience member asked if Ms. Prasse thinks the dispatcher might be too removed from the "team" in a SPO configuration with an advanced AOC, and the audience member further asked if Ms. Prasse thought that control of the aircraft would differ for a remote operator. Ms. Prasse responded by saying that she thinks the dispatcher has to become a more active member in the "loop." She added that there has to be a new level of training for the dispatcher, which might fall somewhere between pilot and dispatcher training. In addition, some sort of computer training must be a part of dispatcher training. Things have changed drastically in terms of having technology-related skills. In fact, she shared a project that examined the roles of aviation mechanics, which has changed from being purely mechanical (i.e., "hands on") in nature to a job that also requires one to be computer savvy. *Second*, another audience member stated that he had been thinking about the advanced AOC configuration Ms. Prasse was suggesting in combination with the discussion of crew resource management in a prior presentation. He reminded everyone that Captain Koteskey had mentioned that pilots often communicate by merely looking at one another. The audience member stated that he had been thinking of an experiment in which a current, two-person crew might fly with a barrier erected between the two pilots. In this way, they would be able to talk with one another but not see one another. This experiment would allow us to learn about the "body aspect" in communications between the team members and understand the manner in which intentions are relayed (verbally or nonverbally). It allows us to consider whether a video image of team members (e.g., a remote dispatcher) might be required. Ms. Prasse said she agreed, and she had also been thinking about video communication because it may allow communications to be more meaningful. *Third*, an audience member shared a current state of affairs at a major airline, because it is analogous to some

of the concepts Ms. Prasse (and others) had discussed. Specifically, the audience member described a version of a "super AOC" at one major airline, in which two people serve as virtual team members to ongoing flights. One of these jobs is labeled as the "flight operations duty manager." This person is actually a captain on the airline, but in this role, the person is considered an assistant chief pilot. The role is filled 24 hours a day, and the person is meant to serve as a representative within the AOC for the captain and crew. In this way, the flying crews can have a representative on the ground who can utilize all resources on the ground (e.g., maintenance, crew scheduling, dispatch, etc.). This job is similar to what Captain Koteskey mentioned in his talk, when he discussed a virtual co-pilot that might serve as an expert on almost any aviation topic. For example, if the crew has a hydraulics problem, the flight operations duty manager facilitates getting information from the expert on the ground. A second job also exists as a supplement to the flight operations duty manager. The second person is referred to as the "wingman," and that person performs administrative duties, assists the flight operations duty manager, and records the activities of the flight operations duty manager. In a mutual exchange between this audience member and the speaker, several additional points were highlighted. The flight operations duty manager at the airline communicates with the onboard crew via a phone patch or ARINC. In addition, the exchange resulted in a further discussion of cost. The cost of training the single pilot and the training and certification costs for dispatch were noted. However, the reduction of the crew by one person with associated cost reductions (e.g., benefits) was also noted. *Finally*, an audience member asked whether any problems will arise due to mixed equipage if the AOC/dispatcher will be doing some of what ATC is doing. The importance of this issue is clear because older aircraft won't be able to take advantage of SPO. Ms. Prasse shared her opinion and suggested that the SPO dispatcher should not have to handle a mixture of flights, similar to the manner in which domestic and international flights currently are handled separately.

5.6. Economic Opportunities and Technological Challenges for Reduced Crew Operations, Dr. R. Michael Norman, The Boeing Company

5.6.1. Abbreviated Account of Dr. R. Michael Norman's Presentation

Dr. R. Mike Norman, of the Boeing Company, reviewed a report he originally delivered to NASA Langley Research Center in May 2007. However, Dr. Norman strongly emphasized the fact that this research is in no way a reflection of the Boeing Company's thoughts, interests, or policies. Rather, the work is that of Dr. Norman as an individual. The report summarized the economic opportunities and technological challenges for reduced crew operations. Dr. Norman was tasked with providing an industry-centric analysis of revolutionary crew-vehicle interface technologies. While Dr. Norman showed a potential significant cost savings associated with reducing crews, the safety statistics he examined showed a potential link between level of safety and number of pilots in the cockpit. Additionally, he found no impediments to certifying a single-piloted, transport category aircraft in current FAA regulations. However, language in some of the FAA regulations and guidance suggests that the FAA would be reluctant to do so, particularly because of the pilot incapacitation issue. Dr. Norman suggested that pilot incapacitation is the most serious impediment to implementing SPO and proposed further investigation into using noninvasive medical screening to rule out arteriosclerosis or cerebrovascular disease, as these are two of the most common reasons for sudden pilot incapacitation. Lastly, Dr. Norman reviewed several technology applications that could aid in SPO such as intelligent voice recognition, enhanced data link, an enhanced caution and warning system, a pilot assistant, and enhanced weather radar. For each potential technology, several workload and safety issues were discussed.

Dr. R. Mike Norman, of the Boeing Company, reviewed a report he originally delivered to NASA Langley Research Center in May 2007. However, Dr. Norman strongly emphasized the fact that the report is in no way a reflection of the Boeing Company's thoughts, interests, or policies. Rather, the work is that of Dr. Norman as an individual. The report is in the public domain and can be easily retrieved. Please see the reference section of this paper (Norman, 2007). The following paragraphs highlight some of the findings from Dr. Norman's report.

In terms of **background for the research,** Dr. Norman's paper summarizes work performed for NASA Langley Research Center, who expressed interest in "revolutionary crew-vehicle interface technologies." These technologies are ones that are meant to optimize operator situation awareness and involve intuitive, cognitive interactions. The motivation for performing the research was twofold. First, because the NAS is quickly evolving, single-crew (very light jet) and unoccupied air vehicle operations at cruise flight levels may share the skies with other aircraft on a more frequent basis. In addition, economic benefits potentially can be derived by operating commercial and business aircraft with minimal crew. Therefore, Dr. Norman was asked to identify technological and non-technological obstacles that may obstruct any reduction in the minimum flight crew requirements. As a further example of his assigned task, he was asked to document the economic opportunities associated with SPO and highlight market survey data.

In terms of the **approach and method used in his research**, Dr. Norman relied heavily on publicly available documents and data. In addition, he used information from interviews, a literature survey, the internet, and publicly available market data. In order to maintain a manageable analysis, he used several aircraft types as examples in terms of economic benefits, crew procedures, and technical issues. Safety data were obtained from public sources, as indicated throughout the paper (e.g., the National Transportation Safety Board). Pilot monitoring procedures and responsibilities were reviewed from representative Boeing flight crew operating manuals and Dr. Norman's own 30 years of experience. Regulatory information was obtained from FAA documents, as well as interviews with subject matter experts. Data relating to technical issues and technology mitigation candidates were obtained from public research documents, interviews with subject matter experts, and Dr. Norman's experience in flight test, flight research, and certification.

In scoping the research, Dr. Norman placed limits on the areas to cover. He limited his examination to that of commercial airline transport operations (FAR Part 121), non-scheduled and commuter operations (FAR Part 135), civilian non-commercial flight operations (FAR Part 91), high-performance jet aircraft, and some (but relatively less) attention was devoted to GA. He did not consider operations outside of the continental United States, Alaska, and Hawaii. He did consider the current-day air traffic management environment and the NextGen concept of operations.

Dr. Norman also identified several **issues related to reduced crews** in an attempt to further scope the research efforts. (These issues are presented in a paragraph separate from his other scoping efforts, because an identification of issues was a primary goal of the TIM that is described in this document.) One set of issues he chose to explore were those that related to the elements of the pilot monitoring's (co-pilot's) role and a consideration of *what might occur if these elements were simply added to the responsibilities and duties of the pilot flying*. In this context, he listed the following issues (Norman, 2007, p. 5):

1. What elements would add to physical or mental workload of the pilot flying?
2. What elements could not be transferred due to cockpit design or layout?

3. What elements would negatively impact safety if simply given to the pilot flying?
4. How is the pilot flying monitored for incapacitation?
5. What elements would violate regulations or standard practice relating to airworthiness and flight certification?
6. What additional elements might arise from future (i.e., NextGen) air transport operations, as well as procedural variations world-wide (i.e., responsibility of flight crew versus AOC in determining optimal routing en-route)?

Dr. Norman also considered *technology solutions to mitigate technical issues*. The following questions were posed to scope technical problems and solutions (Norman, 2007, p. 5-6):

1. What existing technology could be applied to mitigate technical issues and restore flight safety levels to equivalence with multi-crew operations?
2. What technical issues would not be supported by currently available (i.e., certified) technology in reduced crew operations? What technology development is required to fill this gap?
3. How could flight test and/or simulation be used to validate technology application to the technical issues? Is this needed?
4. How could technology be used to mitigate certification risk to reduced crew operations?

Therefore, certification risk is not related to verbatim interpretations of requirements but inferences in reviewing the requirements. Dr. Norman relayed that, when the regulations are reviewed, one finds an implied reluctance on the part of FAA to certify SPO (p. 21-22).

Dr. Norman's paper includes several **findings and recommendations in terms of SPO safety issues**. First, he presented statistics to explore safety records (Norman, 2007, p. 7). The statistics demonstrated an extraordinary level of safety in FAR Part 121 (airline transport) operations, where the accident rate was 0.0236 per 100,000 hours of flight (from 1987 - 2006). He contrasted this safety record with FAR Part 135 (scheduled and unscheduled), which demonstrated safety at an order of magnitude less than FAR Part 121. He also included FAR Part 91 operations, which demonstrated safety at two orders of magnitude less than FAR Part 121 (that is, FAR Part 91 had an accident rate of 1.4803 between 1987 and 2006). He also presented data from the military sector. Interestingly, accident rates for single-pilot operations in the military were found to be in the order of the rates found for GA, whereas the accident rates for the multi-pilot operations were found to be in the order of rates found for FAR Part 121. Given these rates, Dr. Norman explored the causal factors of accidents by operations (p. 7-8). Under all types of operations explored, (FAR Parts 91, 135, and 121), personnel was identified as the leading cause of accidents. However, some differences were noted between operations. For example, under FAR Parts 91 and 135, in-flight loss of control was identified as a frequent cause, whereas weather was identified as a frequent cause under FAR Part 121. As part of his examination of safety-related issues, Dr. Norman also reviewed the National Transportation Safety Board's "most wanted" improvements (p. 8). He highlighted two: a reduction in accidents and incidents caused by human fatigue and improvements in crew resource management. To summarize his findings regarding safety, Dr. Norman stated that mishap rates vary widely among different aircraft types and operations (p. 8). He believes the reasons for the variations are the differences seen in mission risk, aircraft design, pilot training, pilot experience, pilot qualifications, oversight (regulatory and management), and crew coordination. Regardless of the reason, Dr. Norman suggests that the historical statistics imply that the presence of two pilots significantly enhances flight safety (by one to two orders of magnitude). He suggests that this variation in inherent safety (whether or not tied to technical issues) must be addressed in reducing crew requirements for commercial flight operations. Design features would have to restore previous

levels of safety (i.e., an equivalent level of safety to dual-piloted operations), with perhaps an additional margin for confidence.

Dr. Norman also **reviewed findings and provided recommendations with regards to the economic benefits of SPO** (Norman, 2007, p. 10-12). Because the analysis he performed was meant to predict future savings and had the potential to be extremely complicated, Dr. Norman placed some limits on the manner in which he performed the calculations. Therefore, he used only typical aircraft types for specific classes of operation, and he did not assess training impact in this study (other than current, representative costs). In addition, he used seven pilots as an estimate of pilots per seat, aircraft, crew size, and year. This number was used because, for each seat, one does not consider one pilot, because there are approximately seven pilots needed per seat (e.g., some pilots are in training, on vacation, etc.). With those specifications, he performed his analysis using Boeing's market forecast data for the world-wide demand of new aircraft between the years 2005 and 2025. He also estimated cost data for the crew. When he combined the estimated costs with predicted need for aircraft, he was able to make a rough estimate regarding economic impact of SPO. Specifically, *he found* that, if a 20-year service life for the aircraft, data show that the aggregate flight crew cost per cockpit seat over the life of the aircraft, world-fleet-wide to be $6.8 trillion, which is potentially a significant percentage of the market value of the new aircraft (i.e., 54% of $12.6 trillion). Therefore, SPO may have economic benefit, but once again, new costs associated with SPO were not addressed (e.g., new training required, certification and development costs, etc.). He then proceeded to provide a few *recommendations* as to how cost could be reduced (p. 12). He suggested that fewer pilots could be required per seat if, for example, there were more efficient scheduling. Furthermore, he suggested that flight crew augmentation requirements could be reduced for long flights (i.e., the need to have two complement crew members on board aircraft could be reduced to one complement crew member). Finally, of course, he suggested the notion that the flight deck could be designed for single-pilot operations.

Dr. Norman also addressed **regulatory issues** (Norman, 2007, p. 13-22). A portion of his discussion focused on a relatively new class of aircraft, *very light jets*. The importance of aircraft in this category is that they are comparable to FAR Part 121 in several ways: they are relatively heavy airplanes, they fly at comparable flight levels, and they fly at relatively high speeds. Interestingly, these aircraft have stations for two pilots, but the intention is to certify them for one pilot. In terms of *transport category aircraft*, Dr. Norman addressed FAR Part 25 (p. 17-20), which defines airworthiness standards for transport category airplanes. It states that the minimum flight crew is to be based on sufficiency for safe operation considering the workload on individual crewmembers in addition to the accessibility and case of operation of necessary controls. In short, it does not exclude the possibility of SPO, but it does address workload. However, Advisory Circular 25.1523 addresses pilot incapacitation. Specifically, the advisory circular documents that 262 pilot incapacitation events occurred in FAR Part 91 operations from 1980 to 1989, with 180 fatalities. All of the fatalities were attributed to single-pilot operations. In FAR Part 135 operations, 32 occurrences of pilot incapacitation were documented, with 32 fatalities. All of these fatalities also were attributed to single-pilot operations. In FAR Part 121 operations, 51 cases of pilot incapacitation were documented, in which normal recovery of the aircraft was achieved by the second pilot. Therefore, although single-pilot operations are not specifically disallowed, mentions of these events in the advisory circular suggest the FAA is reluctant to approve SPO. After reviewing these regulations, Dr. Norman presented some *challenges in the certification of SPO for transport category aircraft* (p. 21): (1) enabling a single pilot to conduct complex operating procedures (sometimes simultaneously) in normal, abnormal, and emergency scenarios, (2) accommodating actions and procedures requiring a pilot to be unavailable at his/her assigned duty station (i.e., observation of systems, emergency operation of any control, emergencies in any compartment, passenger or cabin crew management,

and lavatory visits on long flights), (3) avoiding failure of automation in aircraft systems and control, (4) accommodating communications and navigation workload, (5) avoiding increased workload associated with any emergency that may lead to other emergencies, and (6) mitigating the effects of pilot illness or incapacitation, especially on board a large aircraft with a significant numbers of passengers.

Dr. Norman reviewed **additional issues related to SPO, with a focus on technology mitigation of these issues**. Specifically, he suggested that each one of the following areas would need to be addressed due to the changes that occur when moving from two pilots to one (Norman, 2007, p. 23): (1) communication, (2) checklists, (3) recording of flight-relevant information, (4) verbal callouts, (5) monitoring of the aircraft state, (6) monitoring of external hazards, (7) verification of visual contact on approaches, (8) aircraft systems monitoring and management, (9) flight guidance and autopilot/autothrottle configuration such as selection of the appropriate mode, (10) aircraft configuration such as gear and flaps, (11) management of passengers and cabin crew, (12) performing emergency and abnormal procedures, and (13) monitor pilot flying or CRM, (14) assume role of pilot flying as required, and (15) perform tasks as assigned by pilot flying. In response to these changes that would arise under SPO, Dr. Norman's research yielded at least 10 suggestions in terms of systems that could be developed in order to mitigate the effects of the changes that would occur under SPO (p. 23-31). These 10 suggestions were not "mapped" perfectly with the aforementioned 15 issues he discussed. Instead, he typically suggested two or more of these systems in order to mitigate any negative effects related to a particular issue. His report (Norman, 2007,) describes the technology mitigation areas in more detail, but to provide the reader with a sense of his suggestions, the technology mitigation areas are listed here: (1) intelligent voice recognition, (2) enhanced data link, (3) enhanced systems automation, (4) electronic systems control, (5) enhanced caution and warning system, (6) pilot assistant, (7) enhanced external view, (8) dispatch critical autopilot and auto-throttle, (9) enhanced weather radar, and (10) pilot monitoring and recovery system.

Dr. Norman discussed the **issue of pilot incapacitation** in his report (Norman, 2007, p. 31-34). He suggested that the issue of pilot incapacitation must be thoroughly addressed (p. 22). As part of his research, he performed a study of data from the National Transportation Safety Board. He searched for accident and incident data from January 1987 through December 2006 to find cases of pilot incapacitation. In terms of SPO, this finding presents cause for concern. In short, FAR Part 91 results in 144 pilot incapacitation events per billion hours, FAR Part 135 operations results in 57 events per billion hours flown, and FAR Part 121 results in 10 events per billion hours flown. In addition to this aviation data, Dr. Norman also drew some conclusions based on more general data. Specifically, he gathered data to learn of the average age of U.S. active pilots. The average was approximately 47 years of age. Thereafter, he examined the mortality rate of that age group as a part of the general population in the U.S. He found the mortality rate to be 427 per 100,000 in the population. Therefore, if the pilot (as a human being) is considered a system in the aircraft, he or she would not be certified as a reliable system! Presently, the requisite human medical reliability is only achieved for FAR Part 121 and 135 operations, by the presence of two pilots in the cockpit. This reliability is NOT satisfied in FAR Part 91 operations in which a pilot is crashing an airplane every three to four months due to incapacitation.

Dr. Norman discussed three very specific concepts in terms of **technology mitigation for pilot incapacitation** (Norman, 2007, p. 33-34). *First*, he suggested the use of arteriosclerosis and cerebrovascular disease screening. In all of the GA accidents he reviewed, and several of the FAR Part 121 and 135 incidents and accident, one or the other of these diseases was the likely cause of incapacitation. *Second*, he suggested the use of a pilot identity detection system (e.g., required

fingerprint or retinal scan). Such a system would prevent unauthorized person from serving as a pilot. This solution is not only meant to identify those who might intend to do harm, but it would also identify anyone who might not be considered "current." In fact, in many of the FAR Part 91 accidents he reviewed, incapacitation occurred in a pilot flying with an expired medical certificate. *Third*, Dr. Norman postulated a pilot monitoring and recovery system to address incapacitation. He suggested that a "first of" design would probably have to over-address the issue of pilot incapacitation. He postulated that pilot incapacitation would have to be sensed by an aircraft system, and the aircraft would have to be immune from inadvertent systems or control inputs by that incapacitated pilot. The determination of pilot incapacitation would have to be error-proof (no more than one failure in a billion flight hours). Errors could not occur in either "direction." In other words, he noted that the system should never be allowed to miss a case of incapacitation, and at the same time, the system should never incorrectly deem a capable pilot as being incapacitated. In short, Dr. Norman said that these requirements imply that the aircraft will need to be capable of being operated with no functioning pilot in the cockpit, at any given time (from initiation of the takeoff roll to completion of a safe landing). In brief, he suggested that the airplane will need to be able to behave autonomously. Essentially, then, if the autonomous aircraft could get certified alone, then all other design would essentially be guarding the aircraft against the pilot. Therefore, he concluded that, from a purely design and certification standpoint, it may be easier to design the aircraft for no pilot than for a single pilot. He suggested that the pilot incapacitation issue (and the required design requirements) is considered the most significant challenge to certification and conduct of safe, single-pilot, transport category airplane operations (p. 22).

5.7. The FAA Transport Airplane Directorate Perspective on Single-Pilot Transports, *Mr. Steve Boyd, The Federal Aviation Administration*

The slides used by Mr. Steve Boyd can be found in Appendix E.

5.7.1. *Abbreviated Account of Mr. Steve Boyd's Presentation*

Mr. Steve Boyd, from the FAA, gave a high-level overview of the U.S. government's role in regulating single-pilot transports. He began by noting what determines the requirement on minimum flight crew in current regulations. He noted that the assurance of safe operation is the primary consideration in formulating regulatory requirements. The determination of minimum flight crew needs to take into consideration the workload of individual crew members and the ergonomics of the work environment so that the appropriate crew members have access to and can easily operate the necessary controls. Mr. Boyd placed a heavy emphasis on designing safe airplane systems for off-nominal situations and failures. From his point of view, there are no apparent safety benefits to be gained from single-pilot operations. Mr. Boyd cautioned those who seek to advance single-pilot operations to fully understand what benefits are being sought and why.

5.7.2. *Extended Account of Mr. Steve Boyd's Presentation*

As a preface to his talk, Mr. Steve Boyd, of the FAA, asked the industry to avoid thinking of certification and regulations as impediments. Rather, certification and regulations should be considered imperfect tools to assist in reaching the goal of safety. He suggested that the primary responsibility of safety lies with industry, and the FAA's job is to promote safety with regulation. He relayed that some may not realize that the FAA can be, and has been, flexible with rules. For example, if new technology surfaces, the FAA may find the current rules are inadequate. Therefore, if a portion of industry finds it impossible to comply with a current regulation, he said that such a

situation is not insurmountable. However, dealing with the underlying safety issues is the ultimate goal, and safety must be achieved in any system.

Mr. Boyd began his formal presentation by reviewing a bit of history. He mentioned a few key events to review the **history of minimum flight crew**. Mr. Boyd shared that, in the late 1960s, systems on smaller transports (e.g., 737/DC-9) were simplified and automated such that a flight engineer was no longer necessary. Mr. Boyd explained that a review of this change is important because it emphasizes the fact that you must prove (with data) that safe conditions will be maintained. Boeing did, in fact, provide proof which allowed for the change from a three-person to a two-person crew. Specifically, they demonstrated that pilot workload for a 737 (two-person crew) was actually lower than pilot workload in a 727 (three-person crew). Not long after this change, wide-bodied aircraft were introduced. However, the FAA considered these aircraft to be too complex for a two-person crew, and for these larger transports, a flight engineer continued to be required. In the early 1980s, Boeing simultaneously developed the 757 and 767. By the existing policy, the 757 could be flown with a two-person crew, but the 767 would have to be flown with a three-person crew. However, Boeing argued that there was no technical or safety reason for requiring the 767 to have a flight engineer (the third crew member). Ultimately, it was agreed that a wide-body could be operated by a two-crew, and the issue was settled. Mr. Boyd said that he was trying to relay *a message in reviewing this piece of history*. Specifically, he stated that, when attempting to change the size of the crew, it is more than a technical issue. Boeing's argument regarding the 767 was highly politicized and visible at the congressional level. He also asked the audience to consider the fact that the unions became involved, and by stating publicly that jobs might be eliminated, the aviation industry might expect "push back."

After reviewing the history, Mr. Boyd devoted the remainder of his presentation reviewing **regulations as they relate to SPO**. Mr. Boyd first reviewed **Sec. 25.1523, which addresses minimum flight crew** and has not changed much since the original regulations were put forth in the 1940s. Sec. 25.1523 states that the minimum flight crew must be established so that it is sufficient for safe operation, considering: (a) The workload on individual crewmembers; (b) The accessibility and ease of operation of necessary controls by the appropriate crewmember; and (c) The kind of operation authorized under Sec. 25.1525. In short, Mr. Boyd noted that a number is not provided in terms of minimum crew size, but instead, the regulation is performance-based. In the 1960s, an appendix was added that provides the criteria for determining minimum flight crew. In that appendix, the following basic workload functions are identified as being areas that are considered: (1) flight path control, (2) collision avoidance, (3) navigation, (4) communications, (5) operation and monitoring of aircraft engines and systems, and (6) command decisions. In addition to the workload functions, Mr. Boyd shared the ten workload factors that are considered when analyzing workload for minimum flight crew determination. Those ten workload factors are as follows:

1. The accessibility, ease, and simplicity of operation of all necessary flight, power, and equipment controls.
2. The accessibility and conspicuity of all necessary instruments and failure warning devices. The extent to which such instruments or devices direct the proper corrective action is also considered.
3. The number, urgency, and complexity of operating procedures.
4. The degree and duration of concentrated mental and physical effort involved in normal operation and in diagnosing and coping with malfunctions and emergencies.
5. The extent of required monitoring of systems.
6. The actions requiring a crewmember to be unavailable at his assigned duty station.

7. The degree of automation provided in the aircraft systems to afford (after failures or malfunctions) automatic crossover or isolation of difficulties to minimize the need for flight crew action.
8. The communications and navigation workload.
9. The possibility of increased workload associated with any emergency that may lead to other emergencies.
10. Incapacitation of a flight crewmember whenever the applicable operating rule requires a minimum flight crew of at least two pilots.

Mr. Boyd highlighted the fact that the manufacturer must meet the aforementioned set of criteria. He further reminded the audience that this set of criteria concerns pilot workload. However, in moving toward a SPO environment, industry may develop many new systems with many new functions in order to replace the second pilot and/or to function autonomously in order to replace a single pilot who is incapacitated. He stated that he was confident that many special conditions would be needed. A special condition, he explained, is an ad-hoc rule that would be written to address the myriad of new issues that would surface. He asked the audience to look at the regulations and notice that there is an implicit assumption that a pilot is at the controls. If airplanes were designed for the single pilot, he explained that the FAA would be challenged to consider (or re-consider) these rules, as they are today.

Mr. Boyd concluded his discussion of minimum crew requirements (and the related concept of workload) by stating he believes it is possible to meet the workload requirements for a single pilot as of today. He reminded the audience that, today, aircraft can be built to fly themselves. Mr. Boyd said it is likely that additional automation could be introduced that would mitigate workload for a single pilot. However, he shared his belief that there are **several issues with SPO as they relate to the minimum crew requirements**. *First*, he said SPO must be considered in the context of NextGen plans. NextGen will provide some verbal communication and navigation relief (e.g., automatically uploading flight plans). However, given the current concept of operations, NextGen will also shift some controller monitoring tasks to pilots, which would presumably increase pilot workload. *Second*, he suggested that the future airspace may be more heavily "populated," which also might add cognitive and task load. *Third*, thus far, he noted that we have only considered normal operations, and the critical issues arise under non-normal operations. *Fourth*, Mr. Boyd emphasized the importance of considering pilot incapacitation under SPO. He reminded the audience that the appendix associated with minimum flight crew requirements necessitates that the design account for an incapacitated pilot. He suggested that pilot incapacitation is not frequent, but it does occur with some regularity. He equated the case of an incapacitated, single pilot on a transport with an ad hoc UAS, but reminded the audience that this UAS has hundreds of passengers on board! He relayed that current design practices are based on a premise that the pilot can take control from a malfunctioning (not just failed) system. The system safety assessments often depend on that mitigation. Under SPO, this premise would also need to be addressed in the reverse (i.e., aircraft systems can take control of the aircraft from a pilot that is "malfunctioning" or has "failed"). He suggested that, in considering a reversal of the said premise, industry would need to completely rethink how airplane systems are designed. In addition, the aviation community would need to consider the introduction of new, potentially catastrophic system failures during which the pilot might be prevented (by aircraft systems) from intervening.

Mr. Boyd continued his review of regulations by discussing **Sec. 25.1309, which addresses system safety.** He explained how the severity of a failure (e.g., catastrophic, severe, major, or minor) is directly related to how often it is allowed to occur. For example, severe cases are considered to occur when there is a large reduction in safety margins or functional capabilities, higher workload,

or physical distress such that the crew cannot reliably perform its tasks accurately or completely. These cases are only permitted to occur one time for every 10 million flight hours.

As with minimum crew requirements, Mr. Boyd shared his belief that there are also **several issues with SPO as they relate to safety requirements**. *First*, he noted that the safety standards in Sec. 25.1309 are for hardware failures only, but warned that they are difficult to meet nevertheless. *Second*, he suggested that the industry must also consider the impact of SPO on the hazard categories of existing systems. System safety assessments attempt to predict failure conditions and their consequences (hazard categories) and then system reliability/integrity are matched to the hazard level. However, he suggested that changing to single pilot will likely elevate the hazard category for many failure conditions, requiring much more robust designs. In short, single-pilot designs may actually increase the number of significant failures. *Third*, Mr. Boyd reminded attendees that the ability to anticipate failure conditions is far from perfect, and industry should never assume an understanding of what failures will actually occur. He presented a recent event as an example. A Qantas A380 experienced uncontained engine failure. He reported that, in the cockpit, the pilots faced a series of critical system failures and were confronted with 54 flight system error messages. He noted that this situation arose from a known failure condition, and one can only imagine what might happen given unknown failures. Mr. Boyd made a *fourth*, and related, point. Specifically, he noted that complex systems and software should not be overlooked in undertaking something as substantial as a move to SPO. The safety rules were developed when most functionality was in hardware. Nowadays, he estimated that about 95% of aircraft functionality is in software (tens of millions of lines of code). He noted that the hardware (e.g., chips) usually does not fail. Instead, he suggested the errors are usually in the form of design errors, and there is no way to attach a probability to a software design error. Therefore, software is placed in categories related to its criticality. At the highest level, the software is very expensive to build because of the level of scrutiny it undergoes. It is so expensive that those in industry often are motivated to get their software out of the highest categories of criticality when possible. The level of automation, complexity, and integration needed for a single-pilot transport will exacerbate the problem of difficult-to-identify design errors and the high cost of critical software. He reminded attendees that model-based development and automatic code generation often are used (i.e., a model generates the code, and no one truly knows the raw code). As more systems are added, more complexity, and a larger web of intertwined systems, one minor coding error could "ripple through" the system and lead to an incomprehensible situation for the pilot. Under SPO, this situation may be worsened because more systems will be added, and some of these systems will be of high criticality because they would take the place of the second pilot. *Fifth*, Mr. Boyd discussed the idea of mitigating flight crew errors. He relayed that the aviation community often ignores the fact that many errors made by one pilot are identified and addressed by the second pilot. Under SPO, this mitigation would be lost. Furthermore, there is a proposed new flight crew error rule (i.e., 25.1302). This rule has a requirement for design features that support error management, and it is questionable as to how this rule will be addressed under SPO.

After addressing regulations and related issues, Mr. Boyd shared his **closing thoughts**. He relayed that he wanted to mention one stray thought. Specifically, he stated that, if the second pilot is replaced by someone at a ground station, security risk is impacted greatly. This configuration, in his opinion, might become highly political. With that said, he asked the audience to consider a set of questions that they might pose to themselves in succession. First, he suggested the following as the starting premise for a research effort aimed at examining use of a single pilot in the transport category: "First, do no harm." Thereafter, the aviation industry should ask what benefit is being sought with SPO and why? Once that question is answered, the aviation industry might ask if SPO is the best manner by which to achieve the benefit. In other words, if SPO is motivated by economic

goals, is SPO the best approach to gain financially? Finally, he asked the audience to consider whether SPO will solve more problems than it creates.

Several audience members became involved during the **question-and-answer session** following Mr. Boyd's presentation. *First,* an audience member asked if there is any credit given to formal mathematical proofs and verifications (in the certification process). Mr. Boyd said "yes." He stated that, oftentimes, certification is performed with a variety of models and tests. He relayed that, instead of flight testing, industry might come to the FAA with a model. Industry simply has to ensure the model being used for the test is not the same as the model used to write the code. *Second*, an audience member shared a comment. Specifically, the audience member suggested that "subtle pilot incapacitation" has been ignored in discussions. The attendee suggested that this type of incapacitation often can be caused by a stroke. The incapacitated pilot will only show symptoms if prodded (e.g., questioned). Some pilots currently are trained to recognize it. *Third*, an audience member relayed that metrics are available to "tap" many of the areas that are regulated (e.g., workload). However, an effective metric of complexity is not yet available. This metric might be important because new systems and their integration create the possibility for error. Mr. Boyd agreed. *Finally,* an audience member wondered if the attendees had forgotten to focus on the strength of having the human in the system. Mr. Boyd agreed. He suggested that the second pilot increases safety. In addition to the pilot as a back-up human on board, the presence of the second pilot also comes with the notion of dual systems on board. These dual systems often are independent; if one fails, you can access the other. With single-pilot designs, you lose the second channel on some systems.

5.8. Single-Pilot Operations: Automation Considerations, *Mr. Sethu R. Rathinam, Rockwell Collins*

5.8.1. Abbreviated Account of Mr. Sethu Rathinam's Presentation

Mr. Sethu Rathinam, from Rockwell Collins, presented a concept for a single-pilot station based on the use of automation. In his proposal, a single-pilot station can be designed in such a way that the pilot serves primarily as a system manager for onboard automation, rather than in the traditional aviator role whose primary skills are associated with safe manipulation of the flight and system controls. Mr. Rathinam gave a detailed breakdown of how the workload criteria under FAR Part 25 could be met with a single pilot. In particular, onboard decision support tools would prevent a pilot's tactical errors by assessing imminent hazards and ensuring that the aircraft was configured correctly. Similarly, the airline's operation center would mitigate any strategic errors. Because the plane could fly itself in the case of pilot incapacitation, a less qualified crew member could take control by putting the plane in a "digital parachute" mode that could find an appropriate airport and land. Such automation is already under development.

5.9. NextGen and the Single Pilot, *Mr. Greg Potter, Cessna*

The slides used by Mr. Greg Potter can be found in Appendix E.

5.9.1. Abbreviated Account of Mr. Greg Potter's Presentation

Speaking from the perspective of an aircraft manufacturer that specializes in single-pilot aircraft, Mr. Greg Potter from Cessna focused on the logistical challenges in realizing SPO. Potter expressed concern that NextGen's emphasis on equivalent operations based on specific aircraft equipage (e.g., DataComm) could potentially reduce the ability for single-pilot flights to access flight level 34000

and above and to operate into and out of metro-plexes. He pleaded that all NextGen research scenarios should include single-pilot operations, and that single-pilot aircraft should be considered first in NextGen implementation.

5.9.2.   Extended Account of Mr. Greg Potter's Presentation

Mr. Greg Potter from Cessna presented ideas generated by his colleague, Ryan Z. Amick, and him. Mr. Potter began his presentation with a **discussion of Cessna, in general, to provide perspective**. Specifically, he shared that Cessna is the world's largest aircraft manufacturer based on unit sales. Having a history of more than 80 years in the industry, Cessna has delivered more than 192,500 and holds the most recognized name in GA. With that said, Mr. Potter relayed that he did not want to focus on all of the aircraft produced by Cessna. Instead, he wanted **to focus on the approximately 3300 single-pilot business jets that have been put forth by Cessna**. He presented two sets of business jets produced by Cessna (i.e., the Mustang and CJ series). He highlighted several facts associated with these jets. In particular, he noted that these business jets are flying at relatively high speeds (on average, around 400 knots) and high altitudes (with maximum altitudes at flight levels in the lower to mid 40,000 ft range). In short, he highlighted that these aircraft are high-performance aircraft operating in high performance airspace. They frequently fly into high density airspaces alongside crewed aircraft. Working in the industry, Mr. Potter argued that these aircraft may be more important to our economy than most might recognize. Typically, these jets are used by small businesses in an effort to visit with customers because the business jets allow them to avoid the extensive time commitment required when traveling via the airlines.

Speaking from the perspective of an aircraft manufacturer that specializes in single-pilot aircraft, he focused most of his presentation on the implementation of NextGen and how it impacts a single pilot. First, however, Mr. Potter **reviewed a few of the goals associated with NextGen**. Specifically, he noted that, for NextGen, the FAA's focus is on increased through-put primarily at the nation's busiest commercial airports. Furthermore, the NextGen emphasis has been on high-performance airspace (i.e., at flight levels above 34,000 feet), high-density airspace, taxi, and the oceanic tracks. One major goal is to reduce weather's impact on the NAS because weather is said to be responsible for 60-80% of delays. Under NextGen operations, aircraft theoretically will have the equivalent to visual operations under all weather conditions. This ability presumably will occur with decreased separation requirements. The realization of NextGen, then, will depend on increased automation.

Given the aforementioned review of the goals associated with NextGen, Mr. Potter asked audience members to **consider the potential difficulty in certifying SPO for the NextGen environment.** He asked attendees to imagine a scenario in the NextGen airspace in which weather is a factor and everyone is trying to "squeeze" through the same portions of airspace. Consistent with NextGen proposals, there would be a reduced number of controllers and reduced separation. Of course, the single pilot would have increased responsibility for this reduced separation. He asked attendees to ponder whether a single-pilot aircraft and a reduced controller cadre can safely manage separation. He made specific reference to a quote on another presenter's slides. He relayed that he wholeheartedly agreed with the following statement Mr. Steve Boyd made: "Given the change in air traffic management strategy embodied in NextGen (more aircraft-centric), single-pilot ops may actually compromise that goal." In addition to merely analyzing the situation as a mental exercise, Mr. Potter reported hearing rumors regarding NextGen requirements. Specifically, he heard that, in NextGen, high performance airspace is going to be tied to equipage and single pilots are going to be categorized as non-equipped for high performance airspace. He asked attendees to consider how industry would design a system such that the single pilot can deal with challenges in NextGen. In

short, Mr. Potter asked attendees how the aviation industry might avoid shutting single pilots out of high-performance airspace and how industry can work to ensure they are certified for NextGen.

Mr. Potter suggested that, at least some of the problem, results from the fact that **NextGen research has ignored the single pilot**. For example, the research exploring the use of optimized profile descent is based on aircraft at a hub. However, Mr. Potter suggested that research should be examining the larger metro-plex regions. General aviation accounts for a significant amount of traffic in airfields that surround major hubs, and some of this traffic is in the form of business jets with single-pilot operators. He stated that it is short-sighted to ignore activity outside of the immediate hub area. **Mr. Potter suggested that all NextGen research scenarios include SPO, with a focus on reduced automation scenarios to mimic what would happen in non-normal conditions.** By including SPO research, he believes the result would be an increase in safety for crewed aircraft as well.

For the latter part of his presentation, Mr. Potter shifted topics in order to share **what Cessna has learned, and does, as a part of the process associated with single-pilot certification**. He relayed that they have not found the FAA guidance to be excessively burdensome, but they have learned that the FAA guidance is somewhat outdated in terms of what it addresses (e.g., AC 23.1523 from January 2005 that addresses "Minimum Flight Crew"). Mr. Potter suggested that, for example, the guidance presumes that modern avionics add complexity and increase workload. In addition, the guidance presumes pilot/crew workload for a FAR Part 25 aircraft is more complex than a FAR Part 23. Mr. Potter suggests this latter presumption is not true. He also shared that, unlike the past, the display technology reduces space allocation challenges (a.k.a., the limited, cockpit real estate problem). The new challenge is to emphasize the non-normal circumstances, and because information is now displayed on multi-function displays, Cessna assesses the number of pilot actions required in deciding how to present required information and controls. Mr. Potter said that, at Cessna, human factors planning begins at design conception and drives decisions at each phase. In short, every system, display, and control is planned and scrutinized. As the design process continues, they produce a cockpit design summary document. This document is quite extensive and provides an explanation for design decisions in the placement of every control and display. In addition, they perform cross-cockpit comparisons in the document. Thereafter, they perform task analyses with the use of humans in the system. For example, they examine the effects of system errors and random errors, study human responses and the types of failures that occur, and they employ SHERPA (Systematic Human Error Reduction and Prediction Approach).

Mr. Potter closed his presentation by highlighting the "**take-home messages**" he was hoping to communicate: (1) NextGen procedures and associated avionics should be designed with less complexity, not more; (2) If two pilots are required for NextGen operations, has the industry made the system better? Has the industry made it safer?; (3) Single-pilot operators fly in high-performance airspace and the metro-plexes alongside crewed aircraft; (4) Single-pilot operators must be able to perform the NextGen-required procedures or risk losing access; and (5) NextGen researchers should ask the single pilot question first rather than as an afterthought.

Several audience members became involved during the **question-and-answer session** following Mr. Potter's presentation. The *first* audience member shared a comment, suggesting that there is something to be learned "from both sides." Specifically, the audience member suggested that Mr. Potter was representing the single pilot and how that configuration could continue to be supported in the future NAS. Those with a perspective consistent with FAR Part 121 operations are examining how to reduce the crew by one person and are asking how to continue supporting the remaining pilot. In short, both perspectives should assist in examining SPO. A *second* comment was shared by

an attendee, who suggested that, technically, all modern two-pilot crewed airplanes are certified for a single pilot, given that pilot incapacitation of one pilot has to be addressed. A *third* comment was in regards to weight limits. An audience member reminded Mr. Potter that he had mentioned the apparently arbitrary distinction between aircraft based on weight. The audience member argued that the public mindset is of importance, and the distinction between 500 people and 3 people being impacted is important to the public. Mr. Potter agreed. He suggested that the point he was trying to make is that complexity is not currently used to separate aircraft in the certification process.

6. Summary of Workgroup Discussions

Section 2.2 provides a summary of the approach to workshop discussions. In short, on the second day, attendees were divided into four working groups, but **all groups received the same instructions as described here**. Specifically, facilitators were asked to have their respective groups develop allocation strategies for responsibilities under SPO. For each strategy identified, they were asked to identify the reason for the choice of said strategy as well as the pros and cons associated with it. Guidelines for implementing each strategy were also requested, if possible. Attendees also were asked to identify barriers, enablers, opportunities, and research issues associated with achieving the selected SPO allocation strategies. Throughout the workshop portion of the meeting (i.e., the second day), attendees were encouraged to consider novel concepts.

This entire section (i.e., Section 6) contains a summary of the presentations given on the third day of the TIM. Each of the four facilitators presented a summary of their assigned workgroup's discussions. As with the accounts of the invited speakers, **for each presentation, an abbreviated account is presented** and serves a function similar to an abstract in a peer-reviewed journal. **An extended account of the presentation also is included**, which provides a more comprehensive description of the thoughts relayed by the speaker. The extended account also includes a summary of the discussions that followed each presentation. These discussions occurred during a time that was set aside for audience members to pose questions or share thoughts with the presenter. When slides were used and the presenter provided permission to include the slides in this document, the slides are included in Appendix E. The inclusion of slides is noted in the relevant subsections that follow. **Please note that the descriptions contained herein review the information that was summarized in the respective facilitator's slides, but the accounts typically contain additional information.** As was reviewed in Section 3.2, the authors of this document reviewed the facilitators' slides, their verbal presentations, and the original notes taken at the time the workgroups met.

6.1. Workgroup 1: *Facilitated by Dr. Doreen Comerford*

Dr. Doreen Comerford, of San Jose State University Research Foundation, served as facilitator for Workgroup 1. Dr. Comerford's slides, which summarize the Workgroup 1 discussions, can be found in Appendix E.

6.1.1. *Abbreviated Account of Workgroup 1 Discussions*

Workgroup 1 provided several recommendations in the consideration of task allocations under SPO. First, the group members relayed that tasks related to the "aviate" category of responsibility would remain relatively unchanged in a move to SPO, and instead, the areas related to "navigate" and "communicate" categories of responsibility should be the focus of research and development. In addition, the group members suggested that several tasks should be reserved for the remaining single, onboard pilot: tasks that require visual senses (e.g., see and avoid, visual separation, etc.), tasks that require the use of other senses (e.g., experienced turbulence), and tasks that require high-

order decision making (e.g., collision avoidance, strategic planning, etc.). In terms of research directions to consider, the topics suggested were plentiful and diverse. Generally speaking, the group offered suggestions that represented various types of research: experimental research, survey research, literature reviews, and contacting persons engaged in related research areas. In an attempt to be succinct but to offer the reader with a better sense of the areas represented by their suggestions, a sampling of topics are as follows: automation issues, polling the aviation community, exploring the real-time transparency of the parties involved in the system, task analysis of current co-pilots, and effects of removing the second pilot from a social perspective (e.g., body language cues, social pressures to remain alert, etc.). Finally, it should be noted that the group noted that the issue of pilot incapacitation is extremely important to consider in a SPO environment, but they felt it is an issue that could be addressed successfully. The group offered many ideas regarding issues that should be considered in regards to pilot incapacitation (e.g., monitoring pilots, conceptualizing incapacitation as a progressive state that could be identified via early "symptoms," etc.).

6.1.2. Extended Account of Workgroup 1 Discussions

Dr. Doreen Comerford, of San Jose State University Foundation, presented the discussions that took place among members of Workgroup 1. For the sake of organization, Dr. Comerford divided her presentation into four general segments: (1) the results of a quick vote, (2) pilot incapacitation issues, (3) suggestions for strategies in allocating tasks, and (4) research directions and suggestions. In accordance with the organization presented by Dr. Comerford, these four topics are addressed successively in the following paragraphs.

Dr. Comerford reported that she began the workgroup session with an **informal, anonymous vote to obtain a general sense of opinions represented by this particular group** of people and also to serve as a way to "break the ice." Of the 13 workgroup members (not including members of the group hosting the workshop), unfortunately, only 8 were able to be present at the start of the session and participate in the vote. Group members were presented with the following four statements: (1) We need two pilots, (2) We should strive to have only a single pilot, (3) We should strive for one pilot on board and one pilot on the ground, or (4) We should attempt to move directly from two pilots to no pilots on board the aircraft. Thereafter, they were asked to cast an anonymous vote for the statement that was most consistent with their own thoughts. The workgroup was asked to vote based only on personal, informed opinions at the present time, to consider a 20-year time frame, and to imagine they needed to simply generalize (i.e., a member of the general public asked them this question). In short, the results suggested that the workgroup did lean toward one particular configuration: one pilot in the air and one pilot on the ground. In fact, each category received one vote, except for the case in which one pilot is in the air and one pilot is on the ground. The latter category received five votes.

Dr. Comerford reported that she had proceeded by presenting the workgroup with a few questions aimed at identifying allocation strategies for SPO. However, the workgroup truly seemed to want to discuss pilot incapacitation because they believed this topic to be one that had to be addressed before all other topics could be explored. As a result, the group spent some time in the morning session focusing on the topic of pilot incapacitation. A core part of the workgroup's argument was that pilot incapacitation is extremely important because it affects every one of a pilot's responsibilities. In addition, as a whole, the group felt that the statistics presented by Dr. R. Michael Norman were striking (See Section 5.6), and some workgroup members became concerned about pilot incapacitation after hearing his report. These workgroup members suggested that the industry must work to see those statistics change in a positive manner before reducing the number of pilots. However, it should be noted that, throughout the conversation regarding pilot incapacitation, there

were several comments suggesting that some attendees felt that the issue of pilot incapacitation was being overemphasized. With that said, the following paragraphs summarize the workgroup's specific thoughts regarding pilot incapacitation.

In terms of pilot incapacitation, Dr. Comerford reported that the workgroup discussions had several recurring themes: defining the concept, monitoring the state, and determining the state. The workgroup seemed to believe a **definition of pilot incapacitation** should include considerations of both mental and physical health. The group generated a list of specific examples of pilot incapacitation: death, unconsciousness, sleeping, under the influence of drugs (including prescription drugs), and mental instability. The group noted that aviation currently has no system to monitor prescription drug abuse. Dr. Comerford also stated that the group felt it was important to recognize that pilot incapacitation can be progressive and does not necessarily represent an "all-or-none" state. Therefore, the state of pilot incapacitation would not necessarily have sudden, radical (all-or-none) impact on pilot behavior.

The workgroup also felt it necessary to address the need for **monitoring pilot incapacitation**, especially in the case of SPO. Without the second pilot, the workgroup suggested that mental health may be extremely difficult to monitor with any level of assurance. However, Dr. Comerford relayed that the group was more confident that physical health may be relatively easier to monitor in the absence of a human. A member of the group identified an example that may be promising. The attendee relayed that there are existing systems for determining whether or not pilots are asleep. For example, every few minutes, the automation requires the pilot to input a certain string of letters. If the pilot does not comply, an alarm goes off. Although such a system may be too intrusive, it could be used as a model for a more practical system in the SPO cockpit. In either case, Dr. Comerford reminded the audience that the workgroup felt pilot incapacitation can be progressive in nature. Therefore, when monitoring the pilot for either physical or mental health, pilot incapacitation should be approached with the recognition that incapacitation may have early symptoms, which could be quite useful in identifying effective monitoring strategies.

In **determining the state of pilot incapacitation**, however, most members of the workgroup believed that a human should be involved. Dr. Comerford relayed that they did not, however, suggest that the human would necessarily have to be a second pilot in the cockpit. However, they felt a human would be best at making this judgment because humans are able to engage in activities that automation cannot. For example, a human can talk to the pilot, interact directly with the pilot to ascertain his or her condition, and make a judgment regarding incapacitation based on many subtle, yet not easily defined, variables. The workgroup advised that extreme caution should be taken if either automation (i.e., technology) is used to decide if the pilot is incapacitated or if an onboard pilot is "locked out" from controlling the aircraft. If automation is used to decide that a pilot is in an incapacitated state, the workgroup made reference to a comment made by Dr. R. Michael Norman, who suggested that such a system should never be allowed to miss a case of incapacitation, and at the same time, the system should never incorrectly deem a capable pilot as being incapacitated. "Locking out" a pilot from the system could become extremely dangerous if the system has been locked by someone who, for example, has malicious intent. In fact, in this case, industry must consider how the pilot can be protected from the airplane. However, the workgroup recognized that automation could be of assistance in the case of pilot incapacitation. They suggested that it could "kick in" (even if temporarily) when a decision needs to made immediately and the pilot *may* be incapacitated. Assuming automation will be used and it can "lock out" the pilot, further issues arise. In particular, can the decision be reversed, allowing the pilot to re-gain control? Furthermore, when control is given to automation and/or given back to the pilot, how can industry ensure the transition in control will be graceful?

Workgroup 1 had a **few additional points to consider when addressing pilot incapacitation**. *First*, Dr. Comerford relayed that the workgroup believed that pilot incapacitation issues could be mitigated by being more proactive. Specifically, the workgroup suggested that more sophisticated medicals could be required of the single pilot. The group wondered if supplemental training also could serve to be proactive. For example, they pondered whether or not pilots could be trained to recognize the symptoms of a heart attack such that they could relinquish control to automation (without penalty for a "false alarm") before they are completely incapacitated. *Second*, the group members suggested that researchers consider the model used for DUIs (driving while under the influence). For example, a notification system could be implemented to allow pilots to report if a nearby pilot is behaving oddly, which might raise suspicion for an incapacitated pilot. In fact, they noted that, with NextGen, there will be tighter spacing and more opportunities for other pilots to directly observe the behaviors of other aircraft. *Third,* the workgroup noted that air carriers almost always have a pilot on board (e.g., commuting), and industry should consider taking advantage of this situation. This "second" pilot would be quite effective in the case of pilot incapacitation.

After discussing pilot incapacitation, Dr. Comerford reported that the group continued with a discussion of the assigned topic: **task allocations in SPO**. In that context, the workgroup had several suggestions. *First*, they provided a general recommendation in that they identified a set of tasks that should be reserved for the remaining single pilot. They suggested that all visual tasks should be reserved for the remaining visual pilot (e.g., see-and-avoid tasks, visual separation, looking at onboard weather radar, any visual procedures in the terminal area, etc.). In fact, one group member shared that these types of tasks (i.e., visual) have been shown to be best done by humans in UAS research. More generally, any task that requires "experiencing" a state should be kept for the remaining single pilot. For example, members of the workgroup suggested that dealing with turbulence and icing would be difficult if the pilot were not actually on the aircraft, and as an important side note, they noted that turbulence and icing issues are not uncommon. They also suggested that all higher-order decision making should be reserved for the single pilot. Dr. Comerford relayed some examples they generated to exemplify "higher-order decision making." The workgroup conceived higher-order decision making to include such tasks as dealing with multiple failures, novel problems, collision avoidance, and strategic planning in general. They also suggested that researchers might identify skills that a pilot would need to maintain. Because automation might yield skill degradation, an effective guideline might be to avoid automation on any skill that must be maintained by the single pilot. *Second*, the workgroup provided some additional, general guidance that might be useful in the process of making the decisions about task allocations. Specifically, members of the workgroup agreed that impact on the "aviate" category of tasks would be minimal in a move to SPO. The job of aviating has become more automated even in the absence of SPO. The "navigate" and "communicate" categories represent the tasks of the present-day co-pilot, and the change would probably be most apparent in these two categories. Ironically, from the perspective of a SPO initiative, the only time you truly will find both pilots in control is when there are mechanical or off-nominal issues, and these circumstances may be the ones that are most challenging to SPO. When something unexpected occurs in a cockpit, a strict division of labor is typically employed. For example, the Captain might say something akin to "I'm flying the aircraft. You take care of X. *Third*, when considering allocations, the workgroup attempted to consider all parties in the NAS. As such, they suggested that AOCs may be able to manage much of flight planning, and this management might even include weather. AOCs have different goals and requirements than ATC. Many of the needs of airlines are not accommodated by ATC, and that can be fixed by giving a larger role to AOCs in general. *Fourth,* this distribution of tasks raises the question as to what types of displays and information will be needed by the ground-based personnel, and *fifth*, it raises the question as to what effects delays will have if collaborating with ground-based personnel. Satellite communications can have delays up to a few seconds. *Sixth*, Dr. Comerford relayed that the

workgroup was concerned with legal responsibilities for flight. Assuming that the amount of automation would increase under SPO, the workgroup wondered if the pilot would continue to have as much responsibility for flight safety as compared to the pilots of today. If not, they wondered if automated systems would be considered other "collaborators" in the aircraft system. And, if automated systems were deemed "collaborators," they wondered who would be responsible for the performance of an automated system? Dr. Comerford relayed a *seventh* related issue identified by the workgroup. Specifically, members of Workgroup 1 stated that concepts for the future NAS (e.g., NextGen, some of the concepts shared at this workshop regarding SPO, etc.) seem to be moving toward a de-centralization of pilot responsibilities. With such decentralization, the legal responsibilities should be re-assessed, but the aviation industry must also remember that there are some advantages in having decisions based on centralized (local) information. One attendee suggested that any decision that requires direct interaction with or experiencing of the environment should be kept as "close" to the information as possible (i.e., the decision and experience should have a shared location). *Eighth*, the workgroup suggested that industry must consider SPO in the context of NextGen. They noted that NextGen will be giving pilots more responsibility, but SPO would remove a pilot from the cockpit. The workgroup wondered if a single pilot would be able to handle the responsibilities associated with NextGen.

Dr. Comerford proceeded to review the **research directions and suggestions** that were generated by Workgroup 1. Many issues were identified that related to **automation**, in particular, and the group thought these issues could be utilized in the research exploring SPO. *First*, the workgroup offered a general approach in identifying automation's role in SPO. Specifically, they suggested approaching automation as a means to enable needed capabilities in SPO. This approach would be in contrast to viewing automation as a way to compensate for the loss of the second pilot. *Second*, they suggested that industry might consider a conservative approach to automation in which automation helps only when it's too late for human input. One group member suggested that a model of such an approach would be the Mercedes Benz brake system, which implements auto-braking only when the car reaches a certain distance from the car in front of it. At the point the braking system intervenes, the possibility of human input is no longer possible. *Third,* they suggested using several taxonomies when considering automation. For example, in addition to the traditional levels of automation that are typically considered, researchers and developers should contemplate how tasks can be shared, blended, or distributed between the agents in the system. In addition, they should consider whether the distribution of tasks between the humans and the automation will be static or dynamic. Furthermore, if automation is dynamic, one must consider if it should be adaptable or adaptive. Static automated systems would always perform in the same way, adaptable automated systems are ones that can change based on the human's input, and adaptive automated systems are ones that would change their behaviors autonomously given the context. The workgroup suggested that any automation that is relatively consistent (i.e., static or adaptable) may be relatively less worrisome than adaptive systems. In the case of adaptive systems, the human would have the added workload associated with "tracking" the automation's current activities (e.g., Should I perform the task or is an automated system already doing that?). *Fourth*, Dr. Comerford relayed that the participants pondered the question as to how industry should choose particular tasks to automate and why some tasks might be selected for automation or not. The workgroup suggested that researchers first must identify tasks at which humans excel and tasks at which technology excels. However, in doing so, the group members warned that one must be careful when thinking in terms of tasks. Specifically, when researchers limit themselves to think in terms of tasks, they may miss "chunks" (or groups) of tasks that are necessarily linked in a cognitive fashion. If industry distributes tasks that are linked in a meaningful manner, they will probably create a less than optimal system. Therefore, tasks, as researchers define them, should be meaningful, should be considered in their contexts, and their relative levels of abstraction should be considered. *Fifth*, the group expressed some concern that,

when tasks are re-allocated amongst agents in the system, the nature of the job may change in ways that are unforeseen. Consultations and testing with subject matter experts might assist in understanding if and how a job may have been inadvertently changed. Researchers and developers need to be ready to address the new tasks that may be created by the change in allocations (e.g., new monitoring or communicating tasks may be created by new allocations of tasks). *Sixth*, because the single pilot presumably will be interacting with relatively more automated systems, Workgroup 1 suggested that the means by which the pilot will communicate his/her intentions must be considered. Although some may be interested in the use of intent inferencing, some workgroup members felt that such capabilities are not necessary. Instead, the human and automated systems could simply interact more directly to ensure their goals are the same (i.e., the human can directly input intent information). *Seventh*, if intent information were directly input into the systems, its validity could be considered high. Therefore, that information could be shared with others in the NAS (e.g., ATC, AOC, etc.). *Eighth*, because the SPO environment may be relatively more distributed than current-day operations, the workgroup discussed how the state of all agents in the system can be transparent. For example, how will the single pilot know the state of the automated systems and vice versa? Furthermore, how will the states of the pilot and onboard automation be transparent to those on the ground? *Finally,* as with any technology, the workgroup suggested that developers must be vigilant about terrorism. Not only are communications between the potentially distributed parties vulnerable, but we must ensure that "hackers" cannot access any automated systems.

The workgroup also identified a set of relatively more **specific research projects**, which represent various topics related to SPO. *First*, the workgroup suggested exploring what visual cues (i.e., body language) are being used by two-person crews. In other words, they suggested performing an experiment similar to the one mentioned by a workshop attendee during Ms. Leigh-lu Prasse's presentation, in which a barrier might be placed between two pilots to learn about body language. (See Section 5.5.) *Second,* because the single pilot necessarily works alone, the workgroup thought the effects of fatigue and boredom should be explored to determine its effects. As an example, the workgroup wondered if fatigue will present the risk of overreliance on automation, and if so, such overreliance should be explored in the context of any new or altered automated systems generated for SPO. *Third*, the group suggested a sort of task analysis, in which the tasks of the current-day co-pilot are systematically identified. One workgroup member suggested using checklists as a guide during any type of task analysis. Workgroup 1 thought this task-analysis type of work should be performed before identifying how the co-pilot's tasks should be allocated and if they should be re-allocated at all. Dr. Comerford also shared their thoughts regarding the following two types of analyses that were in the form of reviewing safety records. In short, their *fourth* suggestion was to perform an analysis of safety records to learn how and when the second pilot has been responsible for mitigating problems. *Fifth*, they thought a review of incidents and accidents should be conducted to search for cases in which design assumptions may have led to an incident and accident. Gathering such information would give researchers a sense of the dangers associated with automation use and would assist the aviation community in guarding against the overuse of engineers in making assumptions about real-time situations. In addition, such a review may allow the lessons learned to guide automation design and avoid making similar mistakes. Dr. Comerford also shared two of the group's recommendations that represent survey-type research. Their *sixth* suggestion was to poll the aviation community to determine which, if any, SPO configuration (i.e., method for allocating the second pilot's tasks) is viable for Part 121 operations. *Seventh*, they suggested that passengers and stakeholders should be polled to learn if they find SPO to be acceptable. Such a poll could be conducted periodically as the concept of operations is progressively refined. *Eighth*, with any research project that is undertaken, the group noted that multiple measures (of performance, behavior, or opinions) should be examined. They noted the findings of Dr. Amy Pritchett (See Section 5.2), who found that measures vary in sensitivity depending on the context. *Finally*, the

group noted one measure that is of particular importance. Specifically, the workgroup suggested that "risk" needs to be defined for SPO, where risk is conceptualized as risk imposed by real-time choices made. This definition will assist in guiding research and development. For example, one attendee mentioned previous work on an emergency landing planner integrated with the flight management system; the software would take into account various routes to nearby runways, along with weather, to provide pilots with a summary of the risks associated with each route. In this case, risk information was provided in real time.

Dr. Comerford reported that, when all was said and done, the workgroup was surprised at the amount of **literature review** that was suggested. The following list represents the workgroup's recommendations for literature reviews that should be undertaken, and these items are presented in no particular order.

1. Literature from the military domain should be reviewed, such that SPO efforts can leverage off of their experience in single-pilot/dual-pilot vehicle operations.
2. Research conducted by DARPA (Defense Advanced Research Projects Agency) should be reviewed. One attendee reported that DARPA has previously researched an ability to infer intent based on physiological measures. Although the studies are no longer being conducted, the attendee suggested that there is much to be gained from reviewing that research. They explored questions such as, "What is the state of the automation, and what is the state of the human?" Thereafter, they examined how to make the information transparent to the operator and/or a human on the ground.
3. Review the work of Mr. Jay Shivley at NASA Ames Research Center. His research provides some guidance as to how tasks can be organized in a meaningful manner.
4. Given the time of the TIM, another group member suggested a review of an upcoming report from Kathy Abbott of the FAA.
5. The 1981 ASRS (Aviation Safety Reporting System) study should be reviewed. This study explored the performance of the single pilot under IFR (instrument flight rules).
6. Review any relevant literature that might exist from NASA's space-related efforts.
7. Review the NextGen concept of operations document, but the review should be performed "with an eye" for SPO. In other words, the NextGen concept of operations should be systematically reviewed assessing the details to understand how or if SPO would fit with the NextGen concept of operations.
8. Examine insurance-related issues. The workgroup thought it would be useful to determine if, how, and why insurance companies may be impediments in the development process. The workgroup suggested that learning about the involvement of insurance companies in past development efforts could only serve to avoid mistakes made in the past.
9. Current-day pilots have regulations regarding oxygen when one pilot exits the cockpit (leaving the cockpit in a single-pilot state). They suggested reviewing these requirements and addressing how these requirements would be met when SPO, necessarily, results in a constant single-pilot state.
10. Review of the work put forth by the task force involved in the move from 3 to 2 pilots. This work, obviously, could serve as a model for an attempt to move from 2 pilots to 1 pilot.

Dr. Comerford closed her presentation by presenting two final **broad recommendations** put forth by the workgroup. *First*, the workgroup noted that there is much to explore for the SPO concept. Therefore, they suggested spending time to scope the problem. *Finally*, they suggested that time should be spent in developing a concept of operations document for SPO. The document could be presented to all interested parties, especially stakeholders. If the document is used to receive feedback, it may allow SPO researchers and developers to save time, effort, and money before too

many resources are spent going down the "wrong path." In the document, numerous alternative "paths" could be presented. By presenting numerous paths, feedback may be received on each alternative and may allow for more flexibility relative to providing only one concept of operations. One group member said that current assumptions about the future NAS may not be accurate. For example, the attendee suggested that, five years ago, the industry was estimating that today's airspace would have three times the traffic density, and the industry was not correct in those projections. Therefore, considering alternative paths might be wise.

Several audience members became involved during the **question-and-answer session** following Dr. Comerford's presentation. *First,* a member of Workgroup 1 added that the group discussed issues related to social issues in the cockpit, and that the aviation community might want to think about being more flexible in terms of allowing the pilot to socialize during flight (e.g., with flight attendants, ground personnel, etc.). *Second*, an audience member asked if Dr. Comerford could elaborate regarding the recommendations for the tasks that should be reserved for the remaining pilot. He suggested that, from the recommendations, it appeared that none of the difficult work could be shared with anyone else in the system. This conclusion might imply that implementing SPO might be difficult. Dr. Comerford replied saying she agreed, and she would causally label those activities as the "hard stuff." In fact, she suggested that the tasks the group thought should be reserved for the single pilot might be more akin to those that would require "artificial intelligence" rather than automation. Another member of Workgroup 1 joined the conversation sharing that he has been working in the context of UASs. In that area, he reports that they are finding humans do, in fact, perform much better than technology when the tasks are the types of things listed by the group (e.g., pattern recognition, decision making, etc.). *Second*, another member of the workgroup shared that they had much discussion regarding strategic and tactical decision making, during which they (as a group) put forth almost the opposite argument. They had discussed the fact that ground personnel might be useful in strategic decision making, but due to its urgency, tactical decision making might need to be done in the cockpit. Another member of Workgroup 1 added that a hazard warning is a perfect example of a tactical maneuver that might need to be reserved for the single pilot. If a hazard warning is heard, it would imply that automation has failed in doing its job, and the pilot would need to act. *Finally*, another audience member asked if the workgroup had identified a time frame. Dr. Comerford reported that they were considering a period that represented 20 to 30 years from now. The audience member noted that another workgroup had considered a relatively less distant time frame (i.e., near term application), and some differences in workgroups' findings may reflect the time frame on which they were focusing.

6.2.   *Workgroup 2: Facilitated by Dr. Kim-Phuong L. Vu*

Dr. Kim-Phuong L. Vu, of California State University at Long Beach, served as facilitator for Workgroup 2. Dr. Vu's slides, which summarize the Workgroup 2 discussions, can be found in Appendix E.

6.2.1. *Abbreviated Account of Workgroup 2 Discussions*

For single-pilot operations, Workgroup 2 thought it would be most feasible to have the "second" pilot be part of the automated system. In an emergency situation, the time needed for a second person to gain awareness of the situation and be able to intervene would take too long. However, for events that are not time-sensitive, the second "pilot" could be another human that is not in the cockpit (i.e., on the ground). Research should focus on how the automated system could be designed to have properties that are similar to a human co-pilot. This approach would require a voice-based system that can interact with the primary pilot and the ability for tasks and functions to be allocated

dynamically. Research also needs to be conducted on how the automation can keep the human pilot aware of what is happening in the environment. Other research areas that need to be explored include ergonomics of the single-pilot cockpit, the human-computer interaction, the role of cultural differences in following and trusting automated systems, and training. Biological (i.e., restroom breaks, boredom, and fatigue) and environmental (i.e., interruptions and social interactions) impacts also need to be explored. Finally, single-pilot concepts of operation should be researched in the context of NextGen and public acceptability.

6.2.2. *Extended Account of Workgroup 2 Discussions*

Dr. Vu began by reviewing the workgroups **general questions as they related to the possible function allocation strategies** in SPO. The workgroup considered general configurations in which a backup for the pilot could be in the air or on the ground and/or the backup could be a human or automation. Furthermore, they wondered if allocation strategies should differ under nominal and off-nominal conditions, and if the allocation of functions is dynamic, they wondered who should be given the authority to assign functions. They considered the possible difficulty in certifying a system that is programmed to behave in an environment with dynamic function allocation. Finally, they pondered whether the aircraft would be designed to fly only in single-pilot mode or if they would be designed to operate under either single- or dual-pilot mode.

Thereafter, Dr. Vu elaborated on the **group's thoughts regarding the configuration in which the "second pilot" is a human.** Workgroup 2 felt that, if the second pilot was a human, it would be best if he or she were *in the cockpit*. They believe the advantage of the second pilot being in the cockpit is that he or she would have faster response time in urgent situations, would have greater situation awareness, and would better understand the nature of the problem. If the second human was *on the plane but not in the role of a first officer* (e.g., another crew member), two issues would need to be addressed. First, access to the cockpit would need to be addressed. Post-9/11 procedures would not support this configuration. Therefore, either the policies would need to be changed or this configuration would need to be excluded from consideration. Second, the issue of training would need to be addressed. Specifically, they wondered what type of training and how much training the back-up pilot would need. They also considered the configuration in which a second team member was located on the ground. They wondered how many flights such a person could support. In addition, they pondered whether or not the ground-based team member would serve to support a flight for an entire trip or assignments would vary by phase of flight. For example, they wondered if critical phases of flight might require a 1-to-1 assignment, with one ground team member assigned to only one flight. Finally, they wondered how certification would be handled and affected under such a configuration.

Compared to the situation in which the second pilot would be replaced by another human, the workgroup documented relatively more thoughts regarding the situation in which the **second pilot would be replaced by automation**. In fact, Dr. Vu reported that the consensus of the group was that this configuration (i.e., automation replacing the second pilot) was the configuration that would be the most likely to be adopted. If this configuration were realized, however, they believed that human subject matter experts (e.g., AOC) might be consulted on particular problems, especially when a situation is not particularly urgent. They also indicated that ground personnel (e.g., ATC) would need to be informed of a flight's back-up plan in order to prevent confusion if pilot incapacitation did occur. They did note that, before automated systems are created, developers should ask what a single pilot is able to do without more automation. This question allows us to ensure that more automation is truly needed, and if it is, asking this question ensures that only the appropriate systems are developed. As was the case with a human replacing the first officer, the workgroup generated

numerous *questions* in regards to the configuration in which automation would replace the first officer. First, they wondered what roles the single, remaining pilot would need to adopt that were once associated with the first officer, what roles the automation would adopt that were once the first officer's roles, and how adaptive the automation would need to be. Given all of the potential changes to the roles and responsibilities of the pilot, they questioned how accepting stakeholders (e.g., insurance companies) would be. In addition to their questions, the workgroup had some opinions and put forth some *general recommendations*. The group noted that the automation should essentially never be incorrect. The workgroup noted that the automation would need to have the ability to successfully perform all tasks. In short, the automation would need to perform the jobs that were previously associated with the first officer (e.g., coordination and monitoring), but it would also need to successfully perform the duties of the primary pilot in case of pilot incapacitation or the like. The group favored a dynamic arrangement, in general, in which tasks were dynamically shared between the human and automation agents. In addition, they shared that the automation must be intuitive to use and must interact with the primary pilot in a human-like manner. Therefore, the automated systems must be voice-controlled, respond to human instructions, anticipate pilot needs, trade-off tasks with the pilot, engage in cross-verification, coordinate with all systems and report to the pilot, have skills that might be considered CRM skills, and be in a form that would be publicly acceptable. Finally, the group noted that decision support tools must be provided to the pilot to support tasks such as trajectory-based decisions, systems management, and systems coordination.

The remainder of Dr. Vu's presentation was devoted to the **research issues** identified by the workgroup. For the purpose of simplicity and organization, Dr. Vu categorized the research issues as being related to (1) design, (2) human-computer interaction, (3) NextGen impacts, (4) training, (5) communication, and (6) trust and acceptability issues. However, the categories are not necessarily mutually exclusive, and they are presented in the following paragraphs.

In terms of **design issues**, Dr. Vu reported that the group identified ergonomics, biological, and environmental issues as ones that need to be addressed. Specifically, the group considered numerous areas in which *ergonomics* principles should be applied. Characteristics of the cockpit that must be considered are display-control layout, icons, labels, color-coding, choice of digital, analog, or mixed information, inclusion of trend information where appropriate, the information display (whether it will be multi-modal or not), menu structures within displays, and musculoskeletal disorders. In short, the group suggested that designers must ensure the amount of information that was once presented to two sets of eyes can now be presented to only the one. They also noted that, if the cockpit is re-designed for a single pilot, a few practical questions arise such as where the FAA or line-check airmen would sit (when appropriate). In terms of *biological issues*, the workgroup asked how long the pilot can be absent before the automation should be "concerned" (i.e., move into a mode in which pilot incapacitation is assumed or attempt to query crew members). Other issues they considered as being related to the human as a biological being were boredom, fatigue, and social interaction. They wondered if flying with an automated system would be equivalent to flying with another human who is currently not talking to you and wondered if the pilot would be left feeling uncomfortable. To offset boredom, the group suggested that the human and automated systems could behave as two pilots in the sense that they might "trade-off" between them. For example, two pilots might decide that the first pilot lands on this flight and the second lands on another flight. Finally, the workgroup considered *environmental issues*. In terms of the cognitive impact, the group suggested that interruptions and distractions from the environment must be considered. In addition, they wondered if the cockpit should be treated separately in terms of loss of cabin pressure (i.e., to ensure the single pilot can maintain a pressurized environment). However, they noted that this arrangement might pose concern in terms of ethics.

Dr. Vu then described what Workgroup 2 identified as being the **human-computer interaction issues**. She explained that they suggested it was of great importance, of course, to first identify for whom the cockpit is being designed. For example, would the design approach assume the user is a well-trained pilot or a novice? The group recommended that, if the design were to support a novice, we must always be mindful that an aircraft is not an automobile. If something goes wrong, the aircraft cannot simply "pull over" to remove immediate danger and consider options thereafter. Once the target group is identified, the group suggested that only then should interactions be considered. They pondered whether the human-computer interactions should be cooperative or not. Furthermore, they wondered if the automated systems would be passive in that it would only respond when queried or if the systems would actively query (or even challenge) the single pilot. They believe that automation could be used in a beneficial manner if it were used to ensure pilots did not get trapped in attention tunneling. The automation could serve to provide different perspectives on a problem. However, they relayed that the automation should be designed such that it honors the pilot's priorities. In fact, they suggested that the aircraft would probably need a "coordinator system" that coordinates all of the automated systems and ensures the pilot's priorities are being honored. They suggested the occasions be identified in which the pilot would be alerted. Specifically, should the pilot be alerted only when there is a problem or when there *may* be a problem? In addition, the manner in which pilots would be alerted must also be addressed as should the way in which the pilot interacts (physically) with the system. For example, they wondered if there would be a dialogue component. If so, the type of voice recognition must be identified. For example, would the voice recognition be in the form of natural language or controlled language, with the latter requiring pre-defined phrases? The context for interactions with systems also must need to be specified. Specifically, how will a particular system "know" when the pilot is talking to it? The workgroup also wondered how the automation would handle interruptions (i.e., interrupting the pilot and/or the pilot interrupting it). Once the particulars of the voice recognition system are identified, the acceptable response time must be identified, such that the automation will be able to infer that the pilot did not hear it, understand it, or is incapacitated. Furthermore, will there be boundaries placed on how often the pilot interacts with automated systems? In other words, if the pilot is silent for "too long" should the automated system be alerted that there may be a problem with the pilot? If there is an emergency situation (e.g., pilot incapacitation), they wondered what the exact role of automation would be. The workgroup also identified broader questions. Specifically, they identified culture as being a variable that should not be ignored. In short, cultures may vary in terms of the automation acceptance and trust, but culture could also affect the acceptance of various design features (e.g., male or female voice). On a broad level, the workgroup also questioned how transparent the automated systems should be in terms of the information that is reported to the pilot and asked how automation will affect pilot situation awareness.

Workgroup 2 also identified **research issues** in terms of the manner in which **NextGen may impact SPO**. First, the group wondered if SPO is feasible in NextGen, especially in off-nominal situations. However, under normal conditions, the group also wondered about the feasibility of SPO under NextGen operations. They voiced concern over the level of precision required by some of the NextGen operations (e.g., tailored arrivals, spacing, etc.) and wondered if a single pilot could handle those demands. On the other hand, members of the workgroup suggested that some of the NextGen-initiated technologies may make SPO relatively more feasible than if it were adopted today. Assuming SPO is possible in NextGen airspace, the group pondered whether and how the interdependence of systems in NextGen will impact the development of SPO. They suggested that the level of precision required by NextGen might determine the allocation of functions. In fact, they suggested that, under NextGen operations, research should explore the limitations of having a human operator in the system. Finally, a relatively more specific consideration they suggested is to determine whether or not SPO will influence acceptable boundaries under NextGen. Specifically,

they asked whether SPO would change the accepted or expected response times for the single pilot as compared to a two-person crew.

Dr. Vu also reviewed several **research issues** that were identified as **related to training**. At the broadest level, Workgroup 2 asked how new pilots for SPO would be selected and trained. They suggested that, regardless of the function allocation that would be realized in SPO, the minimum training regulations would need to be identified. As with training today, skill degradation would have to be prevented in the SPO environment, especially if automation systems are performing relatively more tasks. Again, similar to today, training would need to address unexpected events, situation assessment skills, and decision making skills. However, under SPO (and presumably the related increase in automation), the question of the use of procedures versus the use of creative decision making might become a relatively more important question. Someone in the workgroup reported that recent findings have shown that "over-proceduralizing" harms performance and decreases the amount of communication and cooperation between the team members. Therefore, they suggested that industry should avoid moving to an "over-proceduralized" way of completing tasks when automation use is increased. The workgroup also suggested that researchers must identify any task combinations that are unmanageable in a single-pilot environment. Thereafter, research should address training such that it may be used to mitigate the detrimental impacts of multitasking. Presumably, the single-pilot cockpit might be different enough from current-day cockpits that trainers may need to "un-train" some behaviors to change pilots' "relationships" with automation. In a SPO environment, the effects of being alone may be felt and length of flight may become increasingly important. As a result, the workgroup wondered if training will need to differ by length of flight. They also suggested that, on long flights in particular, some training could occur while en route, when a pilot may become bored. Finally, the group pondered the content of CRM training. Specifically, in the SPO environment, the workgroup wondered about the new types of teamwork skills that might be required.

Workgroup 2 also identified **research issues** that are particular to **communications**. They suggested that research needs to be undertaken to explore voice-controlled automation. As they had identified in terms of human-computer interaction issues, they again mentioned the voice recognition system's ability to take natural language input as being an important issue. In addition, the need to recognize the importance of dialogue and the context of the dialogue is of importance. The need to train the operator to use the voice recognition system would also be an important factor and could be explored as part of research. In this context, they once again mentioned the need for the voice-controlled system to adapt to the pilot's behavior. For example, like a human teammate, the system should be able to repeat information when the pilot may not understand. In repeating the information, the system should perhaps relay the information more slowly or emphasize particular words. Currently, they reported that, when a controller notices that a pilot is having difficulty in understanding a communication, the controller will revert to the standard or formal manner of communicating a request. The automation would need to be "taught" such practices if it were to work effectively. The automated system also should be able to communicate exactly what it is doing and how it is accomplishing a task. This behavior would mimic what the first officer does in current-day practice. The workgroup also suggested that the system might be designed to analyze the human's voice and be able to infer that the pilot is stressed. Finally, the group suggested that research from other domains should be explored in order to leverage off of the work in other industries (e.g., the space and automobile industries).

As a final topic, the workgroup addressed the **issue of trust and acceptability from the public and from stakeholders.** The group wondered how a zero-tolerance policy for accidents would affect whether or not SPO is feasible or able to be certified. They also wondered if the public needs to be

surveyed to assess whether or not they will accept SPO. Furthermore, the group wondered whether the public would simply accept SPO if the FAA certifies it. Another possibility is that the public will gladly accept SPO if it truly results in lasting price reductions. In general, they pondered from where "push back" might originate (e.g., professional communities, unions, the public, etc.). They wondered about pilots' reactions. They wondered if "pilots' egos" will be affected by the greater reliance on automation and also wondered if the extra stress placed on pilots (by having to fly on their own) would affect their willingness to accept a move toward SPO. In the long-term, they wondered if a move toward SPO would affect the number or type of individuals interested in flying as a profession. In closing, the group asked that industry "step back" and considers the overall benefits of SPO. The question to ask is whether not the dollars spent on research and development for SPO would yield cost-savings compared to simply maintaining the job of the second pilot.

Several audience members became involved during the **question-and-answer session** following Dr. Vu's presentation. (Unfortunately, some of the questions asked during this particular session were not recorded well, due to lack of microphone use. Therefore, a few questions have been omitted.) *One* audience member said she was listening to the presentation and found many of the topics to be related to good design in general, and she wondered what the meeting attendees had identified that is unique to SPO. Dr. Vu agreed and said that her workgroup seemed to think that many of the SPO-related discussions and/or research endeavors that are undertaken might also serve to assist the aviation community (and other related disciplines) as a whole. A *second* audience member made the point that fly-by-wire is used today, and it is "Level A" in terms of automation. In other words, it cannot fail, and the aviation industry fully relies on it today. Therefore, rather than asking what to do when automation fails, the question is how automation should be designed so that it does not fail. A *third* audience member, a pilot, described a circumstance when his automation behaved differently in terms of whether or not it intercepted the appropriate location, and this happened on three different occasions. He never could explain the differences in the automation's behavior. On the occasion when the automation "misbehaved," they (the dual crew) were there to take over. His point was that automation will not necessarily be reliable in doing what it is supposed to do, and supervision of the systems may be vital. A *fourth* audience member suggested that "automation" should not be discussed as one concept or one system. Instead, "automation systems" should be discussed with emphasis on the plural nature of the phrase. This language serves as a reminder that multiple systems work to automate numerous processes. In addition, she stated that the processes being automated also need to be identified when one automated system is being discussed. A *fifth* audience member said that the aviation community has FOQA (Flight Operational Quality Assurance) to monitor pilot reliability and performance. He wondered whether the industry has, or should have, something similar for automation. *Finally*, an audience member suggested that the systems approach be used when discussing automation. He gave the example in which a pilot might be doing what he or she is "supposed" to do, and given the programming, the automation also is doing what it is "supposed" to be doing. However, when considered together (as a system), the end-result could be unsuccessful system performance.

6.3.   Workgroup 3: *Facilitated by Dr. Michael Feary*

Dr. Michael Feary, of NASA Ames Research Center, served as facilitator for Workgroup 3. Dr. Feary's slides, which summarize the Workgroup 3 discussions, can be found in Appendix E.

6.3.1. *Abbreviated Account of Workgroup 3 Discussions*

Members of Workgroup 3 had much experience with safe SPO today. The consensus of the group was that SPO is feasible today, but the concern was with off-nominal events. The workgroup

suggested that off-nominal operations in the NextGen environment may present issues that may not be safe with current allocations and technology. The group focused on the relationship between the aircraft, ATC, and dispatch. The group suggested that the allocation strategies between these three entities are going to change regardless of SPO, but they recommended that NextGen concept developers, implementers, and regulators should keep SPO (and possibly UASs) in mind. The group thought that the operations should be considered from a system-centric point of view (i.e., an ATC–AOC–aircraft system), and that complexity needs to be considered from a single-pilot perspective but also must be considered from an overall system perspective. The nature of the relationship and interaction with AOC, FOC (Flight Operations Center), MOCC (Mission Operations Control Center), and dispatch is likely to change in NextGen, and this seemed to be a leverage point for the workgroup. From a system-centric point of view, it is possible that the technologies developed to enable SPO (e.g., robust data communication) may make passengers safer even if it is perceived as less safe to have one pilot on the aircraft. A potential paradigm could be to think about the aircraft as being nominally autonomous, with the pilot serving the role of dealing with off-nominal situations. A second pilot (e.g., on the ground) could be added for "risky" operations (e.g., bad weather). The group thought that Norman's report (Norman, 2007) on SPO should be reexamined to ensure that SPO issues are truly separated from two-pilot safety issues. The report appeared to group various sub-groups who have different training, procedures, backgrounds, operations, and equipment. Such grouping could present a confound in the analysis. The group verbalized that this observation is not meant to criticize the author, since there were some constraints on the writing of the report. The group also identified a number of flight phases and operations as particularly vulnerable to SPO, due to workload or redundancy for off-nominal events. Given the makeup of the group (and the fact that SPO is in operation today), the group suggested locations (e.g., ZAN, Anchorage Center) where equipage is either in place, or will be soon, such that demonstrations and testing of SPO could take place.

6.3.2.   Extended Account of Workgroup 3 Discussions

Dr. Michael Feary, of NASA Ames Research Center, began by describing the **perspective of Workgroup 3**. He explained that the members of the group had much experience with SPO in current-day operations. As a result, Workgroup 3 might have been relatively more focused on current and near-term applications. With that said, Dr. Feary relayed that Workgroup 3 emphasized the fact that SPO is in use today. The workgroup expressed concern that, regardless of SPO, NextGen implementations are going to *force* a change in allocations between the three major portions of the system (i.e., pilots, ATC, and AOC), and this change may have the most impact in Class B above flight level 34000 and in the oceanic sector. The group worried that this impact is not currently well-understood by the GA community.

Dr. Feary proceeded to describe the **general opinions in Workgroup 3 as they relate to SPO and future operations in general**. The consensus of the group was that SPO is feasible under nominal conditions. The group held this belief because, after all, SPO is practiced today, and the FAA is approving those operations. The group recommended some literature review in this context. In this way, if research and development is put forth for SPO in FAR Part 121 operations, the aviation community can be sure it is approached with the appropriate focus. The workgroup's opinion was that automation capabilities are technically sophisticated enough for SPO to be supported in FAR Part 121 operations, and today's aircraft can be flown by one pilot with automation. One workgroup member suggested that the only reason more than one pilot is maintained is because of pilot incapacitation and extreme emergencies. The workgroup noted that automation developments are continuing, and improvements may make the feasibility of SPO that much more likely. They also noted that current operations already include some NextGen elements (e.g., data link, RNAV

departures, arrivals, and approaches). However, Workgroup 3 suggested that off-nominal operations are going to be the biggest challenge for SPO within the NextGen environment.

Dr. Feary continued by presenting, what he labeled as, **general topics that Workgroup 3 identified as being important**. *First*, he reviewed their thoughts regarding *AOC, dispatch, and ATC*. The workgroup suggested that NextGen is going to require more authority of dispatch, and dispatch may directly interact with ATC. This arrangement is a concern for the GA community, particularly the corporate faction. With that said, the group questioned which agents will be responsible for strategic and tactical decision making in the future NAS. If strategic capability is given to dispatch, they thought the single pilot may want dispatch to resolve routing around weather with knowledge of what other aircraft are doing. The workgroup also suggested that it might be beneficial for dispatch to have the same view as the flight deck in order to allow dispatch to make the most informed decisions. They wondered if direct communication between dispatch and ATC might have a beneficial effect (outside of the GA community). Specifically, they suggested that it might be "outside of the single pilot's bandwidth" to negotiate with ATC. They also wondered if, unlike today, it might become an important requirement for the pilot to communicate to ATC that the aircraft is operated by a single pilot. ATC may treat single-piloted aircraft somewhat differently than dual-crew aircraft. Regardless of the specific changes that occur, the group suggested that the changes required for a SPO environment will affect all parties in the system. Therefore, they believe new training and procedure requirements will be required for all parties in SPO. *Second*, in terms of *allocation strategies to consider under SPO*, the group thought a change in regulatory authority might be considered. Specifically, they suggested that an extra pilot could be a MEL (minimum equipment list) item for certain conditions (e.g., when weather minima are questionable). They also suggested a configuration in which automation was considered the default agent in operations, and the single pilot would respond only to off-nominal situations. The workgroup also mentioned the configuration in which a co-pilot would be located on the ground and would support the pilot during off-nominal events. If this configuration is adopted, the group said the ground personnel would have to possess the ability to interrogate the aircraft systems to receive information. However, it would not be surprising if single pilots develop an animosity towards ground crews under such a configuration. The onboard pilots may feel they should necessarily be in a superior role because it is their lives and licenses on the line. *Third*, the group expressed concern about *accountability* under SPO. They believe that there is a shared public perception that the pilots on board the aircraft have the final responsibility for their safety. By removing a pilot, the public's reaction is something that may be cause for concern. They also expressed concern that, by removing a pilot from the cockpit, the potentially positive effects of peer pressure may be removed as well. In other words, the presence of a second crew member may induce a form of peer pressure that encourages professionalism. The group did recognize that FOQA, a system that monitors the performance of aircraft, may help in terms of accountability, but it may not replace the presence of another human being. *Finally*, the workgroup identified the needed *changes in regulatory processes*. In particular, they recognized the role of both insurance companies and the government in the realization of a new concept of operations. They suggested that insurance companies tend to more restrictive than the government is some cases, due to their financial risks. They asked that the aviation community consider whether or when the insurance companies should be consulted. If the insurance companies are consulted, they wondered what the role of government would be in the regulatory process. The workgroup also pondered the question from a different perspective and wondered if the burden should simply be put on passengers, who can determine whether or not they are willing to fly under SPO if it meant savings for them.

After discussing the general issues, Dr. Feary presented the **SPO research issues** identified by Workgroup 3. One set of research issues they identified was related to **measurement**. *First*, the

group suggested that adequate *predictive measures* need to be identified for use in SPO research. They noted that today's environment is not accepting of incidents and accidents, especially in Part 121 operations. Therefore, in order to assess SPO during research, they suggested that the industry needs some idea as to what is meant by "risk." *Second*, the group addressed the need for another category of measurement: *measures of complexity*. Currently, aircraft weight is used to imply complexity, but the workgroup suggested that weight is not a good indicator of complexity. Therefore, early research efforts should be aimed at identifying the elements of complexity, the limits of the human in terms of complexity, and the threshold to distinguish when limits have been exceeded. These efforts will allow us to understand how the single pilot will perform in managing the aircraft under various levels of complexity. *Third*, the group identified yet another type of measurement that will be necessary to consider: *measures related to pilot incapacitation*. The workgroup suggested that, as of today, effective physiological measures, in general, are not available. For SPO-related research, attention should be directed toward this issue. In particular, the group pondered whether or not physiological indicators could determine if the human in the system is failing (e.g., incapacitation). They wondered if cognitive measures might assist in this sense as well. They considered whether or not medical screening would need to change and noted that there currently are some differences in required medical screening as a function of operations (i.e., frequency and types of required screenings). However, they suggested there may be more to consider for required medical screenings under SPO, and they believe the state of the art is not ready to screen for (and therefore assist in avoiding) a failing, single pilot.

In addition, to measurement issues, Workgroup 3 identified **additional SPO research issues**. *First*, the workgroup suggested referring to the literature and/or incident and accident reports in order to explicitly identify how many *incidents and accidents* have been *prevented by a second pilot*. In addition to the frequency, the workgroup suggested an exploration of the types of errors that have been prevented by a second pilot and the impact of these preventative actions. The workgroup identified a *second* issue that also requires a review of literature and incident/accident reports. Specifically, the group thought that *Norman's report* (Norman, 2007) *on SPO should be reexamined* to ensure that SPO issues are truly separated from two-pilot safety issues. The report appeared to group various sub-groups who have different training, procedures, backgrounds, operations, and equipment. Such grouping could present a confound in the analysis. The group verbalized that this observation is not meant to criticize the author, since there were some constraints on the writing of the report. *Third*, the group wondered about the effect of SPO on the single pilot's *ability to diagnose problems*. If a problem arises in current-day operations, oftentimes one pilot works on the problem while the other pilot takes responsibility for flying. With only one pilot, such an arrangement is, of course, not possible. Although automation may assume some of the responsibility under SPO, the group expressed concerns regarding automation. Specifically, group members identified levels of *automation* usage as a *fourth* issue. Group members suggested that a general byproduct of automation is to increase high workload and decrease low workload. Therefore, if SPO relies more heavily on automation, they wondered if the aforementioned problem would be exacerbated. In fact, two workgroup members commented that they do not believe that complete airborne automation can be certified within 20 years, since there are some scenarios that automation cannot be designed to handle. They gave the example of handling multiple failures and noted that they believe automation is not effective at prioritization. On the other hand, the group had recommendations regarding automation if it were going to be used effectively. They suggested fairly advanced automation systems, ones that would replicate a second pilot. The automation would need to be able to communicate through speech, recognize speech, and perhaps recognize certain gestures made by the single pilot. With such a design, the workgroup suggested that the automated systems could engage in verification with the pilot (e.g., read back commands), assist the pilot with prospective memory (i.e., remembering to engage in planned tasks), and could interact naturally

with the pilot via hand or body gestures. A *fifth* issue they identified was the *availability of a back-up pilot*, if that configuration is adopted. If a configuration were adopted in which an onboard human serves as the back-up to the pilot, the group had some suggestions for such a configuration. Specifically, they noted that current-day flights often have "deadheading," commuting, or positioning pilots as passengers. They suggested exploring the notion of utilizing these human resources to serve as readily available (and qualified) back-up pilots. *Sixth*, the group suggested that *training* changes would probably need to occur, but those changes are not readily understood. If SPO were adopted, it would yield a loss in the apprenticeship training that typically occurs when a pilot serves in the role of first officer. In addition, ground support (e.g., ATC and AOC) would probably also need additional training in terms of the technical, cultural, and organizational changes under SPO. Today, there is already evidence of tension between parties within the NAS, and we would need to ensure all parties were trusted when AOC and ATC communicated directly. *Seventh*, the workgroup noted that *SPO under NextGen operation*s may result in challenges. Specifically, because NextGen will result in less flexibility and will be more tightly constrained, off-nominal operations will have more impact on the system. This impact will increase workload during such events and may make the single pilot especially vulnerable to high workload. *Finally*, on a broad level, Workgroup 3 suggested that *system-centric performance* be considered during research and development. They cautioned against using an approach that focuses only on the single pilot. Dr. Feary presented an example of current-day realities that emphasizes the interactive role that pilots have with the ground. Specifically, the workgroup noted that ATC currently does not necessarily know how many pilots are on board an aircraft. Instead, the controller hears only one voice during communications and does not concern himself or herself with the number of additional pilots on board. However, controllers do "profile" flights and alter requests accordingly. In other words, the controllers do attend to the type of flight, and they may ask certain flights to perform in ways that are different than other flights. For example, if they are dealing with a regional flight that lands frequently in the area, that regional flight may be asked to do more than an international flight that is arriving after a 14-hour flight. If the real effects of such interactions are ignored by focusing only on the single pilot, the group felt evaluative research would not yield realistic results.

Workgroup 3 also identified a list of **pilot tasks** that result in high workload and may be particularly **vulnerable under SPO.** They suggested that these tasks may be particularly vulnerable under SPO, not only because a pilot would be working alone, but the tasks may be difficult to handle if something fails because it's dependent on automation. *First*, they suggested that the pre-flight phase, in general, may be vulnerable under SPO. One workgroup member performed a review of incidents and accidents and found this phase to be the most vulnerable under current-day operations, and the removal of a pilot may exacerbate this problem. More specifically, during the pre-flight phase, the members expressed concerned about the "walk around" and management of systems tasks. In terms of verification of fitness to fly, they also expressed concern but suggested that gate agents may be able to assist in this process. *Second*, the workgroup wondered how emergency evacuation would be handled with a single pilot and suggested that another member of the cabin crew could get training to compensate for the loss of the second pilot. *Third*, the group wondered whether or not a single pilot would perform well on extended flights. They further noted that the public might be more accepting of SPO if it were limited to short flights. The workgroup identified additional tasks that have required two sets of eyes or requires two people to perform tasks: (a) taxiing to avoid runway incursions; (b) preparing for arrival and approach; (c) amended clearances, particularly when close to the airport; (d) diversions; (e) rapid decompression; and (f) diagnosis of systems failures. *Finally*, the group identified a set of tasks that might pose a challenge to the single pilot, and this set of tasks is primarily associated with NextGen: (a) closely spaced parallel approaches; (b) optimized profile descent; (c) in-trail procedures; (d) merging and spacing; and (e) delegated separation.

Dr. Feary ended the formal portion of his presentation by presenting Workgroup 3's thoughts regarding **implementation strategies**. *First*, the workgroup suggested that ZAN (Anchorage Center) is a good place to begin examining SPO. In this particular center, AOC already has the capability to speak directly with ATC. *Second*, the group presented a potential plan that might be used in evaluating SPO. They suggested examining FAR Part 135 in a bit more detail first and to ask what experienced companies have done (e.g., Cessna) in designing single-pilot aircraft. Thereafter, researchers might ask what needs to be added to the research and design that has already been completed. After that task is completed, they suggested examining FAR Part 121 cargo operations with an evaluation of FAR Part 121 VFR passenger flights (short flights) and fractionals following the cargo exploration. *Third*, Dr. Feary reminded the audience that the group suggested having insurance companies involved in the research, development, and certification process. However, he also added that the workgroup felt union involvement is of utmost importance. The group wondered if there might be some "push back" from pilots. For example, they pondered whether single pilots will demand more pay. Pilots may argue that they are doing the job of two persons, and the liability is solely that of the single pilot under SPO. The workgroup suggested including not only pilot unions but the unions for dispatch and ATC. *Finally*, as either a testing or final implementation strategy, the group wondered if SPO implementation could begin with an arrangement in which a second pilot observes the "single pilot" before the "single pilot" transitions into single-pilot operations. This model might be seen as analogous to receiving a driving permit for automobiles, which allows a new driver to operate an automobile but with supervision.

Several audience members became involved during the **discussion session** following Dr. Feary's presentation. *First*, an audience member suggested that "complexity" might be an interesting research avenue to follow, so to speak. However, the attendee noted that the meaning of complexity needs to be clarified. When speaking about complexity, the audience member asked the attendees to ponder if complexity refers the automated systems, the pilot's tasks or job, or the overall system. Dr. Feary agreed with the audience member's observations. He further added that, when Workgroup 3 was discussing complexity, he believes they were referring to system complexity. However, he also noted that they sometimes were referring to the complexity involved in decision making. He reminded the audience that he had mentioned the distinction between strategic and tactical decision making. In this context, the workgroup was pondering how much an agent in the system needs to know in order to achieve situation awareness. Put another way, they considered how much information can be taken away from an agent (and given to another agent, perhaps) before the agent is no longer able to accomplish the task. A *second* audience member asked how the job of ATC will change. The attendee noted that it seems as if ATC will have reduced flexibility in the future NAS. In short, the audience member wished to underscore a point made by Workgroup 3: the "other side" needs to be examined (i.e., not just the pilots). Dr. Feary agreed with the audience member's comment. A *final* comment from an audience member was in regards to the system-centric focus Dr. Feary had mentioned. This audience member re-emphasized the point that the SPO system needs to be defined as an entire entity, and the system must be considered as a whole when it is defined and designed. After all, the audience member noted that ATC, for example, is one third of the system under discussion. Dr. Feary agreed and presented a few details to further emphasize the point. He suggested that some real-world practices would not be captured if the ground-based personnel are ignored. He suggested to the audience that ATC engages in some subtle practices that have real-world impact on behavior in the NAS. For example, he reminded the audience that ATC cannot provide guidance regarding weather, but they do share what others are reporting. These exchanges are subtle cues from ATC (i.e., to let pilots know what they might consider doing in the face of weather challenges).

6.4.   Workgroup 4: *Facilitated by Dr. Richard Mogford*

Dr. Richard Mogford, of NASA Ames Research Center, served as facilitator for Workgroup 4. Dr. Mogford's slides, which summarize the Workgroup 4 discussions, can be found in Appendix E.

6.4.1.   Abbreviated Account of Workgroup 4 Discussions

Workgroup 4 suggested that single-pilot operations could be achieved using a dynamic, distributed team consisting of the pilot on board, flight deck automation, a cabin commander, airborne support, and an enhanced AOC (specialists and automation). This concept would have the advantage of utilizing existing, but perhaps underutilized, resources (e.g., the pilot of a nearby aircraft who is experiencing low workload conditions at cruise) in addition to the presumably innovative new concepts and tools also envisioned. The pilot on board, with flight deck automation, flies the airplane under normal and some non-normal conditions. The cabin commander takes care of passenger and cabin-related matters, relieving the pilot on board of these tasks. When the pilot needs assistance to deal with extreme or high workload situations, he/she requests help from the enhanced AOC team. The team also might include, what might be called a "wingman," or pilot of another aircraft flying in the same area who could assist with weather avoidance, system problems, and the like. The enhanced AOC coordinates the required knowledge, skills, and data to support the single pilot, flight deck automation, and the cabin commander. The enhanced AOC systems display the necessary video, instrument, and aircraft data to support problem solving. The matter of single-pilot incapacitation is, of course, a concern. The cabin commander could help evaluate a situation in which the pilot on board becomes unable to work. The flight deck automation and the enhanced AOC could provide resources to fly the aircraft. Research questions include how to: form dynamic, distributed teams; incorporate good CRM qualities; exchange functions between the pilot on board, flight deck automation, and enhanced AOC; monitor component performance (e.g., of the pilot on board); manage shifts in command; ensure graceful degradation of people and software; determine data to be shared with the enhanced AOC; and address regulatory and certification issues (e.g., how to measure system performance). The planning and conduct of SPO research should consider possible spinoffs that would enhance near- and mid-term aeronautical operations.

6.4.2.   Extended Account of Workgroup 4 Discussions

Dr. Richard Mogford, of NASA Ames Research Center, presented the discussions that took place among members of Workgroup 4. For the sake of organization, Dr. Mogford divided his presentation into three general segments: (1) a review of a specific strategy the group identified for SPO, (2) operational issues and questions that were discussed by the group, and (3) research topics the group thought might be fruitful in exploring SPO. In accordance with the organization presented by Dr. Mogford, these three topics are addressed in succession.

Dr. Mogford began by presenting an **intricate strategy (concept of operations) that Workgroup 4 developed for SPO**. In short, the strategy they put forth represents a truly distributed and cooperative team that would include multiple members of the NAS. *The team Workgroup 4 envisioned includes the following members*: (1) the single pilot on the flight deck, (2) flight deck automation, (3) a cabin manager, (4) airborne support, (5) a ground support team, and (6) ground automation. In the following paragraphs, each of these team members is described in the context of the overall concept of operations the workgroup envisioned.

As a whole, Dr. Mogford reported that Workgroup 4 had no problem in assuming aircraft will be able to fly autonomously in 10 to 20 years. He reminded the audience that aircraft can essentially

accomplish such a task today. Therefore, the group felt comfortable in suggesting that the single pilot on board the aircraft, along with flight deck automation, could handle *normal operations* (e.g., aviating, navigating, communicating, monitoring tasks, following instructions from ATC, managing departure and arrival, etc.). In addition, Workgroup 4 expressed the belief that a single pilot, with the help of flight deck automation, also could handle some off-nominal conditions (e.g., engine out, see-and-avoid, and tactical weather situations).

Under *off-nominal conditions*, the extended team would become important in Workgroup 4's vision of SPO. Specifically, the "Enhanced AOC" would become actively involved when the pilot, along with flight deck automation, cannot handle the current circumstances. The AOC would, of course, monitor the aircraft throughout the flight. However, the AOC would become more actively involved than it is today, and the *"enhanced" version of the AOC* might call upon any of the team members previously mentioned, with the AOC serving in a coordination role for the enhanced team. Dr. Mogford stated that the enhanced AOC might assist the single pilot: (1) with airspace interruptions, such as weather, (2) in any high workload situation, (3) with problems or failures associated with onboard automation, (4) if any security issues arise, or (5) flight-mechanical or difficult-to-diagnose problems. In short, the enhanced AOC would serve as decision support and a source of data in relatively extreme non-normal circumstances.

Dr. Mogford relayed the workgroup's vision of the *enhanced AOC* as being a *dynamic, flexible, and distributed team*. The relevant parties would be asked to participate in the team on an as-needed basis, and therefore, the team would not necessarily include the same people every time the pilot required assistance. For example, the pilot might need a different set of team members if asking about weather-related issues as compared to flight deck automation issues. Once a dynamic team was formed for a given issue, information would be exchanged between team members to support problem solving. In the following paragraphs, the roles of a few potential team members are highlighted.

Workgroup 4 developed the notion of having a "*cabin commander.*" The cabin commander could serve to manage in-flight problems within the cabin. These duties would include problems with passengers but would extend beyond that of a flight attendant. The cabin commander could also serve to address mechanical problems in the cabin, and by forming this job, the single pilot could be relieved of some duties that are expected of pilots today. Dr. Mogford shared a story from one of the workgroup members to demonstrate a real-world event that a cabin commander could address. One of the workgroup members reported that water started running down the corridor of the cabin while the workgroup member was performing his duties as a pilot. The pilot had to leave his station to examine and ultimately solve the problem. The problem ultimately was a leak from the potable water system. The workgroup felt there was no reason someone else could not be trained to deal with problems such as this one (i.e., problems having nothing to do with flying the airplane).

Dr. Mogford also presented Workgroup 4's notion of a "wingman." A *wingman*, like other members of the team, would be called upon on an as-needed basis. The wingman would be a pre-identified pilot in another, nearby aircraft. It is not difficult to imagine how the wingman could be helpful to a single pilot. Dr. Mogford presented several instances to exemplify the role of the wingman. The wingman could assist the single pilot by: (1) providing general operational support to the single pilot, (2) running checklists, (3) navigating around weather and turbulence, especially since they would be proximate, (4) monitoring his or her alertness, (5) providing general decision making support, and (6) "checking back in" with the single pilot to ensure resolution of the problem. Note that some of the aforementioned functions serve to fulfill, what might be considered, CRM-related duties (e.g., monitoring alertness).

Dr. Mogford relayed one last role that Workgroup 4 envisioned for SPO: "airport specialists." An *airport specialist* could assist the single pilot with questions or problems specifically related to arrival and departure. These specialists could serve as a, sort of, "harbor pilot." Because the specialist would be located at the airport, the pilot would receive local information (i.e., presumably the most valid information), and by tapping local personnel, transmission lag issues would be less of an issue.

After completing a review of their vision for SPO, Dr. Mogford reviewed **operational issues and questions** the workgroup identified. One set of issues is related to the *required technologies* for SPO. *First*, because the single pilot's team would be physically distributed, Dr. Mogford addressed the notion of display and control "mirroring." For example, when assisting the single pilot, those on the ground might want the capability to have a visualization of the flight deck displays and controls. This notion might be true for all team members (e.g., the wingman might want to have a visualization of what the single pilot is seeing). *Second*, the workgroup suggested that video links and radar links would be important resources within the SPO environment. *Third*, Dr. Mogford relayed that voice interaction systems would also be required. Such a system could "call out" DataComm instructions from ATC, checklists, or input to onboard systems as a form of feedback. *Fourth*, with a complex distributed team, communication-related technologies must be addressed. Dr. Mogford reminded the audience that radio channels already are full today. Therefore, the workgroup suggested that radio bandwidth and delays would need to be addressed. In addition, with so much information being exchanged, information security issues would need to be addressed as well.

The workgroup also identified issues specifically related to *automation*. The recorded comments from the group suggest that the workgroup was somewhat "torn" regarding its use. *First*, one member of the workgroup suggested that the pilot is the most capable system in aircraft but is also least reliable. *Second,* a few group members addressed the need for training. Specifically, they suggested that a benefit of using automation is that you only have to "train" the automation once. If you have humans performing the same task(s), numerous people must be trained, and industry would need to continually work to ensure they remain proficient. In short, one group member suggested that, as a rule of thumb, automation can be used if a new person can be trained to perform the task(s). However, a *third* argument was put forth in that the workgroup wondered why automation is needed at all, if the pilot will be monitoring it anyway. *Fourth*, the workgroup wondered if there are tasks that the first officer performs that automation absolutely cannot handle. They used the example in which a human would smell something, which would provide a cue that something is wrong. Either way, the group's *fifth* suggestion was to spend time exploring the general question as to which tasks are best for automation, for the human, or for both. Once that question is answered, the group suggested pursuing another question. Specifically, their *sixth* suggestion was to identify the tasks and responsibilities that should be allocated (or traded) between the single pilot, onboard automation, and the enhanced AOC. *Seventh*, Dr. Mogford reported the group's thoughts regarding workload. They suggested that automation may not relieve workload as much as would be expected, and they suggested that the circumstances need to be identified when automation does not assist in reducing workload or when it actually increases workload. *Finally*, the group suggested that automation may need to be transparent and interactive, but under some circumstances these characteristics of automation may not be desirable. The circumstances under which automation should be transparent and interactive must be identified as should the cases in which these characteristics of automation would be undesirable.

The workgroup identified another set of issues which might be categorized as having to do with the general *human components in SPO*. *First*, the workgroup suggested that the required speed of

response from the enhanced AOC could pose a challenge. Specifically, the pilot would be contacting the enhanced AOC when help is needed, and the enhanced AOC would need to respond quickly with an answer or with the formation of the appropriate team. Therefore, the enhanced AOC would need to "get in the loop" quickly. *Second*, CRM methods would need to be identified for the proposed flexible, distributed teams. *Third*, the manner in which the team interacts with ATC would need to be identified (i.e., who interacts with ATC and under what circumstances). *Finally*, the duty cycles (i.e., time on duty, limits on work hours, etc.) of all parties (in the air and on the ground) would need to be identified.

The workgroup gave special attention to one particular human-oriented topic: pilot incapacitation. The group identified *pilot incapacitation* as a concept representing a host of problems. For example, a state of pilot incapacitation could occur if the pilot is asleep, intoxicated, experiencing a mental breakdown, or deceased. In these cases, the group noted that flight controls could be affected or not. For example, in cases where the pilot is conscious but his or her judgment is distorted (e.g., intoxicated or experiencing a mental breakdown), the pilot could attempt to control the aircraft. Of course, an unconscious or struggling pilot (e.g., experiencing a heart attack or fainting) could inadvertently hit controls. A different, but related, situation was noted by the workgroup. Specifically, a pilot with malicious intent also may attempt to gain control of the aircraft. This situation would be similar to a conscious, but incapacitated, pilot attempting to control the aircraft. In addition, when a single pilot must leave his or her station of duty (e.g., a restroom break), the aircraft would be in the same state as if there were an incapacitated pilot (i.e., pilotless). The group wondered how the aircraft systems would predict or detect any or all of the aforementioned conditions. As a final note, a group member noted that having two pilots does not necessarily make passengers safer. This group member suggested that, unlike the discussions on the first day of the meeting, one could think about the situation in reverse. Specifically, one could make the claim that having two pilots doubles the chances that one pilot can become unstable (e.g., the JetBlue incident).

Dr. Mogford reviewed *numerous, potential responses to pilot incapacitation* that were identified by Workgroup 4. *First,* if the pilot is falling asleep or has fallen asleep, the workgroup thought the aircraft systems could include a simple warning or alarm in order to alert the pilot (e.g., "Wake up!). Dr. Mogford presented a system that has been developed by Mercedes Benz, which may be analogous to what might be needed in a single-piloted aircraft. Specifically, Mercedes Benz developed the "Attention Assist System." Based on research, this system is built to predict when the automobile driver may be getting too drowsy. The system prompts the driver to take breaks when they may be at risk for falling asleep behind the wheel. This system is well beyond the research phase and already can be found in some of their cars. The Attention Assist System, and the related research, might be reviewed in developing systems for SPO. Unlike drowsiness and sleep, other types of pilot incapacitation represent situations that are relatively more challenging. *Second*, if the aircraft must be taken out of the pilot's control, the workgroup wondered who or what might serve to replace the pilot. Alternatives they considered were the flight deck automation, ground staff (or their systems), or the enhanced AOC. *Third,* the group wondered what procedures would be used in the case of incapacitation. Specifically, would the agent who gains control (either automation or another human) fly to the departure or arrival airport, or would the aircraft be landed at the closest airport that would allow for a safe landing? *Fourth*, the group wondered how incapacitation procedures would be handled internationally. The group noted that the U.S. aviation community must be mindful of international factors when identifying procedures for pilot incapacitation and consider whether the procedures would work outside of the US. *Fifth*, the workgroup considered the situation in which it might be appropriate to give control back to the pilot (e.g., the pilot had sudden gastrointestinal upset but recovered). The question was raised as to how the pilot would be reinstated as being the agent in control of the aircraft. Furthermore, they wondered how much control should

be given back to the pilot after an event that left him or her in an incapacitated state, and they wondered when the transition of control would occur. *Sixth*, the previous set of questions led the group to question who is ultimately the commander of the airplane. As a *final* note regarding a response to pilot incapacitation, the workgroup thought that, in the SPO system they envisioned (see first few paragraphs of this section), the cabin commander could be quite useful in evaluating and/or validating the state of the single pilot.

Workgroup 4 also addressed *incapacitation that could occur in forms other than pilot incapacitation.* Specifically, the members of the workgroup noted that incapacitation could occur due to automation on the flight deck or at the AOC. These agents, of course, would fail in different ways as compared to the pilot, but they might lead to incapability nevertheless. A failure could be due to system errors or bugs, and a failure could occur in isolation or in the form of multiple (unexpected) failures. In such a case, the workgroup suggested that the single pilot or the enhanced AOC could take control of the aircraft.

Workgroup 4 identified a set of *miscellaneous issues and questions* as well. Specifically, the workgroup *first* asked how a SPO environment would handle mixed equipage and suggested this issue must be addressed. *Second*, given today's procedures, oxygen requirements must be addressed for the single pilot above flight level 25,000. Today, when a single pilot is left in the cockpit about this flight level, he or she is required to have oxygen support. *Finally,* the group suggested that "graceful" degradation of any portion of the system (e.g., automation or personnel) must be ensured, such that the flight experiences minimal or no impact.

The final segment of Dr. Mogford's review addressed **research topics** that were identified by the workgroup. They identified quite a few topics. One group of research topics is related to the *people within the system*. *First,* they suggested that the formation, training, and management of the temporary, distributed teams might be a challenge and could be explored in a research setting. The measurement and evaluation of a team's performance might also be an area to examine. They identified a *second*, related topic in that they wondered how effective CRM could be achieved on such teams. *Third*, they pondered how teams might, not only be monitored, but how the particular individuals who are part of a dynamic team might be monitored. The monitoring of the person monitoring the team also would be required. *Fourth*, the transitions would need to be explored, when the single pilot transitions from receiving a particular level of support to a higher or lower level of support from the extended team. They also suggested exploring the type of help that might be offered to the single pilot as well as how much support could or should be offered. *Fifth*, the "location" of authority must be identified. Specifically, they suggested industry must identify who or what location is ultimately in a position of authority (e.g., the single pilot, the automation, the cabin commander, the enhanced AOC, etc.). They questioned whether this authority should shift depending on circumstances. *Sixth*, the workgroup recommended that the thresholds for workload be defined through some form of measurement, and this threshold would need to be identified for all parties involved in the dynamic team (e.g., the single pilot, the enhanced AOC, etc.). They wondered if workload should be a part of real-time pilot monitoring. *Finally,* they suggested careful consideration of the role of the "harbor pilot" as described previously. They wondered if such a person would be an employee of the FAA or the airlines.

The workgroup identified another set of research topics that are specific to the topic of *automation*. *First*, they suggested examining whether automation should be independent or collaborative. *Second,* they thought that the methods for validating and verifying automation must be identified. *Third*, they suggested that methods be identified to ensure there is a graceful degradation of any agent in the system (e.g., human or automated agents). As an example, Dr. Mogford suggested that it

would be more effective to have a pilot calling for assistance when he or she is beginning to feel drowsy rather than having the pilot fall asleep.

Workgroup 4 identified a couple of research issues that are particular to the *technology for communications within SPO*. *First,* the workgroup suggested examining what information should be shared across the parties in the dynamic, distributed SPO team. They highlighted the notion that it is probably not desirable to allow for sharing of all the information that can be found in the cockpit. They wondered whether the data would be shared in the form of textual data, video, or displays. The group made a *second*, related point in that they suggested exploration of the bandwidth required for any data, video, or displays that would be shared amongst remote team members.

The workgroup also identified a set of relatively *broader research issues having much to do with policies, certification, operations, cost, and the like*. *First,* the group asked that the regulatory issues be identified. After exploring these issues, the group suggested the end-result should include an identification of the size of aircraft, the number of passengers, whether Part 95, Part 121, and/or other parts of the federal aviation regulations are being considered, and whether freight, passenger or both type of carriers are being considered. They also recommended that the operational environment needs to be defined, in general, and the risk to the ground must be addressed. *Second*, they suggested that criteria need to be developed to measure SPO concepts and technology. Such criteria will allow concepts to be evaluated and might affect FAA standards. They suggested that the criteria and related standards must be validated using concept development and simulation. *Third*, the group recommended that developers ensure all viewpoints of stakeholders are taken into account early in the development process. *Fourth*, they asked that all interested parties assess whether the cost-savings from SPO will truly be greater than the costs associated with the development, certification, implementation, and training associated with SPO. *Fifth*, to address the usefulness of SPO, evaluations should be conducted to explore how often the second pilot has been effective in error trapping (i.e., in "catching" errors that were overlooked by the first pilot). They suggested that humans can be instrumental in overcoming problems, and the usefulness of SPO needs to be validated via some systematic endeavor. They suggested consulting the Aviation Safety Reporting System (ASRS) to determine the effects that the second pilot has had on errors. *Sixth*, they suggested that it is important to remain focused on the main goal: safety. The group suggested that it is should not be a primary goal to have a particular number of pilots in the cockpit. Instead, developers should determine the minimum number of pilots necessary in the cockpit in order to reach safety goals. *Seventh*, in terms of the entire NAS, they suggested identifying the manner in which mixed equipage will be handled. *Eighth,* the group recommended that a global perspective is maintained. Although current inquiries regarding the possibility of SPO are focused on operations within the U.S., the implications for international flights must be considered. As an example, one workgroup member wondered about the configuration in which a ground controller could potentially take control of the aircraft. The attendee wondered if it were possible to control an aircraft from halfway around the world. *Finally,* they suggested that the industry should identify potential spinoffs from SPO research, how SPO may have a positive impact on the NextGen environment, and the manner in which the aviation community might receive near-term benefits from SPO research.

Several audience members became involved during the **discussion session** following Dr. Mogford's presentation. The *first* audience member that spoke shared that he was a member of Workgroup 4. He told the audience that he thought his group took an impressive approach in that they focused on finding resources in the system that are currently untapped, and he relayed that this approach is what led them to develop their concept for SPO (as described by Dr. Mogford). He shared a few additional ideas. He suggested that the "wingman" concept could be extended to be "wingmen." In other words, he suggested that nearby pilots (plural) could be a part of a team that assists one

another. He used military operations as an analogy and suggested to the audience that they perform a search on Google using the keywords "F16 Engine Out." He told the audience that they would find an interesting video that demonstrated the cooperation between military pilots during an emergency. A *second* audience member suggested that a debriefing session following flights might be considered. In this way, the single pilot could meet with the ground team and review the lessons learned from each flight. A *third* audience member said he was thinking about the Mercedes Benz technology that Dr. Mogford presented. He wondered if a "ping" approach to attention and wakefulness management might be incorporated. He suggested that the pilot could be "pinged" every half-hour or hour to serve as a "check in" with the pilot. He thought such a technology could have prevented the Northwest incident during which the pilots overflew Minneapolis. A *fourth* audience member suggested that, after this brainstorming session, the aviation community should take some time to ponder what makes sense in moving forward. He suggested imagining a Venn diagram, with circles representing "what we can do," "what is certifiable," and "what makes economic sense." The place where those circles intersect represents what the industry should do. *Finally*, another audience member suggested that completely immersive and realistic environments are used when evaluating SPO. The audience member suggested that workload surveys and the like are useful, but they are limited. Surveying pilots often can illuminate relative differences between two conditions. However, in this particular case, absolute workload is of interest (i.e., can a single pilot handle the job?).

Analysis and Summary of Findings

For the interested reader, Section 3.3 of this document reviews the approach used in organizing the information gathered from the TIM. The following pages review the information obtained across the entire SPO TIM.

7.   Benefits of Exploring SPO

As a whole, attendees seemed to believe that an exploration of SPO feasibility would be beneficial regardless of whether or not single-pilot operations are adopted in the future. In short, the attendees seemed to agree that **almost all components of the current-day NAS could reap benefits from such research and development**. For example, SPO research might yield advances in automation, technologies in general, and assist in creating better air-ground coordination. Furthermore, **in current-day, dual-crew operations, one incapacitated pilot yields a single-pilot environment.** Therefore, SPO research and development could identify technologies and procedures, for example, that might assist the remaining pilot under such circumstances. Although other benefits were identified throughout the TIM, those additional benefits yielded some disagreement. Therefore, those additional, potential benefits are reviewed in the following section.

8.   General Challenges, Issues, Questions, and Recommendations as Related to SPO

This section is meant to highlight topics that yielded at least some disagreement among attendees and topics that attendees believed would present challenges to the implementation of SPO. Although research topics are addressed is a separate section, many of the topics in this section could be re-conceptualized (or merely re-phrased) to represent a research question. The research sub-section of this summary is reserved for topics that were explicitly presented as research topics. With the exception of the first two broad topics, the topics are presented alphabetically in the following sub-sections.

8.1. Overall Feasibility of SPO

The issue of "feasibility" sometimes was discussed when addressing particular configurations (i.e., ways in which tasks might be allocated) for SPO. Those ideas are presented with the discussions of particular configurations. Here, instead, thoughts regarding the issue of *overall* feasibility are summarized.

Most TIM participants seemed to believe that SPO is feasible. **Numerous arguments for its feasibility** were presented. For example, attendees mentioned that, at the time of the TIM, the NAS environment already contains: (1) Part 121 aircraft that generally can fly themselves, (2) optionally piloted and unmanned vehicles, and (3) other aircraft categories certified for the single pilot. However, several attendees did address the issue of feasibility as one that is an "open question" or has arguments on "both sides." From an objective perspective, it should be noted that ideas were collected from experts that were willing to attend the meeting. Therefore, there may have been a bias in the sample of ideas represented.

8.2. Motivations for SPO

Motivations to explore SPO were addressed briefly in the introduction of this document (see Section 1.1.). At the TIM, the question of motivation was addressed on several occasions. As a whole, the attendees seemed to agree that **the biggest motivator for exploring SPO is the potential cost savings**. However, **attendees were mixed in their opinions as to whether or not SPO would result in cost savings**.

On one hand, **some participants found reason to believe the financial motivation was well-founded**. The attendees noted that crew expenses are the second major expense for airlines. One presenter shared a data analysis in which he found that cutting the crew to a single pilot would result in impressive savings over the 20-year life of the aircraft (that is, a value equivalent to 54% of the market value of a new aircraft). In addition, some attendees mentioned the savings that would result from cutting the cost of pilot accommodations and training in half. In fact, according to one presenter, the airline industry has already expressed some interest in reducing the amount of training required to operate aircraft, presumably for the savings. Not all attendees assumed the savings would be a result of jobs lost by pilots. Some attendees specifically addressed the notion that SPO would result in savings due to the flexibility it affords. In other words, SPO would increase flexibility in terms of scheduling pilots, and the pilot pool would be functionally increased without an absolute increase in the number of pilots.

On the other hand, **some attendees were reluctant to conclude SPO would necessarily result in savings**. During the workshop portion of the TIM, several attendees alluded to the idea that all expenses must be considered. They wondered if savings are certain when the cost of research, development, certification, and training (for SPO) would be taken into account.

8.2.1 Motivations for SPO: Recommendations

If motivations are solely based on savings, SPO may be a solution. However, **for financial savings, alternatives exist** that might be used instead of or in addition to SPO. Specifically, one attendee suggested that fewer pilots would be required if attention were given to the efficiency of scheduling. In addition, flight crew augmentation requirements could be reduced for long flights (i.e., the need to have two complement crew members onboard aircraft could be reduced to one complement crew member).

8.3.   Authority, Control, and Conflict between Agents

Authority might be defined as being in an official position of power, whereas *control* might be defined as being able to influence relevant aspects of the environment. A reader who carefully reviews these findings will note that **the topics of authority and control can be found as themes across several other topics**. The specific authority and control issues that were identified are reviewed in particular contexts, where most appropriate. One purpose of this section is merely to highlight the existence of this theme in general. In addition, one general circumstance also is reviewed here: conflict between agents.

Meeting participants suggested that situations would arise under SPO in which there was a conflict between agents. It should be noted that an "agent" can be either a human or an automated system. Therefore, because a single-pilot cockpit would presumably include relatively more automated systems, it should be noted that **human-human conflicts could arise** (e.g., pilot-ATC, pilot-remote pilot, etc.), **and human-machine conflicts also could arise** (e.g., the pilot and the automation are attempting to approach a problem using different methods).

8.3.1. Authority, Control, and Conflict between Agents: Recommendations

TIM attendees made the following **general suggestions regarding conflicts between agents**:

1. A method must be developed that allows for the identification of a conflict state between two agents.
2. Conflict state identification may be especially important when the conflict occurs between a human agent and automation. Because humans typically possess "social skills" to recognize and manage a conflict state, human-human conflicts may be less worrisome. Human-automation conflicts may go unnoticed if these conflicts are not addressed explicitly during the research and development process.
3. After the conflict is identified, the method of managing the conflict also must be identified. Management of the conflict may require explicit identification of the agent that is in a position of authority and ensure that the agent in control is either the same agent or complies with the agent in a position of authority. It is possible that the authority and control status of an agent depends on the context or circumstances.

8.4.   Communications in the NAS

In this section, participants' thoughts regarding communications in the NAS are summarized. Other forms of communications are considered in later parts of the document (e.g., human-automation communication). Here, the focus is on NAS-wide communications under SPO. It also should be noted that the major communication issues are addressed in the context of security, where more appropriate. Other than the security issues, the participants shared recommendations mostly regarding communications in the NAS.

8.4.1. Communications in the NAS: Recommendations

Because SPO could change required communications, and depending on the configuration (i.e., task allocation strategy) chosen, the change could be significant. **Meeting participants had several suggestions regarding NAS communications under SPO.** Most suggestions are related to the types of communications that might be required, with one mention of enabling technologies. The participants' suggestions are as follows:

1. It will be necessary to identify which agents in the NAS will communicate with whom and when.
2. Direct communication between dispatch and ATC may be required, in order to offset pilot workload.
3. In contrast to current-day operations, it might become an important requirement for the pilot to communicate to ATC that the aircraft is operated by a multi-person crew or a single pilot.
4. Assuming the SPO environment will generate more frequent communications between the pilot and other personnel within the NAS, bandwidth and reliability of communications technologies must be enhanced. In short, persistent, broadband communications must be available.

8.5.   Development of Requirements and Certification

Relative to the previous topic, much discussion was directed at the development of requirements for SPO and the certification of SPO. In short, this section addresses **what needs to be done, from an industry-wide perspective, in order to allow SPO to be realized.** Later sections address topics such as particular designs, developments, and research projects, for example, that need to be undertaken.

Not surprisingly, in this context, participants spent much time addressing FAA guidelines and requirements. **Several of the FAA *guidelines and requirements* were identified as potential barriers to SPO. The following list summarizes these potential barriers as described by TIM participants:**

1. FAR Part 25, which defines airworthiness standards for transport category airplanes, does not exclude the possibility of SPO, but it does address workload. Demonstrating that workload for the single pilot is equal to or less than workload for the dual-person crew may be difficult.
2. Advisory Circular 25.1523 includes data associated with pilot incapacitation and attributes the problem to SPO. This advisory circular may suggest that the FAA would be reluctant to certify SPO.
3. Nothing can be found in the advisory circulars and regulations that prohibit single-pilot operations. However, the verbiage appears to imply a reluctance on the part of FAA (i.e., there is an assumption of 2 pilots in language used).
4. Current oxygen requirements must be addressed. For example, if one pilot leaves a pilot duty station of an aircraft when operating at altitudes above 25,000 feet, the remaining pilot must use an approved oxygen mask.

Participants also identified, what they believe to be, assumptions by the FAA**. These FAA *assumptions* also were identified as potential barriers** and are presented in the following list:

1. Current safety assessments often assume and depend on the notion that a pilot can take control from a failing or malfunctioning system. If the pilot becomes incapacitated under SPO, the aforementioned assumption cannot be met.
2. Under SPO, the aforementioned premise would also need to be addressed in the reverse. That is, under SPO, aircraft systems must be able to take control of the aircraft when the pilot is incapacitated (i.e., when the pilot is "malfunctioning" or has "failed"). In considering this reversal, design of aircraft systems would need to be reconsidered completely. In addition, the introduction of new, potentially catastrophic system failures in which the pilot would be prevented (by the aircraft systems) from intervening.

3. FAA guidance currently assumes that modern avionics add complexity and increase workload. Presumably, SPO would require the introduction of novel, advanced technologies.

Meeting attendees also addressed specific requirements associated with certification. These **specific certification requirements also were identified as potential barriers** and are as follows:

1. Because no "back-up pilot" is present, reducing the crew to a single pilot will likely elevate the hazard category for many failure conditions, and by elevating the hazard category of a failure, designs must be much more robust.
2. Certifiable systems often include dual, or even triple, redundancies. Therefore, in developing new systems for SPO, this requirement increases development time and efforts, and developers should be cognizant of this requirement.
3. Software is placed in categories related to its criticality because there is no way to attach a probability to a software design error. Therefore, software is very expensive to build because of the level of scrutiny it undergoes. The level of automation, complexity, and integration needed for a single pilot transport will exacerbate the problem of difficult-to-identify design errors and the high cost of critical software.

8.5.1. Development of Requirements and Certification: Recommendations

TIM participants offered numerous suggestions as to how the aviation industry might reduce some barriers to the certification of SPO. These suggestions do not necessarily "map" directly onto the barriers identified in the previous section. Instead, these suggestions are more general in nature and might serve to reduce barriers in general.

Meeting attendees noted that the **aviation industry needs direction in performing research and development activities aimed at the potential realization of SPO**. They suggested the following **general activities to assist in providing such direction**:

1. The aviation industry needs to develop a concept of operations document. Creating such a document will allow for feedback from all interested parties, and feedback could be obtained intermittently to ensure efforts remain focused.
2. The industry should work with the FAA and insurance companies to identify a feasible approval process, and these communications should occur early in the research and development process.
3. After receiving the aforementioned feedback, researchers and developers need to generate a roadmap of issues and milestones.
4. Overall, the industry needs to spend time "scoping the problem," such that activities are targeted.

TIM participants also shared some of their thoughts in terms of the **types of information that would be useful when receiving direction**. Participants had particular questions in terms of the concept of operations and requirements for SPO. These questions are presented in the following list, and the answers to these questions should be provided when the previously mentioned activities are completed (e.g., concept of operations document, developing a roadmap, etc.):

1. What categories of operations are of interest? Specifically, decisions need to be made in terms the size of the aircraft and the number of passengers that are of concern. In addition, decisions need to be made as to whether there is a targeted effort towards Part 95, Part 121,

and/or other parts of the federal aviation regulations. Finally, a decision needs to be made as to whether freight, passenger, or both types of carriers are of interest.

2. Will the aircraft of interest be designed to fly only in single-pilot mode, or will they be designed such that they can operate under either single- or dual-pilot mode?
3. Would the design approach assume the user is a well-trained pilot or a novice? Or, would we need to design for both categories of users?
4. Would single-pilot duty requirements be something akin to a 2 X 2 X 8 rule, such that SPO would be restricted to two-engine aircraft with two take-offs and landings and under 8 hours flight time?
5. How can technology be used to mitigate certification risk?
6. What issues and topics are unique to SPO? Answering such a question might assist in keeping efforts focused.

Several recommendations were also put forth by meeting participants, which they thought might be useful in the process of research, development, and eventual attempts at certification. As the reader will note, **several** (but not all) of these recommendations are related to **metrics**.

1. Risk analysis must be considered because it is part of the certification process. "Risk" needs to be defined for SPO, where risk is conceptualized as the probability of danger based on real-time decisions. This definition might assist in the certification process, but also might help with research and development. For example, one attendee mentioned previous work on an emergency landing planner integrated with the flight management system; the software would take into account various routes to nearby runways, along with weather, to provide pilots with a summary of the risks associated with each route. In this case, risk information was provided in real time.
2. For certification, the thresholds for workload need to be defined through some form of industry-accepted measurement, and this threshold would need to be identified for all relevant parties in the NAS (e.g., pilot, dispatcher, etc.). In addition, the industry should decide whether or not workload should be monitored in real-time for all relevant parties in the NAS.
3. Metrics are available to "tap" many of the areas that are regulated (e.g., workload). However, there is no widely accepted metric of complexity, and discussions of complexity vary in terms of the meaning of complexity. The complexity of the automation system, complexity of the pilot's tasks or job, or complexity of the overall system could be examined, but the aviation community lacks clarity with current usage of the term "complexity."
4. Historically, an evaluation of equipment and human limitations has guided regulations. Attendees recommended a consideration of performance-based standards, such as RTSP that is currently used for ATM. Performance-based standards are effective because they provide flexibility for new technologies and provide a structured method.
5. When reviewing, editing, or developing policies, the participants suggested that policies should not hinder graceful degradations of agents (human or technological) in the system. For example, it would be effective if a single pilot asks for assistance when he or she is beginning to feel drowsy, as opposed to a pilot that does not ask for assistance for fear of penalty and later falls asleep.

8.6. Design of the Aircraft and Ergonomics

Future aircraft might be designed to support only SPO. In such a case, **the single-pilot cockpit could be reduced in size relative to today's cockpit**. As presented in the following list, participants' provided **mixed feedback** regarding the reduced-size cockpit.

1. The cockpit could be reduced in size, not only because one pilot would no longer be needed, but because the redundant systems would now be hidden. The newly freed space would be desirable.
2. With the presence of the second pilot also comes with the notion of dual systems on board the aircraft. These dual systems often are independent (i.e., if one fails, you can access the other). With single-pilot designs, the second channel on some systems would be lost.
3. The amount of information that was once presented to two sets of eyes can now be presented to only one. Regardless of cognitive issues that might arise from this situation, the layout of the cockpit displays and controls must change to ensure one pilot can access all information.

8.6.1. Design of the Aircraft and Ergonomics: Recommendations

As is the case for several of the topics presented, the recommendations relating to this topic do not necessarily correspond perfectly with the issues identified. Nevertheless, participants shared some recommendations with regards to aircraft design and cockpit ergonomics. These recommendations are presented in the following list:

1. Perhaps the cockpit should be treated separately in terms of loss of cabin pressure (i.e., to ensure the single pilot can maintain a pressurized environment). However, this arrangement might cause concern in terms of ethics.
2. When designing the single-pilot cockpit, ensure widely accepted human factors principles of design are incorporated. For example, the following characteristics of displays and controls should be carefully considered: display-control layout, icons, labels, color-coding, and menu structures within displays. In addition, human factors principles should guide the choice of digital, analog, or mixed information, the use of single- or multi-modal displays, and whether or not trend information is appropriate. Finally, required movements and musculoskeletal disorders need to be considered.
3. Because the single-pilot flight deck may include much automation, the pilot could be (a) presented with simple status lights or indicators to assure the pilot of correct operation, (b) given only pertinent information in case of a fault, and (c) always allowed to command display of any detailed information.

8.7. Enabling Technologies and Decision Support Tools

A few issues were identified as related to enabling technologies and decision support tools (e.g., in the context of pilot incapacitation). Enabling technologies and decision support tools also were discussed in relation to specific task allocation strategies. A review of discussions relating to specific task allocation strategies is reserved for sections of this document that are more appropriate. This section is meant to represent tools and technologies that would probably be necessary regardless of the particular allocation strategy chosen. Participants did not appear to be in disagreement regarding these tools and technologies. In some cases, particular technologies were mentioned on various occasions, by various participants, and in the context of various topics of discussion (e.g., voice recognition software).

8.7.1. Enabling Technologies and Decision Support Tools: Recommendations

To iterate, participants did not appear to disagree regarding these technologies. However, because research and development would be required to develop or enhance some of these technologies and tools, they represent challenges to the realization of SPO. What is presented below this paragraph is merely what was reported by participants. Note that some of the technologies are identified in a vague manner, and in other cases, participants presented a relatively more detailed account of what is needed. **The following list represents the enabling technology and decision support tools that participants identified for the realization of SPO, in general**.

1. A new alerting system for airplane and systems misconfiguration needs to be developed. Such a system may require the pilot to input "intent" information. In this way, the monitors within the system can determine what will, or might, constitute a potentially abnormal or hazardous configuration for the intended operation.
2. Automated checklists need to be developed. To realize these checklists, the appropriate states must be sensed. Therefore, additional hardware and software are required.
3. Communications management should be automated for the single pilot. This automated system should ensure the appropriate ground authorities receive required communications, and this system should automatically communicate with the ground even if the pilot is disabled. Fuel management also should be automated. In fact, all complex tasks (such as communications and fuel management) should be assessed to determine if automation could be used effectively.
4. Routine status information should be presented automatically, and ultimately, negotiate 4D trajectories in both routine and emergency situations.
5. For hazard avoidance, an enhanced external view should be provided as should an enhanced weather radar. Consider including an integrated hazard detection system with vehicle control. Systems such as TCAS, TAWS (terrain awareness and warning system), and weather systems could be integrated, and the automation could navigate the aircraft according to this comprehensive "picture" of the environment.
6. Although not necessarily a "required" technology, consider having something akin to FOQA. Rather than monitoring *pilot* reliability and performance, consider monitoring the reliability and performance of *automation*.
7. Include automatic prompting of the pilot to address the correct procedures, especially in the case of an abnormal situation or emergency.
8. Pilots should be warned of unsafe conditions that a fatigued pilot may have missed (e.g., icing, fuel leaks, etc.).
9. Regardless of who or what initiates it, the system should include *emergency auto-land* in the case of pilot incapacitation. Such a system would choose a nearby runway with the best safety margin, sufficient length for current aircraft configuration, and as little traffic as possible. The system would also declare an emergency, negotiate the appropriate 4D trajectory, and execute the auto-land.
10. Dispatch should have the same view as the flight deck. However, a more general strategy that should be considered is "display and control mirroring." That is, an agent should be allowed to view the displays and controls of another agent with whom he or she is working cooperatively (e.g., ATC or dispatch could view selected displays and controls from the cockpit).
11. Other parties within the NAS could be considered, but for the single pilot, an intelligent voice recognition and effective voice synthesis system must be developed for use in the cockpit.

12. Several technologies and support tools were merely mentioned by name or in passing as tools and technologies that need to be developed or should be considered for development. The following list is meant to capture those items:
    a. a virtual pilot's assistant
    b. decision support tools for trajectory-based decisions
    c. automation for normal and contingency performance calculations
    d. decision support tools for systems management and coordination
    e. enhanced systems automation
    f. electronic systems control
    g. enhanced caution and warning systems

8.8.   Legal Issues (Accountability)

The legal issues, or issues of accountability, did not appear to yield disagreement amongst the participants. In short, because the issue was addressed, accountability is probably an issue that needs to be addressed before SPO could be certified and ultimately realized. **The accountability issue is summarized as follows**:

1. Assuming SPO would yield an increase in automation, would the single pilot continue to have as much responsibility for flight safety (relative to today's operations)?
2. When automated systems are used, the designer of the system might be conceived as the one who is in a position of control. The designer must make assumptions or forecasts about what conditions exist in flight, and aircraft systems are controlled based on the designer's assumptions. Designers are not pilots, and in many cases, they may not be qualified to be controlling the aircraft in general. Having control of an aircraft in an asynchronous fashion would probably pose challenges even for the experienced pilot.
3. Outside of the pilot and the designer, responsibility for a failure in an automated system could, theoretically, be attributed to any one of many stages in the system's "life." For example, automation failures could be conceived as occurring at the design, manufacturing, installation, maintenance, training, or operations stage.

8.8.1. Legal Issues (Accountability): Recommendations

Based on the aforementioned issues, **the participants' recommendation to address accountability** probably is not surprising: An automation policy must be developed to guide design, manufacturing, installation, maintenance, training, and operations for automated systems.

8.9.   Mental Workload and Task Load under SPO

Although mental workload and task load are discussed in the same section, it is important to note that these two concepts are somewhat distinct. *Task load* might be conceived as the number of actions a pilot must complete within a given amount of time, whereas *mental workload* might be conceived as the cognitive demands required to complete a job as compared to the cognitive resources available to the pilot. This section, for the most part, highlights task load. However, one might loosely draw the conclusion that high task load situations often yield high mental workload situations. As a whole, the topic discussed in this section might simply be conceived as "workload" (i.e., tasks and cognitive workload combined).

Participants seemed to agree that workload may become an issue for the single pilot. In fact, workload is mentioned throughout the entire summary of the findings (i.e., within the context of

various topics). However, when addressing workload explicitly, participants made note of **four particular circumstances that may yield workload levels that are too high**: (1) engaging in communications, (2) diagnosing problems, (3) navigation, and (4) managing off-nominal situations.

Across several forums (i.e., presentations from invited speakers and workgroup discussions), participants identified **numerous, specific circumstances or tasks that might yield high task load or mental workload for the single pilot because these circumstances or tasks are performed by both pilots in current-day operations**. These tasks and circumstances are provided in the following list:

1. Addressing rapid decompression
2. Aircraft systems monitoring and management
   a. Diagnosis of systems failures
3. Completing checklists
4. Managing aircraft configuration, such as gear and flaps
5. Managing amended clearances, particularly when close to airport
6. Managing diversions
7. Managing flight guidance and autopilot/autothrottle configuration, such as selection of the appropriate mode
8. Monitoring of the aircraft state
9. Monitoring of external hazards
10. Management of passengers and cabin crew
11. Performing emergency and abnormal procedures
12. Pre-flight phase activities, in general
    a. Of particular concern during the pre-flight phase
       i. Management of systems tasks
       ii. Verification of fitness to fly
       iii. Completing the "walk around"
13. Preparing for arrival and approach
14. Supervising emergency evacuation
15. Taxiing to avoid runway incursions
16. Managing the following tasks primarily associated with NextGen operations:
    a. Closely spaced parallel approaches
    b. Delegated separation
    c. In-trail procedures
    d. Merging and spacing
    e. Optimized profile descent
17. Verbal call-outs
18. Verification of visual contact on approaches

8.9.1. *Mental Workload and Task Load under SPO: Recommendations*

Throughout this paper, one can find recommended methods for reducing mental workload and task load (e.g., design strategies). **One explicit recommendation was offered in response to one of the tasks presented in the previous list.** Specifically, the challenge in completing the verification of fitness to fly might be offset if gate agents were to assist in this process.

8.10. Pilot Incapacitation and Pilot Availability at Duty Station

Almost all participants thought the issue of pilot incapacitation was one that deserved attention. Many of the invited speakers explicitly addressed the topic during their presentations, and every workgroup addressed the topic as well. However, there was **some disagreement amongst participants regarding the *degree* to which the pilot incapacitation issue is important in realizing SPO**. **On one hand, some participants argued that the pilot incapacitation issue is extremely important**. One argument was that pilot incapacitation would, by definition, affect every one of a pilot's responsibilities. Furthermore, some statistics were presented, which highlighted the notion that pilot incapacitation should not be ignored. For example, FAA data was presented, which indicates that a case of pilot incapacitation occurs approximately one time per month (across all types of operations). In addition, accident and incident data from January 1987 through December 2006 indicated that FAR Part 121 results in 10 pilot incapacitation events per billion hours flown. Advisory Circular 25.1523 documents that, from 1980 to 1989, FAR Part 121 operations experienced 51 cases of pilot incapacitation. What might be problematic for SPO efforts is that, in these 51 cases, normal recovery of the aircraft was achieved by the second pilot. For reasons such as these, some suggested that pilot incapacitation is the most significant challenge to certification and conduct of safe, single-pilot, transport-category airplane operations. One participant concluded that it would be easier to certify a pilotless aircraft than a single-pilot aircraft. Specifically, the attendee argued that because of the potential for pilot incapacitation, the airplane would need to be able to behave autonomously, and if such an aircraft could get certified, then all other design efforts would essentially be guarding the aircraft against the pilot. Therefore, from a purely design and certification standpoint, it may be easier to design the aircraft for no pilot than for a single pilot. In fact, one presenter suggested that, if the pilot (as a human being) is considered a system in the aircraft, he or she would not be certified as a reliable system. For the age of 47 (the average age of pilots), human mortality rate is 427 per 100,000 in the general population. This lack of reliability (i.e., unacceptable failure rate of a 47-year-old human) is offset by the second pilot in current-day operations. **On the other hand, some participants suggested that this issue may not impose as much of a threat to SPO realization as some may suggest** and that some may be overemphasizing its importance. In fact, some suggested that you could make the claim that having two pilots doubles the chances that one pilot will become unstable (e.g., the JetBlue incident). Therefore, these participants suggested that it may be unfair to assume the pilot incapacitation issue is a major impediment to SPO. Either way, researchers and developers should be aware that current **FAA requirements regarding minimum flight crew** (i.e., the appendix associated with Sec. 25. 1523) **requires that the design account for an incapacitated pilot.**

Assuming the issue of pilot incapacitation does not create a barrier for SPO, the concept of pilot incapacitation must be defined. **Participants seemed to be in agreement as to what constitutes pilot incapacitation.** Specifically, participants suggested that, among other states, pilot incapacitation would at least include cases in which the pilot is asleep, deceased, experiencing a psychological breakdown, intoxicated, unconscious, or under the influence of drugs. **One issue that seemed to concern most participants is how the state of pilot incapacitation would be determined without a second pilot on board the aircraft.** Some participants seemed to believe a human needs to be involved in the decision regarding incapacitation, but several participants suggested that the person making the decision does not necessarily have to be a second pilot. On the other hand, other participants seemed to believe technologies had potential in this particular area.

Participants also seemed to be in agreement regarding the issue of the pilot's availability (or lack thereof) at his or her duty station. Specifically, when the single pilot must leave his or her duty station, this situation is distinct from current-day practices. In the case of SPO, the aircraft

would be left in a pilotless state. Participants suggested that accommodating the actions and procedures that require a pilot to be unavailable at his/her assigned duty station (i.e., observation of systems, emergency operation of any control, emergencies in any compartment, passenger or cabin crew management, and lavatory visits on long flights) may be a challenge. In many ways, this situation is similar to the case of pilot incapacitation. Therefore, the two situations (pilot incapacitation and lack of availability at the duty station) may have to be treated similarly.

8.10.1. Pilot Incapacitation and Pilot Availability at Duty Station: Recommendations

Meeting attendees shared many ideas in terms of recommendations and potential solutions to the issue of pilot incapacitation and pilot availability. **One set of recommendations relates to defining the notion of pilot incapacitation**, such that other related issues (e.g., identifying when it has occurred) may be addressed more readily.

1. A definition of pilot incapacitation should include considerations of both mental and physical health.
2. Do not ignore subtle pilot incapacitation (e.g., caused by a stroke), in which the incapacitated pilot will only show symptoms if prodded (e.g., questioned). Some pilots currently are trained to recognize it.
3. Pilot incapacitation can be progressive and does not necessarily represent an "all-or-none" state.
4. Do not ignore the potential impact of prescription drugs. The aviation industry currently has no system to monitor prescription drug abuse.

Meeting attendees provided several **recommendations to address the question as to how, in a single-pilot environment, pilot incapacitation can be identified once it has occurred**.

1. Aircraft systems could be developed for real-time monitoring of the pilot for incapacitation. Such real-time monitoring might be in the form of physiological measures and/or cognitive measures. Real-time monitoring of mental health may be challenging. Wakefulness confirmations also could be incorporated. Specifically, a "ping approach" could be used to monitor wakefulness and attention, in which the pilot would be prompted every so often to respond to an inquiry, for example, from an aircraft system. When using any of these measures or similar measures, consider the idea that incapacitation may be progressive and early symptoms might be exhibited.
2. Caution should be taken if technologies are used as the sole arbiter in the decision regarding whether or not a pilot is incapacitated. Consider the strengths associated with a human making the ultimate decision regarding pilot incapacitation. A human can talk to the pilot, interact directly with the pilot to ascertain his or her condition, and make a judgment regarding incapacitation based on many subtle, yet not easily defined, variables.
3. If you consider a human as the ultimate arbiter in determining that pilot incapacitation has occurred, this human would not necessarily have to be a second, onboard pilot. Other personnel could be quite useful in evaluating and/or validating the state of the single pilot. For example, flight attendants or commuting pilots could be involved in the decision making. Ground personnel also could interact with these onboard personnel and the pilot. Because NextGen will provide more opportunities for pilots to directly observe the behaviors of other aircraft, some participants also suggested using a system in which pilots are able to report if a nearby pilot is behaving oddly. This system would be analogous to DUI (driving under the influence) reporting systems.

4. For whichever method is chosen, the determination of pilot incapacitation would have to be error-proof (i.e., no more than one failure in a billion flight hours). In addition, be mindful that errors can occur in two ways, and neither type of error is acceptable. Specifically, the system should never be allowed to miss a case of incapacitation, and at the same time, should never incorrectly deem a capable pilot as being incapacitated.

Participants also addressed the notion that proactive approaches should not be overlooked in an attempt to address pilot incapacitation issues. **The following list represents participants' recommendations for proactive approaches in addressing pilot incapacitation.**

1. Medical screening, in general, needs to be enhanced in order to support SPO. State-of-the-art screening is not adequate in order to screen for failing pilots to the level required by SPO.
2. Consider screening for arteriosclerosis and cerebrovascular disease. One participant reviewed historical cases of pilot incapacitation and found that these diseases surfaced often as a causal factor.
3. Consider the use of a pilot identity detection system (e.g., required fingerprint or retinal scan). Such a system would detect those who are not "current" on screenings (e.g., medicals). An additional benefit is that such a system would also recognize unauthorized personnel (e.g., those with malicious intent).
4. Supplemental pilot training might be useful. For example, pilots could be trained to recognize early signs of a heart attack.

Meeting attendees also offered **suggestions as to how pilot incapacitation cases should be managed once they have occurred**.

1. Relatively speaking, a sleeping pilot is the simplest instance of pilot incapacitation to manage. If the pilot is falling asleep or has fallen asleep, the aircraft systems could include a simple warning or alarm in order to alert the pilot (e.g., "Wake up!). The Mercedes Benz "Attention Assist System" could serve as a model for such a system.
2. A back-up for the pilot must be identified, and this back-up does not necessarily need to be the same agent that serves to determine that the pilot is incapacitated. Apparent examples of back-ups for the pilot are ground-based personnel, automation, or onboard personnel. Combinations of these agents can be imagined. For example, onboard personnel could work with either or both the ground-based personnel and automation.
3. Regardless of the particular agent(s) chosen to be the back-up for the pilot, the agent(s) must be able to intervene quickly.
4. If automation is chosen as the back-up to the pilot, consider a conservative approach. Automation could "kick in" (even if temporarily) when a flight-related decision needs to made immediately, and the pilot *may* be incapacitated (i.e., a firm determination has not yet been made).
5. Determine where the back-up agent would land the aircraft. For example, the aircraft could be flown to the departure airport, arrival airport, or the closest airport that would allow for a safe landing.
6. Once a state of pilot incapacitation is determined, the aircraft would have to be immune from inadvertent inputs by that incapacitated pilot. However, adhering to this recommendation could become complicated. For example, if onboard personnel are serving as the back-up to the pilot, those personnel would need access to some controls. In addition, caution should be taken, in general, if the aircraft is able to "lock out" the pilot from controlling the aircraft. Security issues are of concern if the aircraft has the ability to "lock out" the pilot. The mere existence of the ability implies that "hackers" could access the "lock out" function.

7. If a pilot recovers, determine how or if the pilot could be reinstated as being the agent in control of the aircraft. If the pilot can regain control, determine if the pilot should be given full or limited control after an episode of incapacitation.
8. Be cautious in choosing automation as the sole agent that serves as a back-up for the pilot. If the pilot is deemed to be incapacitated, recovers, and asks an *automated* system for permission to have control, this circumstances raises the question as to who (or what) is ultimately in command of the aircraft. In this case, the pilot clearly is not. Instead, the automation appears to have the highest level of authority or has, at least, the same amount of authority as the pilot.

Finally, participants addressed **pilot availability at the duty station and provided a couple of recommendations.**

1. Aircraft may need to react to a pilot being away from the duty station in a way that is similar, but not necessarily identical, to an incapacitated pilot. The same state results in both cases (i.e., pilotless aircraft).
2. The particular agent to serve as a back-up to the pilot does not necessarily have to be the same agent that serves as a back-up in the case of pilot incapacitation. For example, it is reasonable to believe that automation might be more widely accepted as a back-up for the pilot under these circumstances as opposed to the case of pilot incapacitation. In the case of being away from the duty station, the pilot is aware, able, and onboard the aircraft and presumably will be away from the controls only briefly.
3. Identify how the pilot can communicate to the back-up agent that he or she will be unavailable for a given amount of time.
4. If automated systems are used as the back-up to the pilot, determine the amount of time the pilot will be allowed to be absent before the automation should be "concerned" (i.e., move into a mode in which pilot incapacitation is assumed or attempt to query crew members). This determination would need to be made in conjunction with the communication regarding the pilot's intentions regarding how long he or she will be away from the duty station and whether or not the pilot informed the system that he or she would be away from the station.

8.11. Public and Stakeholders' Reactions to SPO

Participants' opinions were not consistent regarding, what they believe, would be experienced in terms of the public's reactions to SPO. On one hand, some participants suggested that the general, flying public may gladly accept SPO if it truly results in lasting price reductions, and they may simply accept SPO if the FAA certifies it. Therefore, they felt the public would not necessarily be a barrier to SPO, and they noted that the public typically is adaptable to technological change. On the other hand, numerous participants mentioned that SPO may decrease perceived safety and increase fear in the public eye.

Participants appeared to be in agreement regarding the reaction of all other interested parties. Based on analogous attempts in the past, participants suggested that attempting to change the size of the crew can become highly politicized and visible. Meeting attendees suggested that **negative reactions from both Congress and the media would not be surprising.** In addition, they noted that SPO **may generate negative reactions from unions** due to the potential loss of pilot jobs (i.e., removal of the second pilot). Furthermore, **pilots may react negatively to SPO for several reasons**. First, pilots' "egos" may be affected by the greater reliance on automation. Second, adoption of a SPO environment could affect the number or type of individuals interested in flying as a profession because the job of the pilot may change so drastically. Specifically, some may argue

that the job would change from a traditional pilot to a computer operator. Third, the extra stress placed on pilots (by having to fly on their own) may affect willingness of pilots (in terms of compensation or otherwise) to accept SPO.

8.11.1. Public and Stakeholders' Reactions to SPO: Recommendations

Meeting participants provided several **recommendations meant to address the reaction of the public and stakeholders**. These recommendations are presented in the following list.

1. At least initially, consider limiting SPO to short flights. The public may be more accepting of such an arrangement.
2. Get all stakeholders involved early in the process. Of particular note, do not limit union involvement to those representing pilots. Be sure to involve all relevant unions (e.g., pilots, ATC, dispatch).
3. Insurance companies need to become involved in the process sooner rather than later. The insurance industry has played a very heavy role in the certification and requirements associated with very light jets (which have many comparable characteristics), and therefore, there is every reason to believe they would be influential in SPO requirements.
4. Ultimately, perhaps the burden should simply be put on passengers, who can determine whether or not they are willing to fly under SPO if it means savings for them.

8.12. Safety of SPO

Meeting attendees thoughts regarding the safety of SPO were somewhat mixed, with more participants leaning toward a concern regarding safety. Some data suggests that a reduction in crew does not necessarily yield a reduction in safety. Data was presented that indicates accident rates from 3-person crews were higher than accident rates observed today, under two-person crew operations. **A neutral or indeterminate perspective was represented by data from GA.** When GA data were examined to compare single- and dual-pilot operations, the data are mixed. Specifically, some comparisons suggest there is no difference in safety, and some comparisons suggest dual-pilot operations are safer. Finally, **some data may result in a conclusion that dual-pilot operations are superior to single-pilot operations**. Some historical statistics presented at the TIM suggest that the presence of two pilots significantly enhances flight safety (by one to two orders of magnitude). In addition, accident rates for single-pilot operations in the military were found to be similar to the rates found for GA, whereas the accident rates for the multi-pilot operations were found to be similar to the rates found for Part 121.

8.12.1. Safety of SPO: Recommendations

Although many recommendations were offered during the TIM which may affect safety (e.g., research, development, and design suggestions), **only one explicit recommendation was put forth regarding safety**: Remain focused on the main goal: safety. It should not be a primary goal to have a particular number of pilots in the cockpit. Instead, developers should determine the minimum number of pilots necessary in the cockpit in order to reach safety goals.

8.13. Security in a SPO Environment

Security issues were addressed in a general sense as well as in relation to specific allocation strategies. Here, **only the general security issues are meant to be addressed. Other security issues are addressed in the context of specific allocation strategies to which they may be tied.**

Only one general security issue was mentioned that would be applicable regardless of the allocation strategy adopted. Specifically, participants wondered how a pilot with malicious intent would be detected under SPO, where a person with ill intent would not need to worry about the presence of a second pilot.

8.13.1. Security in a SPO Environment: Recommendations

Participants offered **two suggestions regarding security in the cockpit**, and those suggestions are presented in the following list.

1. The method identified to manage an incapacitated pilot may be the same, or similar to, the method that would be used in reaction to a pilot with malicious intent. For example, if incapacitated pilots would be locked out of controls, the software would be in place to respond to a pilot with malicious intent in a similar manner. If the back-up pilot is on the ground for the incapacitated pilot instance, such a configuration could be used if there were a pilot with malicious intent.
2. Consider the use of a pilot identity detection system (e.g., required fingerprint or retinal scan). This system could assist by preventing unauthorized person from serving as a pilot, and as previously mentioned, it could also be used to ensure pilots are "current" in terms of medical screening and the like.

8.14. Selection and Training for SPO

Although selection and training are addressed in relation to specific task allocation strategies later in this document, several general selection and training issues were identified by the participants, and these issues are relevant regardless of the task allocation strategy under consideration. **The general selection and training issues that were identified are presented in the following list**.

1. Selection of the single pilot may need to differ significantly from today's selection methods. The desirable attributes of a single pilot working in a highly automated, distributed environment may be substantially different than the desirable attributes sought today. Similar statements could be put forth regarding training and the manner in which it would need to change.
2. Assuming the single-pilot cockpit included a relatively greater amount of automation than today's cockpit, the question arises as to how skill degradation will be prevented.
3. The single-pilot cockpit might be different enough from current-day cockpits that the question arises as to whether or not some behaviors need to be "un-trained."
4. The apprenticeship type of training provided to the co-pilot is lost, and pilots would immediately assume the role of captain.
5. Because flight length might become relatively more important under SPO, the question arises as to whether or not training would need to differ for the flight lengths assigned to the pilots.
6. The question arises as whether or not ground support would need additional training (e.g., in terms of technical, cultural, or organizational changes under SPO).
7. If voice recognition systems are included in the cockpit, the question arises as to how much and what type of training would be needed for the pilot.

8.14.1. Selection and Training for SPO: Recommendations

Participants presented **recommendations to address two of the aforementioned issues regarding training**. These recommendations appear in the following list.

1. To compensate for the loss in the apprentice-style training as a co-pilot, consider alternate arrangements. For example, a single pilot could begin with an arrangement in which a second pilot observes the "single pilot" before the "single pilot" transitions into single-pilot operations. This arrangement might be comparable to the "driver's permit" that is given before a full license to drive is issued.
2. To compensate for the loss of apprenticeship training (but also boredom that may occur on long, single-pilot flights), some video-based or multi-media training could occur while en route, when a pilot may become bored.

8.15. SPO in the Context of NextGen

Some, but very little, disagreement existed among meeting participants when discussing SPO in the context of NextGen. A few participants suggested that NextGen might be conducive to SPO. Specifically, these participants suggested that NextGen will provide some technologies that may make the pilot's job easier, which may offset any concern that workload will be too high for the single pilot. In particular, these participants suggested that NextGen technologies will, for example, provide verbal communication and navigation relief (e.g., automatically uploading flight plans). However, **the number of participants who felt SPO and NextGen may be "at odds" with one another far exceeded the number who thought NextGen might be conducive to SPO**. As such, the **following list provides a summary of the ways in which participants thought the NextGen concept of operations may create challenges for SPO.**

1. Numerous participants suggested that workload for the single pilot may be too high in NextGen airspace. For example, participants suggested that it may be difficult for a single-pilot aircraft and a reduced controller cadre to safely manage the required precision of NextGen (e.g., tailored arrivals and spacing), especially in complicated or off-nominal situations (e.g., weather factors, emergencies, etc.). More generally, participants suggested that NextGen will shift some controller monitoring tasks to pilots, which also will presumably increase pilot workload.
2. Whether addressing NextGen or future airspace in general, participants expressed concern that future airspace may be more heavily "populated," which might add cognitive and task load to a single pilot that already would have increased workload.
3. Participants suggested that it may be difficult to get single-pilot aircraft certified in the context of NextGen. However, single-pilot operators must be able to perform the NextGen-required procedures or risk losing access to portions of airspace. If two pilots are required for NextGen operations, participants wondered if the system has been improved or made safer. They suggested that a safer system would not place new restrictions on single pilots.
4. Meeting attendees wondered if SPO would change the accepted or expected response times (e.g., in respond to ground personnel) for the single pilot as compared to a two-person crew in NextGen.

8.15.1. SPO in the Context of NextGen: Recommendations

Meeting attendees presented **a few recommendations regarding SPO in the context of NextGen**. These recommendations are presented in the following list.

1. Review the most recent NextGen concept of operations documentation paying special attention to how the operations would interact with SPO.

2. Ascertain which NextGen agents will be responsible for strategic and tactical decision making. Such a determination will directly impact SPO and may assist in establishing a realistic task allocation strategy.
3. NextGen research has been ignoring the single pilot but should begin addressing SPO immediately.

8.16. Social Aspects of the Single Pilot's Job

Separate from the notion of teamwork, one can consider the social aspects of a job and its effects on behavior. Meeting attendees identified **social aspects of the single pilot's job as having the potential to raise issues for the concept of SPO**. Specifically, participants seemed to agree that the following issues may arise.

1. Because social interaction would be removed (or at least reduced) in the single-pilot cockpit, the single pilot may experience boredom. Although boredom is unpleasant, the more concerning problem is that boredom often produces lack of vigilance/attentiveness. A lack of vigilance/attentiveness could yield very real effects on the safety and efficiency of flight.
2. Two pilots in the cockpit may generate a type of peer pressure dynamic. For example, the mere presence of a second pilot may serve to encourage, and possibly ensure, professionalism. For many years, the field of social psychology has demonstrated the very real effects the presence (or absence) of other humans has on the individual.

8.16.1. Social Aspects of the Single Pilot's Job: Recommendations

In regards to the social aspects of the single pilot's job, the following two, general recommendations were noted by participants.

1. Consider limiting SPO to relatively short flights in order to avoid pilot boredom and the associated decrement in vigilance/attention.
2. Unlike today, pilots working under SPO might be encouraged to engage in social conversations with ground personnel or onboard flight attendants when workload is low (e.g., en route).

8.17. Teamwork and CRM

Teamwork occurs when two or more agents cooperate to perform a job. Therefore, this topic is distinct from purely social interactions. Crew Resource Management is related to teamwork in that it provides a method for ensuring a team is working effectively. Therefore, because these topics are necessarily related, they are discussed in the same section. **Participants identified two issues related to teamwork, in general, and one issue related to CRM.**

1. Because a second pilot would not be present in the cockpit, challenges and cross-checking of the pilot would need to be performed by another agent in the system.
2. When there is an exchange of full or partial control between agents, it may be a challenge to ensure the exchange is graceful.
3. Given a potentially significant change in task allocations, new CRM skills may be required under SPO.

8.17.1. Teamwork and CRM: Recommendations

Participants provided the following **recommendations related to teamwork and CRM**.

1. Challenges and cross-checking of the pilot need to be systematic and active, such that items are not missed and the pilot is able to internalize the information.
2. CRM is technically the effective use of *all* available resources. Therefore, CRM is relevant to SPO. When CRM is ignored, the industry might limit considerations to only aircraft control tasks (e.g., power control, flight control, and navigation).

9. Task Allocation Strategies and Configurations for SPO

One major goal of the TIM was to identify **task allocation strategies** for SPO and to identify the strengths and weaknesses associated with each strategy. In other words, one major goal was to identify the **ways in which the tasks of the second pilot could be redistributed amongst remaining members of the NAS** and/or be replaced by automated systems. In this section, the strategies identified by participants will be reviewed. The term "**configuration**" is used to mean the **arrangement that results from a particular strategy for task allocations.** The strengths, weaknesses, issues, and/or recommendations are presented for each configuration. However, the participants identified a set of general recommendations and thoughts regarding task allocation strategies, and these general thoughts are summarized first.

9.1. General Thoughts and Recommendations Regarding Task Allocation Strategies

9.1.1. Use the Systems Approach when Considering SPO and Task Allocation Strategies

On several occasions, participants noted the importance of considering the problem of SPO at a system's level. *First, participants suggested that researchers and developers consistently use a systems-oriented, not an agent-oriented, approach when designing studies and products.* For example, when designing a study, thoughts should extend beyond the single pilot to include automated systems. One participant gave an example in which two agents in the system (e.g., an automated system and a human agent) could be doing what they are "supposed to do" (that is, what they have been trained or programmed to do), but an undesirable outcome could be the result of the two actions occurring simultaneously. If a systems approach is not used, such a circumstance may go unnoticed.

Participants shared a *second* recommendation that is similar, but it is worth noting due to the difference in emphasis. Specifically, *participants suggested using a NAS-centric, not a pilot-centric, approach.* In short, this recommendation places emphasis on the notion that all parties within the NAS be considered in development activities. *The following list includes participants' thoughts and exemplifies the types of issues and questions that surface when a NAS-centric approach is utilized.*

1. There are many types of operations to examine for SPO, only one of which includes the single pilot. Specifically, one might examine (1) aircraft automated systems and performance, (2) flight operations and pilot requirements, (3) the maintenance operations control center, and (4) the AOC.
2. How will mixed equipage be addressed by all parties within the NAS (e.g., pilots, dispatch, ATC, etc.)?
3. How will the job of ATC change? The job of the dispatcher?

4. Failure to utilize a NAS-centric approach may yield research findings that are not realistic. For example, current-day ATC "profiles" flights based on the type of flight and sometimes has different expectations for different types of flights (i.e., requests more or less of them). This type of "profiling" has very real effects on individual flights and the NAS, and it may affect single-pilot flights in particular.

9.1.2. General Challenges, Issues, Questions, and Recommendations as Related to Task Allocation Strategies

Participants offered numerous thoughts regarding task allocation strategies, in general. One set of observations and recommendations is related to the **task allocations in SPO based on the tasks of current-day pilots**. These observations and recommendations are presented in the following list.

1. The impact on the "aviate" category of tasks would be minimal when moving from current-day operations to SPO.
2. The "navigate" and "communicate" categories represent the tasks of the present-day co-pilot, and the change will probably be most apparent in these two categories. Therefore, efforts might be focused on these activities.
3. The following tasks should be reserved for the remaining single pilot because UAS research has shown the human to outperform automation on these activities:
   a. any task that requires "experiencing" a state (e.g., turbulence and icing)
   b. higher-order decision making or any task that might require "artificial intelligence" as opposed to automation (e.g., dealing with multiple failures, novel problems, collision avoidance, and strategic planning in general)
   c. visual tasks (e.g., see-and-avoid tasks, visual separation, looking at onboard weather radar, any visual procedures in the terminal area, pattern recognition)
4. The following guidelines also address those tasks that should be reserved for the remaining single pilot, but these guidelines are not necessarily tied to UAS research findings.
   a. Because automation might yield skill degradation, an effective guideline might be to avoid automation on any skill that must be maintained by the single pilot.
   b. The single pilot should address any tactical error that is not addressed effectively by automation (i.e., automation errors). Hazard avoidance is a perfect example of a tactical maneuver that might need to be reserved for the single pilot. If a hazard warning is heard, it would imply that automation has failed in doing its job, and the pilot would need to act.

As can be seen in other sections of this report as well, participants expressed most concern about SPO when off-nominal situations are considered. Therefore, it is not surprising that **participants suggested that the distinction between nominal and off-nominal conditions be considered when task allocations strategies are determined.** The following short list presents two recommendations regarding task allocation strategies when considering the nominal/off-nominal distinction.

1. Consider whether or not task allocation strategies should differ under nominal and off-nominal conditions, and if so, what can be done to ensure the change in allocation strategies would not yield confusion for the pilot.
2. The only time you actually find both current-day pilots in control is when there are mechanical or off-nominal issues. When something unexpected occurs in a cockpit, a strict division of labor is typically employed. For example, the Captain might say something akin to "I'm flying the aircraft. You take care of X." In some ways, this situation is ironic from the perspective of SPO. Specifically, since the off-nominal situations may be of most

concern and the off-nominal situations tend to require the actions of both pilots, the outlook for SPO may be concerning. However, research could capitalize on this circumstance and observe how two, current-day pilots divide the labor under various circumstances. This would allow researchers and developers to learn what might be the best task allocation strategy under varying off-nominal conditions.

As mentioned in the previous section, participants emphasized the importance of using a NAS-centric approach in examining SPO's feasibility. The following **two recommendations were put forth to be considered while determining task allocation strategies, and they both have a NAS-centric focus.**

1. Consider the NAS environment when determining task allocation strategies. For example, the level of precision required by NextGen might determine the allocation of functions.
2. For any configurations in which the task allocation strategy includes a distributed team (e.g., remote pilot, use of AOC, etc.), consider how the state of all agents in the system can be made transparent to any or all other agents that are relevant.

Participants also presented some **very general strategies that might be employed when identifying task allocation strategies**.

1. Any decision that requires direct interaction with or experiencing of the environment should be kept as "close" to the information as possible (i.e., the decision and experience should have a shared location).
2. Consider tasks in their context before allocating tasks.
   a. If tasks are distributed but they are linked in a meaningful manner, the system will be less effective.
   b. When tasks are re-allocated amongst agents in the system, the nature of the job may change in ways that are unforeseen. Researchers and developers also need to be ready to address the new tasks that may be created by the change in allocations (e.g., new monitoring or communicating tasks may be created by new allocations of tasks).

9.2. Task Allocation Strategies/Configurations Identified

In short, **participants identified *five* configurations that might be utilized under SPO. In the following list, these configurations are merely introduced and described**.

1. **One pilot on board, who inherits the duties of the second pilot.** This first option was not a particularly popular suggestion. Rather, it was sometimes noted in order to compare it with other configurations.
2. **One pilot on board, with automation replacing the second pilot.** This second option was mentioned much more frequently and seemed to be treated as a more feasible alternative than the first.
3. **One pilot on board, with a ground-based team member replacing the second pilot.** This third option also was mentioned frequently and seemed to be treated as a feasible alternative. Two options were suggested for the ground-based team member: a remote pilot or a dispatcher.
4. **One pilot on board, with onboard personnel serving as a back-up pilot.** The fourth option was mentioned frequently and seemed to be treated as a feasible option. A few options were suggested for the onboard personnel member who might serve as a backup: commuting pilots, flight attendants, and flight marshals.

5. **One pilot on board, with the support of an intricate, distributed team.** The intricate distributed team was conceived by one of the workgroups. Therefore, it was not mentioned frequently, but the relative infrequent mentioning of it is probably only related to the fact that it was a workgroup-generated idea. The workgroup suggested that the distributed team might consist of: (1) the single pilot on the flight deck, (2) flight deck automation, (3) a cabin commander, (4) airborne support, (5) a ground support team, including an airport specialist, and (6) ground automation. They conceived of the *cabin commander* as someone who could serve to manage in-flight problems within the cabin. Duties would include problems with passengers as well as mechanical problems in the cabin. The single pilot could be relieved of some duties that are expected of pilots today. Airborne support could be in the form of a *wingman* (or wingmen). A wingman would be a pre-identified pilot in another, nearby flight. This pilot could assist the single pilot by: (1) providing general operational support to the single pilot, (2) running checklists, (3) navigating around weather and turbulence, especially since they would be proximate, (4) monitoring his or her alertness, (5) providing general decision making support, and (6) "checking back in" with the single pilot to ensure resolution of the problem. The *airport specialist* would be a person located at the airport who could assist the single pilot with questions or problems specifically related to arrival and departure.

In the sections that follow this section, a more detailed examination of each configuration is presented. When possible, each configuration is discussed in terms of its strengths, the issues or barriers it presents, and the recommendations put forth by the participants.

9.3. Task Allocation Strategy/Configuration 1: One Pilot on Board, Who Inherits the Duties of the Second Pilot

Because this configuration did not appear to be favored by participants, it was mentioned relatively infrequently. As such, all information regarding this configuration is presented within this short section. To start, **participants did NOT offer any thoughts regarding the strengths or advantages of this configuration**. However, a set of questions was generated. Specifically, one participant asked **questions about the "elements" of the second pilot's job and the result of transferring these elements to the remaining single pilot**. These questions are listed here and could be considered "issues" with this particular configuration. In some cases, these questions could serve as research questions as well.

1. What elements could not be transferred to the remaining pilot due to cockpit design or layout?
2. If given to the remaining pilot, what elements would violate regulations or standard practice relating to airworthiness and flight certification?
3. What elements would negatively impact safety if simply given to the remaining pilot?
4. What elements would add to physical or mental workload of the remaining pilot?

9.4. Task Allocation Strategy/Configuration 2: One Pilot on Board, with Automation Replacing the Second Pilot

9.4.1. Feasibility and Strengths of this Configuration (One Pilot on Board, with Automation Replacing the Second Pilot)

As presented in the following list, participants presented several thoughts suggesting **this configuration is feasible, reasonable, and possibly advantageous**.

1. Aircraft can essentially fly themselves today. Therefore, in general, this configuration is feasible under nominal conditions and some off-nominal conditions.
2. The aviation industry fully relies on fly-by-wire today (i.e., it cannot fail). Therefore, the aviation industry should not be worried about what should be done when automation fails under this configuration. Instead, the industry should be asking how to design the automation so that it does not fail.
3. Technology has decreased the frequency of situations in which there are many events occurring simultaneously that are of high difficulty. Therefore, a further increase in technology (automation) may be beneficial.
4. The loss of teamwork may not be as problematic as it may first appear.
    a. Human redundancy (e.g., for error checking) does not always yield better performance. Two humans can, and sometimes do, make the same mistake.
    b. Teamwork adds work because work must be performed that is associated with managing teams.
5. As a rule of thumb, automation can be used if you can train a new person to perform the task(s). Therefore, in this case, automation theoretically can be "trained" to perform the job of the second pilot.
6. The benefit of using automation is that automated systems only need to be "trained" once. If you have humans (the second pilot, in this case) performing the same tasks, industry must train numerous people and continually work to ensure they remain proficient.
7. Some participants believed this configuration may be the most likely to be adopted.

9.4.2. General Challenges, Issues, and Questions as Related to this Configuration (One Pilot on Board, with Automation Replacing the Second Pilot)

Discussions of automation and automation-related issues occurred frequently throughout the three-day TIM, and **a recurrent theme throughout the TIM was the idea that automation-related issues must be seriously considered**. This topic could have been discussed in a previous section, where the general SPO issues were discussed (i.e., issues that are not specific to a configuration). However, *a discussion of automation-related issues is presented here only because this particular configuration* (one pilot on board, with automation replacing the second pilot) *is the only configuration that, theoretically, necessitates the use of relatively more automation than is used today.*

Participants noted numerous concerns regarding the use of additional automation. In fact, the mention of automation presenting issues occurred quite frequently during the TIM. **The following list summarizes some of the general concerns participants expressed as related to the introduction of more automation, in general.**

1. A general byproduct of automation is to increase high workload and decrease low workload.
2. Automation may reduce situation awareness.
3. If the pilot must understand the state and activities of the automation in order to monitor the automation, the industry should question why automation is needed at all.
4. There are some tasks or scenarios that automation cannot be designed to handle. For example, automation would be unable to effectively prioritize tasks when multiple systems fail or be able to smell an odor that serves as a cue that something is wrong.
5. When automation fails, it can be catastrophic since automation has only a pre-defined set of responses. Humans can be innovative and often can deal effectively with novel situations.

6. Culture should be considered in the development of automated systems. Cultures may vary in terms of automation acceptance and trust. In addition, variations could be found across cultures in terms of design features (e.g., preference for a male or female voice to represent the automated system).

Participants also had some **questions and concerns about this particular configuration** (i.e., one pilot on board, with automation replacing the second pilot) as well. These questions and concerns are presented in the following list.

1. With this configuration, the role of the single pilot would become primarily a "systems manager" whose primary skills are associated with managing the onboard automation. In other words, the single pilot would shift from "aviate" tasks to managing complex systems. Therefore, this configuration may produce boredom, which often produces lack of vigilance/attentiveness.
2. Before adding automation, the aviation industry should ask what a single pilot is able to do without more automation.
3. Because automated systems would replace the second pilot, subtle human forms of communication are lost (e.g., body language, inflections in voice, etc.).
4. As is further elaborated in the recommendations section, this configuration could include an arrangement in which the task allocations change dynamically depending on the circumstances (e.g., sometimes the human performs the task, but other times, the automation performs the task). This notion is presented as an issue, because one workgroup identified the dynamic allocation of tasks as being the best option, whereas another workgroup identified it as being the most worrisome. In the first case, the rationale was probably the flexibility afforded by dynamic task allocations. In the second case, the rationale was presented. One workgroup expressed concern that, in the case of adaptive systems, the human would have the added workload associated with "tracking" the automation's current activities (e.g., "Should I perform the task, or is an automated system already doing that?"). Such required "tracking" also provides the opportunities for errors ("I thought the automation was doing X, but it wasn't.").
5. It may be difficult to certify a system in which task allocations amongst the human and automated systems are dynamic.
6. Because the software has become so complex, one minor coding error in automation could "ripple through" the system and lead to an incomprehensible situation for the pilot. With this configuration, this situation may be worsened because more systems will be added, and some of these systems will be of high criticality because they take the place of the second pilot.
7. From a certification perspective, it may be difficult to design automated systems such that they reach the level of safety achieved with two pilots.
8. This configuration treats the aircraft as an optionally piloted aircraft. Such a design is a very expensive alternative.
9. Because automated systems would be performing the essential tasks of the second pilot, systems would have to be immune to "hackers."
10. Stakeholders and the public may not easily accept this configuration.

9.4.3. *Recommendations as Related to this Configuration (One Pilot on Board, with Automation Replacing the Second Pilot)*

Participants shared many thoughts regarding the conceptualization, design, and use of automated systems for the single pilot. The following list presents the **participants' thoughts regarding a**

general approach to automation use, which might be particularly useful in early stages of development.

1. The use of automation should be conceived in levels and not be treated as an all-or-none state. For example, automation may complete an entire set of tasks, not be involved, or be somewhat involved (e.g., prompting the pilot).
2. Automation should be approached using several taxonomies that classify automation levels.
3. When identifying automation's role, do not limit the process by using only a task-oriented approach to automation. Concepts such as prioritization and urgency could be missed otherwise.
4. With the increase in automation, be sure to avoid "over-proceduralizing" the pilot's job. Allow for the possibility of some creative decision making on the part of the pilot. Recent findings have shown that the "over-proceduralizing" of jobs harms performance and decreases the amount of communication and cooperation between team members.
5. Separate from conceiving automation in levels, the architecture of automation might be built in levels, such that if a relatively higher level of automation fails, the pilot can move to a lower level of automation and not be left without any assistance.
6. Humans should not always be in the position of authority or have control. Humans should *not* be in control when the human is inattentive, there is little time to respond, or the human is lacking the knowledge to manage the situation. In short, the human should *not* have authority if he or she does not have ability, the human should not have control if he or she does not have authority, and the human should not have responsibility if he or she does not have control. Therefore, each of the following concepts serves as a pre-requisite for the concept that follows it: responsibility, control, authority, and ability.
7. Consider a conservative approach to automation in which automation helps only when it's too late for human input. Such an approach is analogous to the auto-brake systems found in some automobiles (i.e., the system applies brakes when an accident is imminent and the human has not responded).

Participants offered numerous ideas regarding the manner in which automated systems could be designed such that they might compensate for the loss of interaction with a *human* co-pilot. As was mentioned in the context of issues, this particular configuration may cause some problems because two pilots often use subtle, nonverbal communication to relay information. If automated systems replace the second pilot, such natural forms of communication are lost (e.g., body language, inflections in voice, etc.). In addition, the human co-pilot presumably utilizes generally accepted social skills and interacts with the pilot based on their shared awareness of their environment. The participants' ideas for creating human-like interactions with automation are shared in the following list.

1. Automation must interact with the single pilot in a human-like manner.
2. Consider a system that recognizes a pilot's hand or body gestures.
3. Include an intelligent voice recognition system.
   a. Attempt to develop a system that can analyze the pilot's voice and be able to imply that the pilot is stressed. Humans often have the ability to imply stress levels based on voice quality.
   b. Determine the manner by which a particular automated system will "know" when the pilot is talking to it.
   c. Two pilots may need to interrupt one another. Automated systems must be able to handle interruptions (i.e., interrupting the pilot and/or the pilot interrupting it).

d. Determine whether the most effective voice recognition system would be able to utilize natural language as input or if controlled language would be more effective, where "controlled language" is such that the pilot must use pre-defined phrases. If controlled language is necessary, consider how the pilots must be trained.

4. Include an effective voice synthesis system.
   a. Like a human, an automated system should be able to communicate exactly what it is doing and how it is accomplishing a task. This behavior would mimic what the first officer does in current-day practice.
   b. Like a human, the system should be able to repeat information. Such a system would serve to assist the pilot when he/she does not initially understand information or when the pilot needs to verify information. In repeating the information, the system should perhaps relay the information more slowly, emphasize particular words, or revert back to the standard/formal manner of communicating a request (as ATC does in these circumstances).
   c. The voice synthesis system would allow the automated systems to assist the pilot with prospective memory (i.e., remembering to engage in planned tasks).

5. Automation must anticipate the pilot's needs as would a second pilot.

6. Automation must have CRM-like skills. In order to do so, an automation coordinator is probably required. This coordinator should communicate with all systems and with the pilot.

7. Automated systems should honor the pilot's priorities.

8. Like a co-pilot, consider whether or not the automated systems should have active communications with the single pilot. In other words, rather than have the automated systems respond only when queried, the automated system could query or challenge the single pilot. Furthermore, the automated systems could not only alert the pilot when there is a problem, but the systems could alert the pilot when there *may* be a problem.

9. Automation could be used to assist pilots in a way such that they do not get trapped in attention tunneling (e.g., presenting alternative views, prompting pilots to attend to information to which they have not yet attended, etc.).

10. To offset boredom for the single pilot, the human and automated systems could behave as two pilots in the sense that they might "trade-off" between them. For example, two pilots might decide that the first pilot lands on this flight and the second lands on another flight.

11. When an automated system communicates with the pilot, the acceptable response time must be identified, such that the automation will be able to infer that the pilot did not hear it, understand it, or is incapacitated.

12. A decision must be made as to whether or not there will be boundaries placed on how often the pilot must interact with automated systems. In other words, if the pilot is silent for quite some time, the automated system may proceed to ensure there is not a problem with the pilot. The system could prompt the pilot with a question (e.g., "Are you doing okay? Can you use any help?").

13. As is the case between two pilots, the pilot and automated systems must be continually giving feedback to one another in order to remain synchronized. Such a system could include intent inferencing on the part of the automated system. However, intent inferencing may not be necessary. Instead, perhaps the pilots should be required to communicate their intentions more actively/directly than they do today. Although the explicit communication of intentions might require additional training on the part of the pilot, intent information that is directly input into the system would be considered high in validity. Therefore, that information could be shared with others in the NAS.

TIM attendees had **several additional thoughts to provide guidance for this configuration** (i.e., one pilot on board, with automation replacing the second pilot). However, these recommendations

did not necessarily relate to the required human-like qualities addressed in the previous list, but instead, they **reflect a variety of topics**.

1. Tasks and circumstances must be identified under which tasks should (a) be given to the human, (b) be given to the automation, (c) be shared between the human and the automation, (d) be traded between the human and the automation, and (e) have a dynamic allocation.
   a. If the allocation of functions is dynamic, an extremely important task is to determine which agent should be given the authority to assign functions and under what circumstances.
2. Identify the strengths and weaknesses with static, adaptable, and adaptive automated systems, with the first two cases representing relatively consistent task allocation strategies and the latter representing dynamic task allocations. *Static* automated systems would always perform in the same way. *Adaptable* automated systems are ones that can change based on the human's input (i.e., the system is customizable). *Adaptive* automated systems are ones that would change their behaviors autonomously given the context.
3. Keep in mind that it may be difficult to certify a system that is programmed to behave in an environment that is using dynamic function allocation.
4. Determine the appropriate level of "transparency" for the automated systems and if transparency needs to vary with circumstances.
5. Identify the circumstances under which automation increases high workload or decreases low workload.
6. To compensate for the absence of any form of a second pilot, consider including a virtual pilot's assistant, an enhanced external view, an enhanced weather radar, enhanced caution and warning systems, and a person or system that can cross-check the pilot's judgments (e.g., AOC or an automated system).
7. For this configuration, no other person is extensively involved in a particular flight other than the single pilot. Therefore, ground personnel (e.g., ATC) would truly need to be informed of a flight's back-up plan in order to prevent confusion if pilot incapacitation did occur.
8. Keep in mind that automation would need to have the ability to successfully perform *all* tasks. Automation would need to perform the jobs that were previously associated with the first officer (e.g., coordination and monitoring), but it would also need to successfully perform the duties of the remaining single pilot in the case of pilot incapacitation or the like.
9. Methods for validating and verifying automation must be identified.
10. As much as possible, do not discuss "automation" as one concept or one system. Instead, consider discussing "automation systems," with emphasis on the plural form of the word "system." This language serves as a reminder that multiple systems are used to automate various processes.

9.5. Task Allocation Strategy/Configuration 3: One Pilot on Board, with a Ground-based Team Member Replacing the Second Pilot

9.5.1. Feasibility and Strengths of this Configuration (One Pilot on Board, with a Ground-based Team Member Replacing the Second Pilot)

As presented in the following list, participants presented several thoughts suggesting **this configuration is feasible, reasonable, and possibly advantageous**.

1. The configuration in which a dispatcher serves as a ground-based team member is feasible. In fact, one major airline already has a type of "super AOC," in which two people serve as virtual team members to ongoing flights.

2. The particular configuration in which the ground-based team member is a remote pilot may be the most favored alternative. In addition, it may be the safest alternative.

9.5.2. General Challenges, Issues, and Questions as Related to this Configuration (One Pilot on Board, with a Ground-based Team Member Replacing the Second Pilot)

As previously noted, this configuration is distinct from those previously mentioned, but it also is slightly more complicated because a few options were considered in terms of the particular person who would serve as the team member on the ground. Therefore, **first, participants' general thoughts regarding this configuration are presented. Thereafter, their thoughts regarding the particulars of the configuration (i.e., when the ground-based team member is a remote pilot *or* is a dispatcher) are presented.**

Participants presented the following issues as ones that are pertinent to this configuration, in general. The first few issues are oriented toward practical and technological issues, and the latter items might be conceived as relatively more oriented toward human factors issues.

1. For any possible situation in which a ground-based human serves to replace tasks formerly performed by a pilot, certification may become problematic.
2. Communication issues may create a barrier for this configuration. Because the ground-based team member would replace the second pilot, his or her job would theoretically be essential to flight. Therefore, the quality of the communication channel would be of utmost importance as would any time lag experienced in this communication. Much work might be required because redundant and non-overlapping channels of communication probably are needed to avoid complete failures in the communication system.
3. This configuration creates a new "doorway" for terrorism. Both the physical location of the remote pilot and the electronic communications between the ground and air are vulnerable to terrorism. The communication channel between ground and air would certainly need to be fully secured. Because of this risk, this configuration could yield high publicity (i.e., negative reactions from the public, media, and/or stakeholders).
4. The ground-based team member may use automated systems for controlling the flight. If that is true, automation failures on the ground could yield undesirable outcomes. Procedures associated with any ground-based automation failures would have to be identified.
5. Although the current TIM focused on the continental U.S., it may be irresponsible to ignore potential international factors. Specifically, when identifying procedures for pilot incapacitation, the industry should question whether the procedures would work outside of the U.S. For this particular configuration, one would need to address whether or not it is possible to control an aircraft from halfway around the world.
6. Benefits can be identified for the arrangement in which a ground-based team member monitors an entire flight (e.g., consistency, building an awareness of the flight's circumstances, etc.). However, benefits also can be identified for the arrangement in which a ground-based team member does not monitor an entire flight (e.g., flexibility in the pool to accommodate off-nominal situations).
7. The types of displays and information that would be needed by the ground-based team member are unclear and would require research and development efforts.
8. It would not be surprising if single pilots develop an animosity towards ground crews under such a configuration. The onboard pilots may feel they should necessarily be in a superior role because it is their lives and licenses on the line.
9. Compared to an onboard pilot, a remote team member may have slower response times in urgent situations and may have lower situation awareness.

9.5.3. General Recommendations as Related to this Configuration (One Pilot on Board, with a Ground-based Team Member Replacing the Second Pilot)

The following list represents **participants' recommendations for this configuration in a general sense** (i.e., regardless of the particular person who serves as a ground-based team member).

1. Technologies and tools need to be developed to support the ability to interrogate the aircraft systems to receive information. Without this ability, the ground-based team member would be limited in the amount he or she can contribute as a team member and/or a back-up pilot in case of pilot incapacitation.
2. Consider and identify the number of aircraft with which the ground-based team member will work. If cost-savings are to be realized, the ground-based team member will need to work with several aircraft.
3. Consider incorporating debriefing sessions following flights. In this way, the single pilot could meet with the ground team and review the "lessons learned" from each flight.
4. Because this team is distributed (by definition), the appropriate CRM methods need to be identified.
5. Because this configuration includes team members that extend beyond the cockpit, methods for measurement and evaluation of the team's performance must be identified.
6. If the job of ATC will change as a result of this configuration, consider whether the duty cycle will need to be changed for controllers.
7. Although it may not be considered an effective alternative, some may suggest that the ground-based team member's tasks could simply be combined with that of a regular controller. The role of the ground-based team member should probably remain separate from the regular controller's tasks, but how these two roles might be integrated, if at all, must be considered.

9.5.4. Challenges, Issues, and Questions as Related to One Particular Case for this Configuration (One Pilot on Board, with a Dispatcher Replacing the Second Pilot)

Participants shared numerous **thoughts regarding the situation in which a <u>dispatcher</u> serves as a ground-based team member**, and these thoughts are presented in the list that appears in this section. Some of these thoughts are, in fact, particular to this situation. In other cases, the thoughts might be considered general enough that they could be applied to another case for this configuration. However, the authors of this document wished to remain objective and report the information such that it represents the context in which the discussions occurred.

1. Dispatchers would need to obtain a special certification for SPO operations.
2. It will probably be a challenge to have the adequate bandwidth for communication and surveillance systems that support this real-time interaction.
3. A mixed equipage environment will be a challenge from the perspective of the dispatcher's job.
4. New training, with the associated loss in time and dollars, would be required for dispatchers.
5. This arrangement would require three-way communication between the onboard pilot, dispatcher, and ATC. The challenge would be in developing and certifying the controller-dispatcher data link communications and the dispatcher-pilot data link communications. Currently, the dispatcher does communicate through company data link systems to flights but not with required communications performance standards.
6. Numerous technologies and decision support tools would need to be provided to the dispatcher, and these technologies and tools would require development and certification.

9.5.5. Recommendations as Related to One Particular Case for this Configuration (One Pilot on Board, with a Dispatcher Replacing the Second Pilot)

Participants shared **numerous recommendations regarding the situation in which a <u>dispatcher</u> serves as a ground-based team member**, and these recommendations are presented in the list that follows**.**

1. If this particular configuration is adopted, allow the AOC to manage much of the flight planning, including weather.
2. Consider a highly automated AOC, which is integrated with the aircraft systems through advanced mediums.
   a. The dispatcher should be able to interrogate the aircraft systems for real-time flight planning predictions (with 4-D trajectory information).
   b. Dispatch must have real-time aircraft situational displays.
   c. The dispatcher must receive enhanced weather from onboard avionics.
3. The dispatcher's communication with the pilot should be in the form of direct links (e.g., primarily with digital data messaging, voice, or streaming video).
4. The dispatcher must receive ample information in order to effectively serve as a team member.
   a. Technologies such as the ADS-B would need to be enabled for the dispatcher, such that the dispatcher can receive the same signal as the controller.
   b. The advanced AOC system would need to be integrated into a single display in order to support the higher level of responsibility (e.g., Ocean 21).
5. The job of the dispatcher certainly needs to be re-designed.
   a. Consider the number of aircraft the dispatcher would be able to handle. Currently, the dispatcher typically can handle around 20 aircraft, but the number decreases rapidly in off-nominal circumstances.
   b. With much more responsibility, the duty cycle of the dispatcher needs to be re-considered.

9.5.6. Challenges, Issues, and Questions as Related to a Second Particular Case for this Configuration (One Pilot on Board, with a Remote Pilot Replacing the Second Pilot)

Participants shared only two thoughts that might truly be considered a major challenge to **the situation in which a <u>remote pilot</u> serves as a ground-based team member**, and these thoughts are presented in the following list.

1. Identifying the number of aircraft that can be handled by the remote pilot may be challenging if the goal is to maintain a relatively stable number of aircraft under the remote pilot's control and accommodate off-nominal situations.
2. This case requires that the aircraft can serve as a remotely piloted vehicle (i.e., in the case that the onboard pilot becomes incapacitated). This arrangement may be the most expensive.

9.5.7. Recommendations as Related to a Second Particular Case for this Configuration (One Pilot on Board, with a Remote Pilot Replacing the Second Pilot)

TIM attendees presented several **recommendations for the situation in which a <u>remote pilot</u> would serve to replace the co-pilot**. These recommendations are presented in the following list.

1. Consider some sort of flexible arrangement amongst the pool of ground pilots to relieve pilots when off-nominal or high workload situations arise. The industry needs to establish expectations regarding the highest and lowest number of aircraft that a remote pilot should manage.
2. Consider whether or not the remote pilot will serve an aircraft for the course of an entire flight. As was mentioned for ground-based team members in general, benefits can be identified for the arrangement in which a remote pilot monitors an entire flight (e.g., consistency, building an awareness of the flight's circumstances, etc.). However, benefits also can be identified for the arrangement in which a remote pilot does not monitor an entire flight (e.g., flexibility in the pool to accommodate off-nominal situations).
   a. An alternative approach is to have the dispatcher monitor the flight and alert an on-duty remote pilot only when assistance is needed.
3. The duty cycle for the remote pilot needs to be identified.

9.6.   Task Allocation Strategy/Configuration 4: One Pilot on Board, with Onboard Personnel as Back-ups

Although attendees seemed to react to this configuration as a feasible configuration (i.e., having mentioned it on numerous occasions), they offered few comments that might be considered specific to this presentation. Other than the previously mentioned options for back-ups (i.e., commuting pilots, flight attendants, and flight marshals), participants identified only **three issues related to this configuration and one recommendation**. Therefore, these comments are combined into one list, which follows this paragraph.

1. Because the back-up to the pilot is onboard the aircraft, the post-September 11th policy regarding the locked cockpit door becomes an issue. In short, this policy would need to be re-considered in some fashion in order to allow the onboard back-up to enter the cockpit if pilot incapacitation occurred.
2. Flight attendants presumably will always be needed on a flight. However, commuting pilots and flight marshals are not required on flights. If commuting pilots or flight marshals were chosen to serve as back-ups, the gains in flexibility due to SPO might be offset by the complications of requiring one of the aforementioned persons to be on a flight. In fact, flexibility might be reduced compared to today's operations.
3. The back-up personnel would require training. Time and money associated with such training must be considered as should the type of training that would be required.
4. Consider including simplified types of functions (e.g., the "big red button" or "digital parachute") on the aircraft to allow for several types of back-up options (e.g., flight attendant or commuting pilot) in case pilot incapacitation occurs.

9.7.   Task Allocation Strategy/Configuration 5: One Pilot on Board, with Support of an Intricate, Distributed Team

This configuration is not discussed further because, relatively speaking, not much discussion was devoted to this particular configuration when everyone was in attendance. Instead, as described in a previous section, this configuration was conceived by a particular workgroup. The audience members appeared to believe the configuration was reasonable. Specific responses to the presentation of this configuration have been embedded in other (more relevant) sections. The interested reader could refer to the detailed account of Dr. Richard Mogford's presentation, during which he reviewed this configuration.

10. Recommendations for Research in the Assessment of SPO Feasibility

TIM attendees provided ample suggestions for research that might be pursued in exploring SPO. As previously mentioned, many of the topics in other sections of this document could be re-conceptualized (or merely re-phrased) to represent a research question. This particular section is reserved for topics that participants explicitly presented as research topics. Although such information was not necessarily provided by the participants, the authors have placed participants' suggestions into several categories of research in order to assist in making the information more manageable for the reader. The categories used are as follows: (1) general guidance for research, (2) experimental and simulation research, (3) survey research, (4) large-scale, real-world research, (5) modeling and task analyses, and (6) literature reviews. The recommendations associated with each of these six areas of research are reviewed in the following pages.

10.1. General Guidance for Research Exploring SPO

In addition to providing specific research ideas, various comments were recorded that were of a more general nature. Those comments are represented in this section. *First*, **two suggestions were offered in terms of a "big picture" (or general) plan to SPO research.** These suggestions are as follows.

1. Consider examining SPO by engaging in the following activities and engaging in these activities in the order presented here:
    a. Examine FAR Part 135 in a bit more detail and learn what experienced companies have done (e.g., Cessna) in designing single-pilot aircraft.
    b. Ask what the aviation industry would need to add to the research and design (identified in the first step) in order to examine the concept of SPO.
    c. Examine FAR Part 121 cargo operations.
    d. Evaluate FAR Part 121 VFR passenger flights (short flights) and fractionals.
2. Perform research in such a way that successively more challenging platforms are included and proceed in the following order:
    a. fast-time models
    b. human-in-the loop simulations
    c. flight trials with SPO-certified GA passenger jets
    d. trials by express mail carriers
    e. trials by short-distance passenger carriers

Second, **participants offered several bits of general advice for those researching SPO.** These ideas are presented in the following list.

1. Use completely immersive and realistic environments when evaluating SPO. Workload surveys and the like are useful, but they are limited. Surveying pilots regarding workload often can illuminate relative differences between two conditions. However, in this particular case, absolute workload is of interest (i.e., can a single pilot handle the job?). Immersive and realistic environments are the only means by which the pilot's ability to perform under SPO will be made apparent.
2. Use a variety of metrics in testing SPO. For example examine interruptive automation, considerations for boundary conditions, predictability of the human's work environment and workload.
3. Consider incorporating the theoretical framework put forth by Sheridan and Inagaki (2012) in which the automation-human machine relation can be examined.

Third, **participants offered a few suggestions in terms of general topics that should be explored.** However, suggestions were not offered or implied in terms of the method that might or should be used when exploring these topics. Therefore, these recommendations are presented in this section rather than a later section.

1. Assess the effects of fatigue and boredom on the single pilot. For example, researchers might address whether or not fatigue will increase the risk of overreliance on automation.
2. Identify the elements of complexity, the limits of the human in terms of complexity, and the threshold to determine when limits have been exceeded. These efforts will allow us to understand how the single pilot will perform in managing the aircraft under various levels of complexity. Simultaneously, the results of such research might remove the need to equate complexity with aircraft weight.
3. Define what is meant by "risk" and identify effective predictive measures of risk.
4. The thresholds for workload need to be defined through some form of measurement, and this threshold needs to be identified for all parties that would be affected by SPO (e.g., ATC, AOC, etc.).
5. Consider the types of errors that are made during testing (e.g., verification and communication errors). Do not limit the exploration of errors and error types to human agents.

10.2. Guidance and Suggestions for Experimental and Simulation Research

Meeting attendees offered several **thoughts regarding experiments and simulations in particular**. Those thoughts are summarized in the following list.

1. Generally speaking, use simulations to validate technology that has addressed a previous technical issue for SPO.
2. Generally speaking, experiments might be directed at making some of the SPO unknown unknowns merely unknowns.
3. Consider an experiment in which a current, two-person crew might fly with a barrier erected between the two pilots. In this way, they would be able to talk with one another but not see one another. This experiment would allow us to learn about the "body aspect" in communications between the team members and understand the manner in which intentions are relayed.
4. Use experiments and simulations to determine what information should be shared, and with whom, if "display and control mirroring" is adopted as a means of sharing information.
5. When testing a new display, decision support, control, or the like, consider:
   a. assessing the effects of system errors and random errors on pilot performance,
   b. employing SHERPA (Systematic Human Error Reduction and Prediction Approach), and
   c. studying the types of failures that occur as a result of various human responses.

10.3. Suggested Survey Research

Meeting participants had **two suggestions regarding survey research that should be undertaken**. Those two suggestions are listed here.

1. Poll the aviation community to determine which, if any, SPO configuration (i.e., method for allocating the second pilot's tasks) is viable. When distributing this survey, ensure all stakeholders are represented.

2. Survey the public to determine whether or not they will accept SPO and under what conditions.

10.4. Suggestions for Large-scale, Real-world Research

TIM attendees had suggestions for the type of **research that would be undertaken in practical settings** (i.e., in the NAS). Their two suggestions appear in the following list.

1. NextGen research has ignored the single pilot. Research should be examining the larger metro-plex regions, as opposed to only hubs. General aviation accounts for a significant amount of traffic in airfields that surround major hubs, and some of this traffic is in the form of business jets with single-pilot operators. Therefore, NextGen research (and SPO research) should begin actively addressing these types of flights.
2. ZAN (Anchorage Center) is a good place to begin examining SPO, especially if SPO changes the interactions between the AOC and ATC. At this particular center, AOC already has the capability to speak directly with ATC.

10.5. Guidance and Recommendations for Modeling and Performing Task Analyses

Participants had **suggestions for research that attempts to use modeling as a form of research, and they also addressed task analyses,** which can be related to modeling of human and system behavior. These suggestions are found in the following list.

1. Consider modeling the workflow of the flight deck as a means to gain insights into the possibility of SPO. Dr. Pritchett's method could be considered. (See Section 5.2).
2. Carefully examine the tasks of the pilot-not-flying. Only thereafter, ask how, or if, those tasks can be re-allocated.
3. Use checklists as a guide during any type of task analysis (or decisions regarding task allocations).
4. Consider work tasks at different levels of abstraction.
5. If you model any teamwork (e.g., second pilot or team member of the ground), consider the notion that the second team member becomes a part of the first team member's environment, and therefore, team members cannot be modeled separately.
6. Pre-existing models of pilot behavior should be reviewed. Review relatively newer models of pilot behavior, which take the cognitive components of the piloting task into account. A few examples of potentially relevant models are as follows: ACT-R (Johnson-Laird et al.), Air Midas (Corker et al.), D-OMAR (Deutsch & Pew), and the challenges of model credibility with increasing complexity and pace of change (Foyle & Hooey). (The previous examples were provided by a speaker. Therefore, the references are not included in the reference section of this document.)
7. Attempt to measure and model the intentions and adaptive behavior of the human so that the computer can "understand" the human's intentions and behaviors.

10.6. Literature Reviews

Participants provided numerous **suggestions in terms of literature that should be reviewed**. The following list includes all of these suggestions. Note that, in some cases, the literature review suggested is in the traditional form (e.g., journal articles or technical reports), but in other cases, records of incidents and accidents are suggested sources of information.

1. Explore RTSP, a performance-based standard for ATM, as a model for SPO requirements.
2. Norman's report (Norman, 2007) on SPO should be reexamined because it appeared to group various sub-groups who have different training, procedures, backgrounds, operations, and equipment.
3. Refer to the literature and/or incident and accident reports in order to explicitly identify how many incidents and accidents have been prevented by a second pilot. In addition, explore the types of errors that have been prevented by a second pilot and the impact of these preventative actions. One resource to use is the Aviation Safety Reporting System (ASRS) to explore this question.
4. Refer to the literature and/or incident and accident reports in order to search for cases in which design assumptions may have led to an incident and accident.
5. Research the details of a "super AOC" at one major airline, in which two people serve as virtual team members to ongoing flights. One of these jobs is labeled as the "flight operations duty manager." This person is actually a captain on the airline, but in this role, the person is considered an assistant chief pilot. The role is filled 24 hours a day, and the person is meant to serve as a representative within the AOC for the captain and crew.
6. Review an upcoming report from Kathy Abbott of the FAA. (Note: no other details are available other than using the date of this TIM as a relative reference.)
7. Review any relevant literature that might exist from NASA's space-related efforts.
8. Review insurance-related issues. In particular, learn about the involvement of insurance companies in past development efforts.
9. Review literature from the military domain, such that SPO efforts can leverage off of their experience in single- and dual-pilot vehicle operations.
10. Review literature to understand SPO as it is being practiced today.
11. Review the body of research on CRM, which dates back to the 1960s and 1970s. Review CRM training of today. Together, these two sources can be used to guide requirements and criteria.
12. Review the 1981 ASRS study that explored the performance of the single pilot under IFR (instrument flight rules).
13. Review the NextGen concept of operations, but the review should be performed "with an eye" for SPO.
14. Review the work of Mr. Jay Shivley at NASA Ames Research Center. His research provides some guidance as to how tasks can be organized in a meaningful manner.
15. Review the work put forth by the task force involved in the move from 3 to 2 pilots.
16. Review work from DARPA in general.
    a. Review one particular DARPA effort. They performed research on the ability to infer intent based on physiological measures. They explored questions such as, "What is the state of the automation, and what is the state of the human?" Thereafter, they examined how to make the information transparent to the operator and/or a human on the ground.
17. The Mercedes Benz "Attention Assist System," and the related research, might be reviewed in developing systems for SPO.

11. Closing Remarks

11.1. Notable Comments

While reviewing the findings from the TIM, the authors identified **a few notable remarks** made by participants. These remarks are presented here and may be thought-provoking.

1. Compare the answers to the following questions: (1) "What we can do?" (2) "What is certifiable?" and (3) "What makes economic sense?" The "place" where those answers overlap represents what should be done in research, development, and realization of SPO.
2. Is one pilot a logical stepping stone on the way to zero pilots?
3. Will SPO generate more problems than it solves?
4. Keep in mind that the pilot is the most capable system in aircraft but is also least reliable.
5. Are non-technical issues more challenging than the technical issues in the case of SPO?

11.2. Issues Unique to SPO

During a discussion, one participant asked the audience to consider a question: **What issues have been identified during the workshop that are unique to SPO (as opposed to questions that address human factors research, development, and design, in general)?** Because this question was posed very late in the course of the TIM, participants were not able to address this question in any systematic manner (e.g., during the workshop sessions). However, the authors have attempted to provide a brief, yet subjective, answer to this question.

As mentioned in the introduction to this document, crew size has progressively decreased in aviation's history, beginning in the 1950s. This reduction in crew size has been progressive in nature. However, a reduction from two to one pilot presents several circumstances that are unique. The following list represents areas that might be conceived as unique to SPO, but the list is probably not comprehensive. Instead, it is meant to be thought-provoking for researchers and developers that explore the concept of SPO.

1. **Pilot Incapacitation and Pilot Availability at Duty Station.** If SPO were adopted, pilot incapacitation and pilot availability at the duty station would become crucial issues to address and could present barriers to the safe operations if not addressed effectively and comprehensively. Currently (and previously), if one pilot was unavailable to attend to the flight, at least one additional, trained human was on board and available to assume responsibility.
2. **General Value of the Onboard, Human Pilot.** Although automation issues have historically been addressed in aviation, discussions of SPO force the industry, public, and stakeholders to address the value of the *human* pilot being *on board* the aircraft, especially because the aircraft would theoretically need to provide the option of being controlled otherwise (e.g., in the case of pilot incapacitation).
3. **Authority and Accountability.** Especially in relatively recent history, the role of automated systems has increased in flight. However, the concept of SPO seems to be unique in that automated systems would become agents in the system that might be conceived as "equal" in status to the pilot, and in some cases (e.g., pilot incapacitation or threat of malicious intent), the automated systems might be conceived as being at a higher level of authority than the onboard pilot. If undesirable outcomes result from pilot error, the situation may be complex in terms of analyzing fault (e.g., poor design led to the pilot's mistake). However, if

automated agents are in err, the question of accountability may be still more complex (i.e., who is responsible for these errors?).

4. **Social Aspects of and Teamwork for the Single Pilot's Job.** For the first time, SPO would leave the pilot in a situation where no human team member shares his or her physical location. As discussed in a previous section, the lack of social cues and pressures may yield new problems, boredom may become relatively more important than in the past, and for the first time, the pilot's teammates would all be in remote locations.

11.3. Brief Conclusion

The authors do not wish to impose bias by offering an overriding conclusion regarding the particular areas that need attention. The summary of the findings are meant to serve the reader by allowing the reader to develop an informed opinion about SPO's feasibility and the areas that might need to be addressed. Although the aforementioned areas may require special attention in an exploration of SPO, many issues and questions were raised at the TIM, and all of the participants' thoughts and suggestions seem to deserve attention. Much research and development could, and probably should, be performed in order to assess the feasibility of SPO. What can be said without bias is that the meeting attendees seemed, as a whole, to believe that SPO deserved exploration, and in theory, may be feasible.

References

ALICIA. (2012). HCI Aero 2012-Workshop "Human factors for reduced-crew operations." *Alicia-Project.eu*. Retrieved July 20, 2012, from http://www.alicia-project.eu/CMS/events/hci-aero-2012.html.

Charette, R. (2010). Ryanair boss: I want only one pilot in the cockpit. *Spectrum.IEE.org*. Retrieved July 10, 2012, from http://spectrum.ieee.org/riskfactor/aerospace/aviation/ryanair-boss-i-want-only-one-pilot-in-the-cockpit.

Deutsch, S., & Pew, R. W. (2005). *Single Pilot Commercial Aircraft Operation*. BBN Technical Report No 8436. Cambridge, MA: BBN Technologies.

Harris, D. (2007). A human-centred design agenda for the development of single crew operated commercial aircraft. *Aircraft Engineering and Aerospace Technology: An International Journal, 79*, 518–526.

McCartney, S. (2010). Imagining a day when airliners are flown solo. *Online.WSJ.com*. Retrieved July 10, 2012, from http://online.wsj.com/article/SB10001424052702304011604575564212371734270.html.

Norman, R. M. (2007). *Economic Opportunities and Technological Challenges for Reduced Crew Operations.* Technical paper prepared for: Crew Vehicle Interface Element, NASA Langley Research Center, under contract NNL06AA04B Task #NNL06AA63T.

Sheridan, T. B., & Inagaki, T. (2012). Authority and responsibility in human–machine systems: Probability theoretic validation of machine-initiated trading of authority. *Cognition, Technology and Work*, *14*, 29-37.

Appendix A: Recurring Acronyms

Note: Any acronym that is used only once is defined within the text.

ADS-B ....Automatic Dependent Surveillance Broadcast
ACARS ....Aircraft Communications Addressing and Reporting System
AOC ....Airline Operations Center
ATC ....Air Traffic Control
ATM............................Air Traffic Management
CRM............................Crew (or Cockpit) Resource Management
FAA ....Federal Aviation Administration
FAR.............................Federal Aviation Regulation
FOQA.........................Flight Operational Quality Assurance
GA..............................General Aviation
NAS ....National Airspace System
NextGen ....Next Generation Air Traffic System
OPA (or OPV) ....Optionally Piloted Aircraft or Optionally Piloted Vehicle
RSSP..........................Required SPO Systems and Performance (a notional concept)
RTSP..........................Required Total System Performance
SPO ....Single-Pilot Operations
TCAS ....Traffic Collision Avoidance System
TIM ....Technical Interchange Meeting
UAS (or UAV)...........Unmanned Aerial System or Unmanned Aerial Vehicle

Invitation to a NASA Technical Interchange Meeting on Research Issues in Single Pilot Operations

There is growing aviation community interest in the potential of future operations involving a single pilot rather than a two-person flight crew. It is our pleasure to invite you to participate in a NASA-sponsored technical interchange meeting that will focus on exploring the challenges, feasibility, and practicality of single pilot operations. We do not assume that single pilot operations are feasible or desirable, but rather we will focus on identifying the considerations that must be explored to determine this. The meeting will be held at the NASA Ames Research Center, Moffett Field, CA, on April 10-12, 2012.

The meeting goal is to support a rich dialogue that will ultimately lead to clear research issues. These issues will inform future NASA research and development. We are interested in attracting avionics manufacturers, pilots, airline operations specialists, aircraft manufacturers, and researchers.

Topics include:

- *What motivates interest in single pilot operations?*
- *What do we know from current single pilot operations?*
- *What research is needed to determine the feasibility, benefits, and practicality of single pilot operations?*
    - *What are the feasibility challenges?*
    - *In what situations do we need two pilots today and why?*
    - *What are the technology and aeronautical infrastructure enablers?*
    - *What are the socio-cultural issues?*
    - *What should we consider in cost and benefits analyses?*
- *What are the most likely approaches to single pilot operations?*
    - *How might current or proposed NextGen flight deck roles and responsibilities need to be changed to accommodate single pilot operations?*
    - *What advanced flight deck/ground automation would likely be needed?*
    - *What procedures would likely be required to enable single pilot operations?*

We hope that you will join us for this event. However, there is limited space at this meeting and participation will be limited to those responding before the space fills up. Please RSVP with your intent to attend. The event is by invitation only so please do not disseminate this announcement to others. More information on this meeting can be found at:

http://humansystems.arc.nasa.gov/groups/FDDRL/SPO

Questions and RSVPs should be directed to: summer.l.brandt@nasa.gov

Thanks,

Walter Johnson
Flight Deck Display Research Laboratory
NASA Ames Research Center

Appendix C: Final List of Meeting Participants

Count	Affiliation	Title	First Name	Last Name
1	American Airlines	Capt.	Jeff	Osborne
2	ARINC	Ms.	Leigh-lu	Prasse
3	Boeing Company, The	Dr.	Jack	Dwyer
4	Boeing Company, The	Mr.	Richard	Jones
5	Boeing Company, The	Dr.	R. Michael	Norman
6	Boeing Company, The	Mr.	Ronald	Provine
7	Boeing Company, The	Mr.	Stephen	Whiston
8	California State University Long Beach	Mr.	R. Conrad	Rorie
9	California State University Long Beach	Dr.	Thomas Z.	Strybel
10	California State University Long Beach	Dr.	Kim-Phuong L.	Vu
11	California State University Northridge	Dr.	Nhut Tan	Ho
12	Cessna Aircraft Company	Mr.	Ryan	Amick
13	Cessna Aircraft Company	Mr.	Greg	Potter
14	Cognitive & Human Factors	Dr.	Thomas L.	Seamster
15	Dell	Mr.	George	Lawton
16	Dell	Mr.	Jonathan	Luk
17	Eclipse Aerospace, Inc	Mr.	Paul	Burns
18	Embry-Riddle Aeronautical University	Dr.	Elizabeth	Blickensderfer
19	Embry-Riddle Aeronautical University	Dr.	Kelly	Neville
20	Federal Aviation Administration	Mr.	Steve	Boyd
21	GaryAir Air Taxi	Mr.	Dave	Guerrieri
22	Georgia Institute of Technology	Dr.	Amy	Pritchett
23	Honeywell Laboratories	Dr.	Michael	Dorneich
24	IPR Matters	Dr.	Roland	Williams
25	Massachusetts Institute of Technology	Dr.	R. John	Hansman
26	Massachusetts Institute of Technology	Dr.	Thomas B.	Sheridan
27	NASA Ames Research Center	Mr.	Bimal	Aponso
28	NASA Ames Research Center	Mr.	Rudolph	Aquilina
29	NASA Ames Research Center	Dr.	Stephen	Casner
30	NASA Ames Research Center	Dr.	Thomas A.	Edwards
31	NASA Ames Research Center	Dr.	Michael	Feary
32	NASA Ames Research Center	Mr.	Chad	Frost
33	NASA Ames Research Center	Mr.	Michael	Gaunce
34	NASA Ames Research Center	Mr.	Steven	Green
35	NASA Ames Research Center	Dr.	Walter	Johnson
36	NASA Ames Research Center	Dr.	Barbara	Kanki
37	NASA Ames Research Center	Dr.	Parimal	Kopardekar
38	NASA Ames Research Center	Mr.	David	McNally

Count	Affiliation	Title	First Name	Last Name
39	NASA Ames Research Center	Dr.	Richard	Mogford
40	NASA Ames Research Center	Mr.	R. Jay	Shively
41	NASA Ames Research Center	Mr.	Brian	Smith
42	NASA Ames Research Center	Mr.	Barry	Sullivan
43	NASA Ames Research Center	Mr.	Joseph	Totah
44	NASA Ames Research Center	Ms.	Shannon	Zelinski
45	NASA Dryden Flight Research Center	Mr.	Troy A.	Asher
46	NASA Dryden Flight Research Center	Mr.	Barton E.	Henwood
47	NASA Dryden Flight Research Center	Mr.	Mark E.	Pestana
48	NASA Dryden Flight Research Center	Mr.	Denis	Steele
49	NASA Langley Research Center (Remote Attendee)	Ms.	Danette	Allen
50	NASA Langley Research Center	Mr.	Mark	Ballin
51	NASA Langley Research Center (Remote Attendee)	Mr.	Kenneth H.	Goodrich
52	NASA Langley Research Center	Mr.	David A.	Hinton
53	NASA Langley Research Center(Remote Attendee)	Mr.	Paul	Schutte
54	NASA Langley Research Center	Ms.	Anna	Trujillo
55	New Mexico State University	Mr.	Doug	Davis
56	Research Integrations, Inc.	Dr.	Elizabeth A.	Lyall
57	Rockwell Collins, Inc.	Mr.	Kevin	Kronfeld
58	Rockwell Collins, Inc.	Mr.	Sethu R.	Rathinam
59	Rockwell Collins, Inc.	Dr.	Frederick M.	Rudolph
60	San Jose State University Foundation	Mr.	Vernol	Battiste
61	San Jose State University Foundation	Dr.	Dorrit	Billman
62	San Jose State University Foundation	Ms.	Summer	Brandt
63	San Jose State University Foundation	Dr.	Doreen	Comerford
64	San Jose State University Foundation	Mr.	Quang	Dao
65	San Jose State University Foundation	Ms.	Lisa	Fern
66	San Jose State University Foundation	Capt.	Richard	Geven
67	San Jose State University Foundation	Ms.	Caitlin	Kenny
68	San Jose State University Foundation	Capt.	Robert	Koteskey
69	San Jose State University Foundation	Mr.	Josh	Kraut
70	San Jose State University Foundation	Dr.	Joel	Lachter
71	San Jose State University Foundation	Ms.	Sarah	Ligda
72	San Jose State University Foundation	Dr.	Shu-Chieh	Wu
73	SUPAERO/ONERA	Mr.	Sergio	Pizziol
74	United Airlines	Capt.	Andrew	Allen

Appendix D: Agenda that was Disseminated to Confirmed Participants

SPO TIM- AGENDA

Below is the agenda for the Single Pilot Operations Technical Interchange Meeting.

NASA Ames Conference Center (NACC), Building 3
NASA Ames Research Center, Moffett Field

Tuesday, April 10, 2012

9:00 - 9:15	Welcome	Tom Edwards
9:15 - 9:30	Goals	Parimal Kopardekar
9:30 - 10:00	Project Overview and Future Concepts	Ames and Langley SPO Leads
10:00 - 10:15	Break	
10:15 - 11:15	Human-Automation Interaction in Single Pilot Carrier Operations	Tom Sheridan, MIT
11:15 - 11:45	Modeling the Work of the Flight Deck	Amy Pritchett, Georgia Institute of Technology
11:45 - 12:15	Single Pilot Operations: Motivation, Issues, Architectures and Con-Ops	John Hansman, MIT
12:15 - 1:30	Lunch	
1:30 - 2:00	Defining Research Issues for Single Pilot Operations in Transport Aircraft: Why Should We Care About CRM?	Robert Koteskey, San Jose State University
2:00 - 2:30	Establishing Advanced AOC Systems for Single Pilot Operations	Leigh-lu Prasse, ARINC
2:30 - 3:00	Economic Opportunities and Technological Challenges For Reduced Crew Operations	Mike Norman, The Boeing Company
3:00 - 3:15	Break	
3:15 - 3:45	Single Pilot Operations: Automation Considerations	Sethu Rathinam, Rockwell Collins
3:45 - 4:15	The FAA Transport Airplane Directorate Perspective on Single Pilot Transports	Steve Boyd, FAA

4:15 - 4:45	NextGen and the Single Pilot	Greg Potter, Cessna Aircraft Company
4:45 - 5:00	Wrap-up	Ames and Langley SPO Leads
6:00 - 8:00	Dinner at Tied House	

Wednesday, April 11, 2012

9:00 - 9:30	Instructions for Breakout Sessions	(Ballroom)
9:30 - 12:30	Breakout Session #1	(Assigned Breakout Room)
12:30 - 1:30	Lunch	
1:30 - 4:30	Breakout Session #2	(Assigned Breakout Room)
4:30 - 5:00	Wrap up	(Ballroom)

Thursday, April 12, 2012

9:00 - 9:30	Instructions for Discussion
9:30 - 10:00	Group 1 Report
10:00 - 10:30	Group 2 Report
10:30 - 11:00	Break
11:00 - 11:30	Group 3 Report
11:30 - 12:00	Group 4 Report
12:00 - 12:30	Wrap-up and Adjourn
1:30 - 2:00	Lab Tour (optional)

(Johnson) Slide 1

(Johnson) Slide 2

(Johnson) Slide 3

(Johnson) Slide 4

(Johnson) Slide 5

Goal of this Meeting

Develop a set of critical research issues that can be used to inform the planning for a 2-5 year research effort examining the feasibility of a move from two-pilot to single-pilot flight decks

NASA

Single Pilot Operations - *Technical Interchange Meeting*

(Johnson) Slide 6
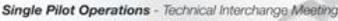
Two Potential Paths

Flight Deck Automation: In the future we will have a flight deck with very intelligent automation that can effectively replace the functions of the First Officer

Ground-Based Support: In the future we will be relying much more extensively on air-ground collaboration, with many of the First Officer functions being handled remotely

NASA

Single Pilot Operations - *Technical Interchange Meeting*

(Johnson) Slide 7
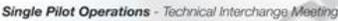
Some Issues to Consider for SPO

The proposed time frame is post-NextGen (20-30 years out), although we might expect nearer term benefits.
- Trajectory Operations
- Predicted Weather
- Flight Deck Managed Spacing
- Delegated Separation Management
- DataCom
- Higher degrees of air-ground integration
- Optimized Profile Descents
- UAVs
- Advances to automation

NASA   *Single Pilot Operations* - *Technical Interchange Meeting*

(Johnson) Slide 8
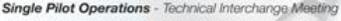
Some Issues to Consider

The advent of UAVs should have us considering not only the impact of removing a pilot from an otherwise two person flight deck, but also the value of leaving a pilot on the flight deck

NASA   *Single Pilot Operations* - *Technical Interchange Meeting*

(Johnson) Slide 9
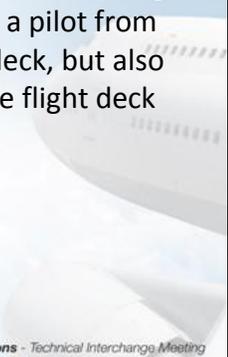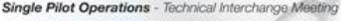
Barriers to SPO

Barriers
- Perceived and actual reduction in safety
- Increased pilot workload
- Reduced ability to handle off-nominal events

New Requirements
- Smarter advanced automation
- Improved coordination/collaboration
  – With both remote people and automation

Single Pilot Operations - Technical Interchange Meeting

(Johnson) Slide 10

Tuesday Agenda

Time	Topic	Speaker
9:00 – 9:15	Welcome	Tom Edwards
9:15 – 9:30	Goals	Parimal Kopardekar
9:30 – 10:00	Project Overview and Future Concepts	Ames and Langley SPO Leads
10:00 – 10:15	Break	
10:15 – 11:15	Human-Automation Interaction in Single Pilot Carrier Operations	Tom Sheridan, MIT
11:15 – 11:45	Modeling the Work of the Flightdeck	Amy Pritchett, Georgia Institute of Technology
11:45 – 12:15	Single Pilot Operations: Motivation, Issues, Architectures and Con-Ops	John Hansman, MIT
12:15 – 1:30	Lunch	
1:30 – 2:00	Defining Research Issues for Single Pilot Operations in Transport Aircraft: Why Should We Care About CRM?	Rob Koteskey, San Jose State University
2:00 – 2:30	Establishing Advanced AOC Systems for Single Pilot Operations	Leigh-lu Prasse, ARINC
2:30 – 3:00	Economic Opportunities and Technological Challenges For Reduced Crew Operations	Mike Norman, The Boeing Company
3:00 – 3:15	Break	
3:15 – 3:45	Single Pilot Operations: Automation Considerations	Sethu Rathinam, Rockwell Collins
3:45 – 4:15	The FAA Transport Airplane Directorate Perspective on Single Pilot Transports	Steve Boyd, FAA
4:15 – 4:45	NextGen and the Single Pilot	Greg Potter, Cessna Aircraft Company
4:45 – 5:00	Wrap Up	Ames and Langley SPO Leads
5:00 – 6:00	Break	
6:00 – 8:00	Dinner at Tied House	

Single Pilot Operations - Technical Interchange Meeting

1 of 2

(Sheridan) Slide 1

**Human-Automation Interaction
in Single Pilot Carrier Operation**

Tom Sheridan
MIT

(Sheridan) Slide 2

Of course techologically it <u>can</u> been done. <u>Should</u> it?

• Long history of GA single pilot operations, including
   some aircraft as large as 19 passengers (e.g BE 1900)

• Allegedly Sullenberger handled all tasks in the
   Hudson River ditching

• Embraer is designing aircraft for single pilot operations
   in the 2020-2025 timeframe

(Sheridan) Slide 3

Arguments against Singe Pilot Operations

- Unacceptable to flying public?

- Too much faith in automation and communication
 reliability?

- Won't save money; just moves people to the ground?

(Sheridan) Slide 4

Different types of challenges

A1. Add routine tasks of pilot-not-flying to those of pilot-flying:
 increased workload

A2. Substitute ground-based human to be second pair of eyes
and hands: attention and communication issues

B1. Take over control in case of single plot incapacitation - **benign**

B2. Take over control in case of single pilot incapacitation - **conflict**
(e.g., Jet Blue 191 JFK to LAS A320 with no other on-board pilot)

C1. Cope with on-board automation failure

C2. Cope with communication or ground-based automation failure:
need for redundant and non-overlapping channels

(Sheridan) Slide 5

Agents and variables in single pilot operation

4D flight plan   FAA rules

Air traffic control

- Aircraft
- Phase of flight
- Weather
- Traffic
- Emergency?

Pilot

Ground agent(s)

- What is authorized?
- What is accepted?
- What is contested?

Automation

Situation

(Sheridan) Slide 6
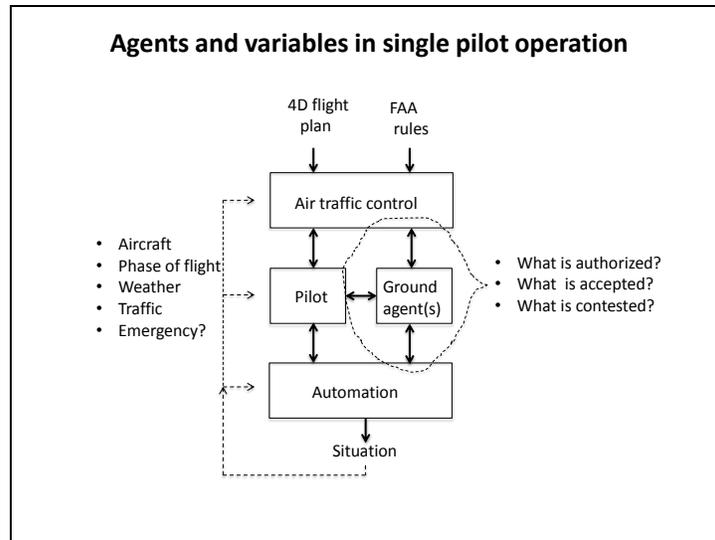
Task assignment to ground controller /automation

	TRADE CONTROL	SHARE CONTOL
COOPERATE	• All tasks reassigned • Pilot initiated	• Selected tasks reassigned • Pilot initiated
CONFRONT	• All tasks reassigned • Ground or automation initiated	• Selected tasks reassigned • Ground or automation initiated

(Sheridan) Slide 7

Tasks of human agent on the ground

1. CONCERNED ONLY WITH tasks of PILOT-NOT-FLYING?
- Shared by ~5 other aircraft
- Capability to hand off to other ground agent if get too busy

or…

2. COMBINED WITH tasks of REGULAR CONTROLLER?

Also…

Any tasks for human staff agent on-board?

(Sheridan) Slide 8

Teamwork: What does it take for humans and computers to "cooperate"?

- If their goals are different there will surely be conflict (as clearly demonstrated in control theory).

- They must also be continually giving feedback to one another to stay synchronized.

- A big challenge is how to measure and model the intentions and adaptive behavior of the human so that the computer can "understand."

How much information is too much information for a user to assimilate and utilize in the available time?

- There is a limit on how fast human can absorb information and decide what is relevant.

- Human response times follow a lognormal distribution, meaning some fraction of responses may take a very long time.
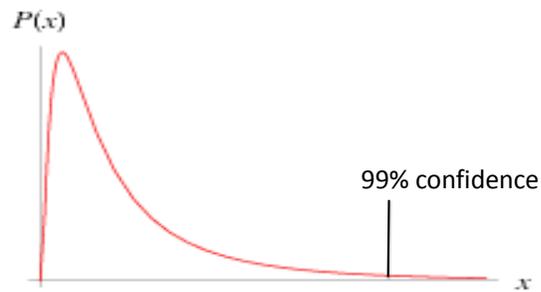
Lognormal distribution. Exact shape depends upon σ. P(log x) would be normally distributed.

(Sheridan) Slide 11

Flying alone can be boring, so

- Increase communication with human controller on ground beyond nominal tasks?

- Allow communication with a designated on-board staff person?

(Sheridan) Slide 12

Human-centered automation: Should humans always be in charge?

- Not when the designated human is inattentive.

- Not when there is no time for a human to respond (even though attentive).

- And not when the human does not have the knowledge on how to manage responsibly.

- ABILITY > AUTHORITY > CONTROL > RESPONSIBILITY

(Sheridan) Slide 13

How smart and how useful can we expect decision support tools and automation to be?

- Human may have unrealistic expectations of what given decision support tools know or what automation can do (experience, training, trust).

- Using decision support tools takes time, and if time is critical it may be best to act on experience and intuition.

(Sheridan) Slide 14

DARPA PILOT'S ASSOCIATE, CIRCA 2004

- Infer from detected actions the intent of the pilot and communicate these intentions to the other subsystems,

- Model the current pilot workload in order to adapt the behavior of the information presentation and aiding subsystems,

- Configure cockpit displays and controls to present the most important information in the most effective manner,

- Assist the pilot by performing actions approved for the PA to implement,

- Identify and compensate for pilot actions that might result in errors with serious consequences, and

- Provide the interface between the pilot and planners by managing and presenting proposed plans, allowing the pilot to accept or reject proposals, proposing alternatives where appropriate, and removing proposals when the were no longer appropriate.

(Sheridan) Slide 15

Who is in charge what when?

(Sheridan) Slide 16
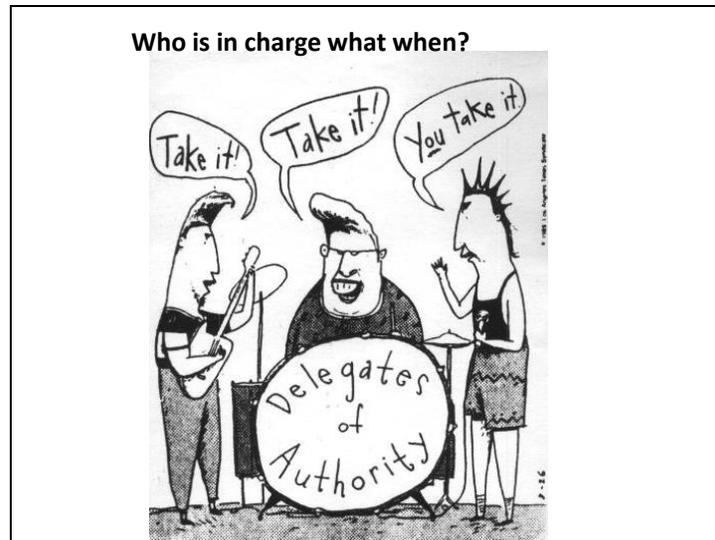
Should or can authority (how control is enabled) and responsibility (accountability in case of failure) always go together? Complicating factors are:

- In modern organizations both authority and responsibility tend to be shared vertically.

- Human users become dependent upon automation and decision support tools. Can automation be held responsible?

- Difficult to pinpoint a specific locus of human input (design, manufacture, installation, maintenance, training, operation).

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(Sheridan) Slide 17

A Scale of Levels of Automation

1. Computer offers no assistance; human must do it all.
2. Computer suggests many alternative ways to do the task.
3. Computer narrows set of alternatives to just a few.
3. Computer recommends one way to do the task.
4. Computer executes that recommendation when and if human approves.
5. Computer allows human a restricted time to veto before automatic execution.
6. Computer chooses a method, executes, and necessarily informs human.
7. Computer chooses a method, executes, and informs human only if requested.
8. Computer chooses a method, executes, and ignores the human.

(Sheridan) Slide 18

Modes of supervisory control/adaptive automation

α = automatic braking in response to lead vehicle deceleration
β = automatic lane change prevention when vehicle coming in new lane

"Authority and responsibility in human–machine systems: probability theoretic validation of machine-initiated trading of authority"
Toshiyuki Inagaki and Thomas B. Sheridan
Cognition, Technology and Work, Vol. 14, No.1, March 2012

DERIVED CONTINGENT PROBABILITY EQUATIONS where
U=unsafe, S=safe PARTICULAR SITUATION,
NA=no action, A=action BY PILOT
w=warning, a=computer intervention; "…" means "computer said"

$$P_{\mathrm{w}}(\text{accident prevention}|U, \mathrm{NA}) = P(\text{"}U\text{"}|U)\, P(\text{"}\mathrm{NA}\text{"}|\mathrm{NA})\, P(\mathrm{IA}|\text{warning})$$

$$P_{\mathrm{w}}(\text{unnecessary warning}|U, A) = P(\text{"}U\text{"}|U)\, P(\text{"}\mathrm{NA}\text{"}|A).$$

$$P_{\mathrm{w}}(\text{inappropriate warning}|S, \mathrm{NA}) = P(\text{"}U\text{"}|S)\, P(\text{"}\mathrm{NA}\text{"}|\mathrm{NA}).$$

$$P_{\mathrm{a}}(\text{accident prevention}|U, \mathrm{NA}) = P(\text{"}U\text{"}|U)\, P(\text{"}\mathrm{NA}\text{"}|\mathrm{NA})$$

$$P_{\mathrm{a}}(\text{unnecessary automatic braking}|U, A) = P(\text{"}U\text{"}|U)\, P(\text{"}\mathrm{NA}\text{"}|A).$$

$$P_{\mathrm{a}}(\text{inappropriate automatic braking}|S, \mathrm{NA}) = P(\text{"}U\text{"}|S)\, P(\text{"}\mathrm{NA}\text{"}|\mathrm{NA}).$$

(Sheridan) Slide 21

Designing for surprise: What are the tradeoffs?

- Preparation for any contingency is good, but how much to spend on preparation?

- A most conservative criterion, to be prepared for the worst case, is too conservative. But an expected value criterion (probability times cost) is too liberal.

(Sheridan) Slide 22

History of Pilot Models

Pilot as servomechanism: analytic models
using differential equations of control theory
- Simple crossover model (McRuer, Krendel, Jex)
- Optimal control, internal model (Baron, Kleinman, Levison)

Pilot as cognitive agent (supervisor of automation, flight manager) using rule-based computer simulation
- ACT-R (Johnson-Laird et al)
- Air Midas (Corker et al)
- D-OMAR (Deutsch and Pew)

Foyle and Hooey: challenge of model credibility with increasing complexity and pace of change

(Sheridan) Slide 23

Experiment with successively more challenging platforms

- Fast-time models

- Human-in-the loop simulations

- Flight trials with SPO-certified GA passenger jets

- Trials by express mail carriers

- Trials by short haul passenger carriers

(Sheridan) Slide 24

Development of "automation policy" to guide design, operation and management of highly automated systems

Specify:
- Specific responsibilities of humans in specific situations.

- Who or what will be held responsible for which kinds of failures.

- What kinds of evidence are admissible in making such judgments.

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Single Pilot Operation: Which will it be?

(Pritchett) Slide 1

(Pritchett) Slide 2

(Pritchett) Slide 3

(Pritchett) Slide 4

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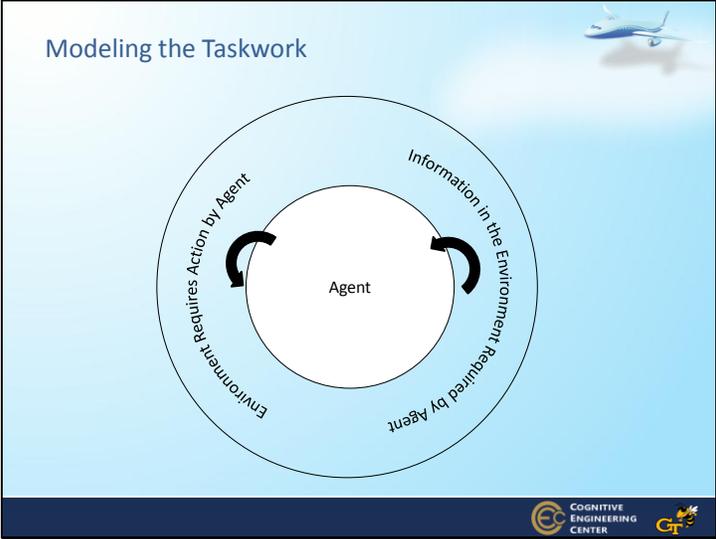
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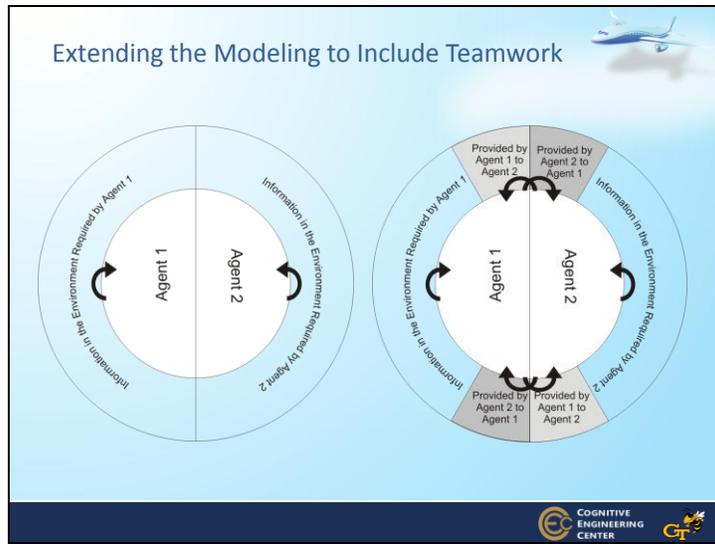
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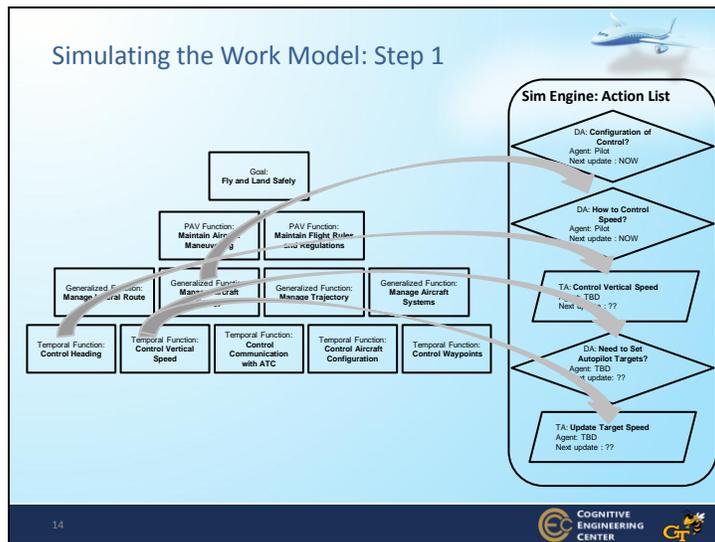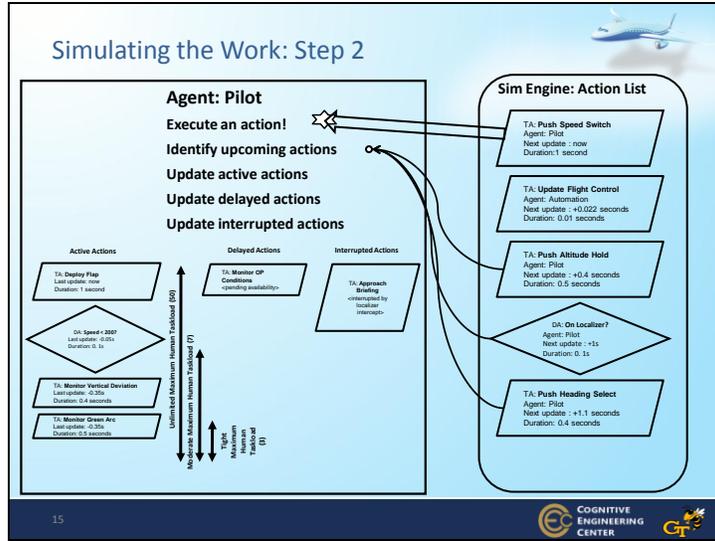
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(Pritchett) Slide 21

E.4. Dr. R. John Hansman's Presentation Slides

(Hansman) Slide 1

(Hansman) Slide 2

(Hansman) Slide 3

(Hansman) Slide 4

(Hansman) Slide 5

(Hansman) Slide 6

(Hansman) Slide 7

Air Carrier Crew Trends

- **Crew of 5**
  - **Captain, First Officer, Flight Engineer, Navigator, Radio Operator**
- **4 - Radio Operator (1950s)**
  - Tuned Radios, SELCAL, Satellite Communication
- **3 – Navigator (1970s)**
  - IRS, Area Navigation, Satellite Navigation
- **2 - Flight Engineer (1980s)**
  - Systems Simplification
  - Engine Indication and Crew Alerting Systems (EICAS)
- **1 ? First Officer**
  - Ground Decision Support, Cabin Crew Backup
- **0 ? Captain**
  - Cargo or Passenger Carrying UAV's?

7

(Hansman) Slide 8

Accident Rates by Airplane Type
Hull Loss Accidents – Worldwide Commercial Jet Fleet – 1959 Through 2010

Sorted by Year of Introduction	Hull Losses (HL)	HL with Fatalities	Rate
*No longer in service	99	53	4.64/8.68
707/720	152	74	4.27/8.78
DC-8	75	51	4.01/5.90
727	91	52	0.68/1.19
DC-9	91	49	0.78/1.46
BAC 1-11	27	12	1.40/3.15
737-100/-200	98	49	0.85/1.70
F-28	43	22	2.38/4.66
747-100/-200/-300/SP	35	19	1.47/2.71
DC-10/MD-10	28	12	1.33/3.10
L-1011	4	3	0.56/0.75
A300	14	4	0.62/2.17
MD-80/-90	24	13	0.31/0.57
767	6	2	0.13/0.38
757	5	5	0.24/0.24
BAe146, RJ-70/-85/-100	12	7	0.68/1.17
A310	10	8	1.76/2.20
737-300/-400/-500	35	19	0.28/0.52
A300-600	5	3	0.55/0.92
A320/321/319/318	18	11	0.20/0.33
F-100/F-70	10	3	0.31/1.03
747-400	4	2	0.31/0.62
MD-11	8	5	2.30/3.69
A340	2	0	0/0.87
A330	2	2	0.46/0.46
777	1	0	0/0.18
737-600/-700/-800/-900	10	6	0.18/0.30
717	0	0	0/0
CRJ-700/-900/-1000	0	0	0/0
EMB-170/-190	2	1	0.26/0.52
**A380	0	0	0/0
Total	911	487	0.83/1.55

3 Crew

Hull loss accident rate – total bar
Hull loss with fatalities accident rate – lighter shaded portion

* The Comet, CV880/990, Caravelle, Concorde, Mercure, Trident and VC-10 are no longer in commercial service.
**These types have accumulated fewer than 1 million departures.

Hull loss accident rate per million departures

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2010 STATISTICAL SUMMARY, JUNE 2011

BOEING

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(Hansman) Slide 9

(Hansman) Slide 10

(Hansman) Slide 11

(Hansman) Slide 12

(Hansman) Slide 13

Reliability Architectures

- **Failure Modes and Effects Analysis**
- **Avoid Single String Failure**
  - Cannot guarantee 10E-9
- **Fail Safe, Fail Operational**
- **Redundancy Architectures**
  - Dual Redundant for Passive Failures
    - e.g. Wing Spar
  - Triple Redundancy for Active Systems
    - 777 Fly By Wire
      - Sensors
      - Processors
      - Actuators
      - Data Bus

(Hansman) Slide 14

B777 Avionics Architecture

(Hansman) Slide 15

Functional Requirements for Dual Crew

- **Failure Mode Based**
  - Physical
    - Crewmember incapacitation rate historically around 1/month
  - Judgment
-

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(Hansman) Slide 16

Rate of Crew Incapacitation

- **US had 47 events (flights) between 1983 and 1988**
  - CAMI Repot "In-Flight Medical Impairment of US Airline Pilots: 1993-1998", DeJohn, Wolbrink, Larcher
  - 39 incapacitations, 11 impairments, 3 cases of multiple crew members
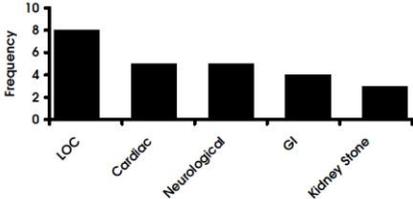
Figure 3. Frequent categories of in-flight medical incapacitation.

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(Hansman) Slide 17

Recent JetBlue Event

(Hansman) Slide 18

Functional Requirements for Dual Crew

- **Failure Modes**
  - Physical
    - Crewmember incapacitation rate historically around 1/month
  - Judgment

- **Strength Based**
  - Hydraulic Failure

- **Task Based**
  - Degraded mode operations (eg pressurization failure)
  - High density airspace
  - Diversions
  - Passenger in-flight emergency
  - Inspection
  - Evacuation
  - Toilet

(Hansman) Slide 19

**Redundancy Architectures
Part 121**

- **Judgment Redundancy**
  - Virtual Co-Pilot - Enhanced Dispatch
    – Comm and Surveillance Systems Support Real-Time
      Interaction Over Most of the World (need Bandwidth)

- **Physical Redundancy**
  - Flight Attendant – Backup Pilot
    – Re-think cockpit doors
  - Automated Backup
    – Optionally Piloted Vehicle
  - Ground Based Backup
    – Remotely Piloted Vehicle
    – Drives Comm Security Standard

(Hansman) Slide 20

Redundancy Architectures

(Hansman) Slide 21

Optionally Piloted Vehicles

- **Aurora Centaur OPA**

(Hansman) Slide 22

**Redundancy Architectures
Part 91**

- **Judgment Redundancy**
  - GA Dispatch Services (cost, liability)
  - In Flight Dispatch, Decision Support Services
  - Cockpit Decision Support Systems
    – Virtual Flight Instructor
    – "Do you really want to do that Dave?"

- **Physical Redundancy**
  - Untrained Passenger
    – Simplified Flight Mode
  - Automated Backup
    – Optionally Piloted Vehicle
    – Emergency Landing Capability (eg Seigel)
  - Ground Based Backup (cost)

(Hansman) Slide 23

(Hansman) Slide 24

(Hansman) Slide 25

(Hansman) Slide 26

Fatalities by CAST/ICAO Common Taxonomy Team (CICTT) Aviation Occurrence Categories
Fatal Accidents – Worldwide Commercial Jet Fleet – 2001 Through 2010

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(Koteskey) Slide 1

(Koteskey) Slide 2

(Koteskey) Slide 3

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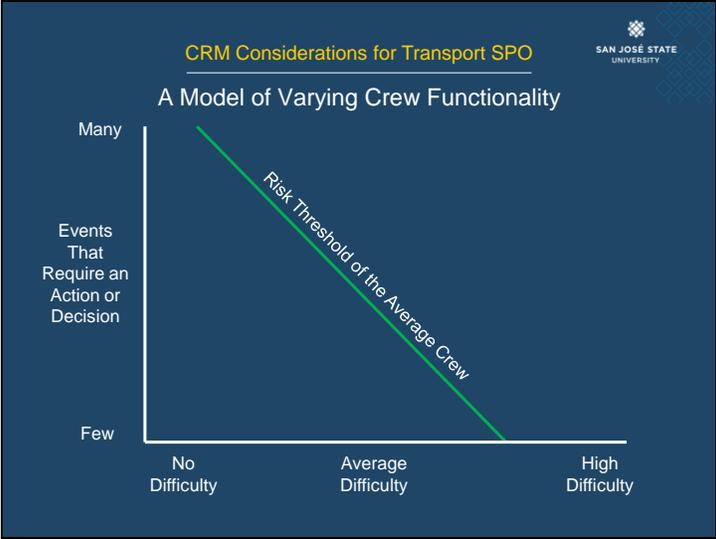
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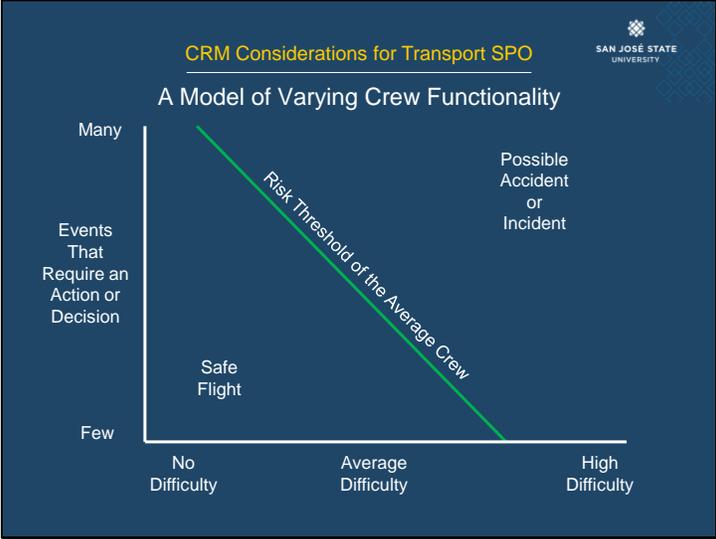
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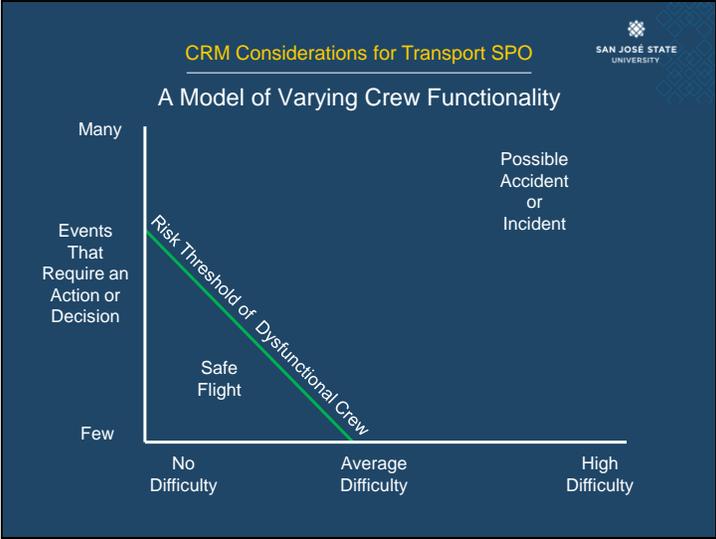
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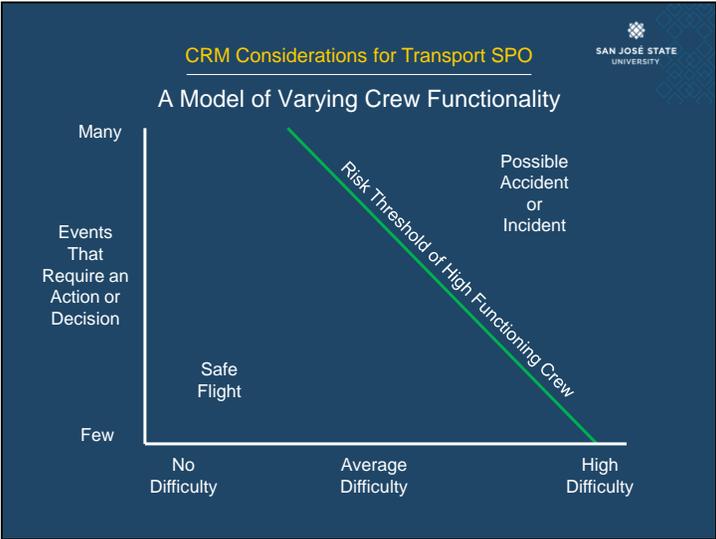
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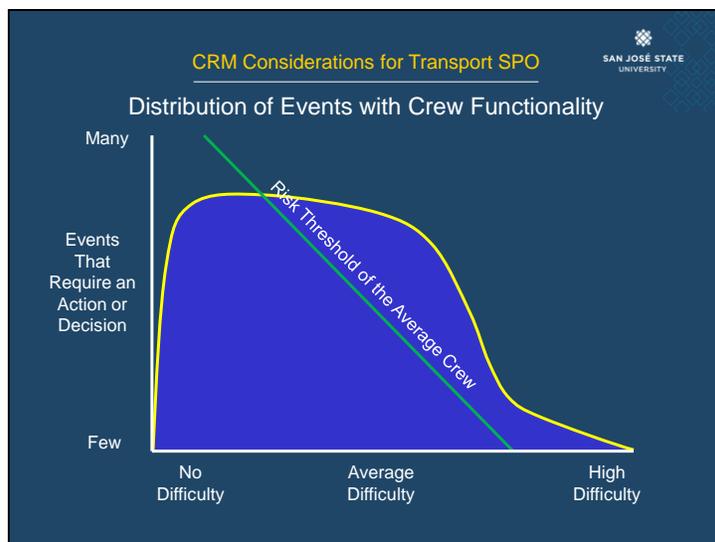
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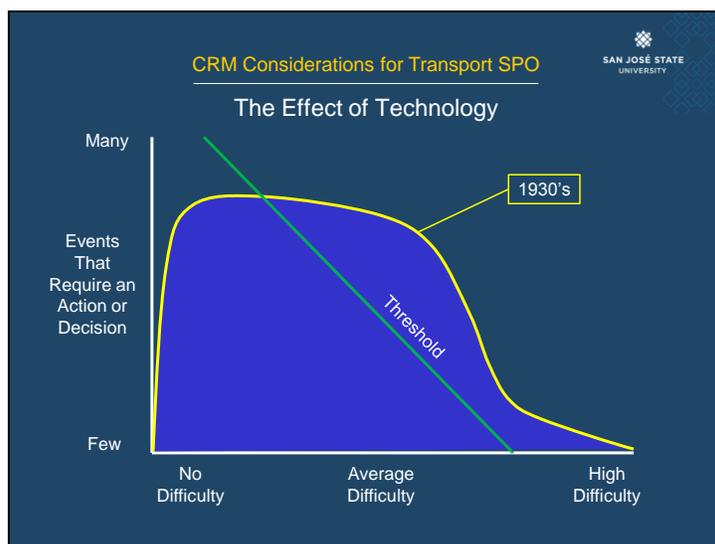
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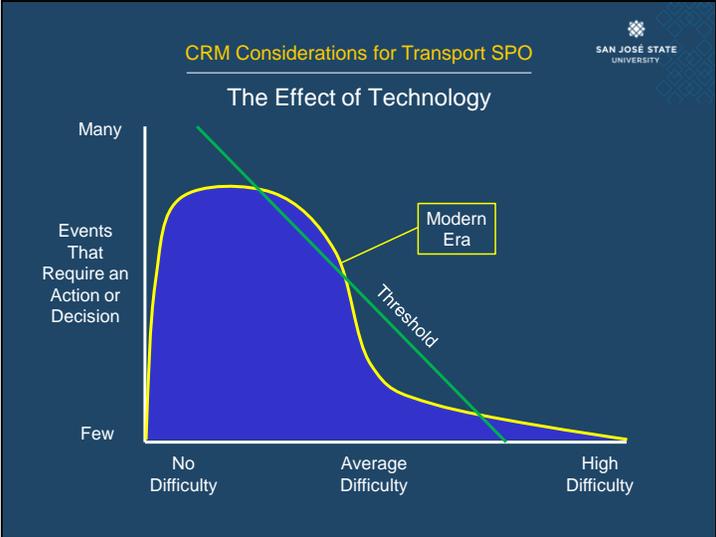
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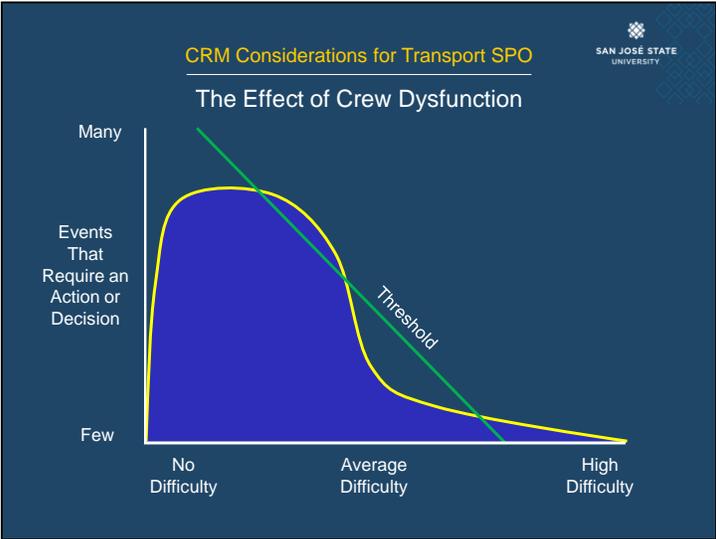
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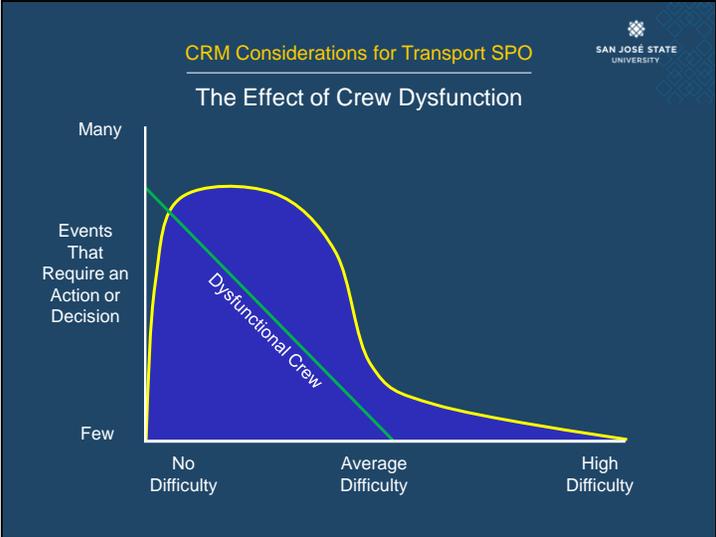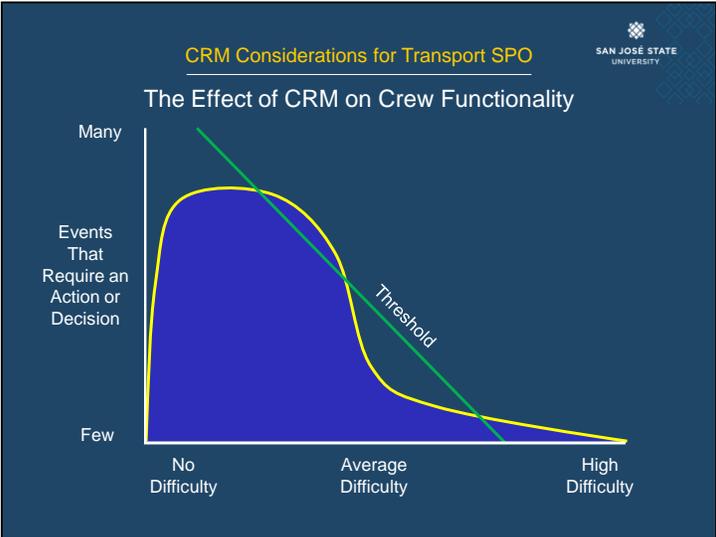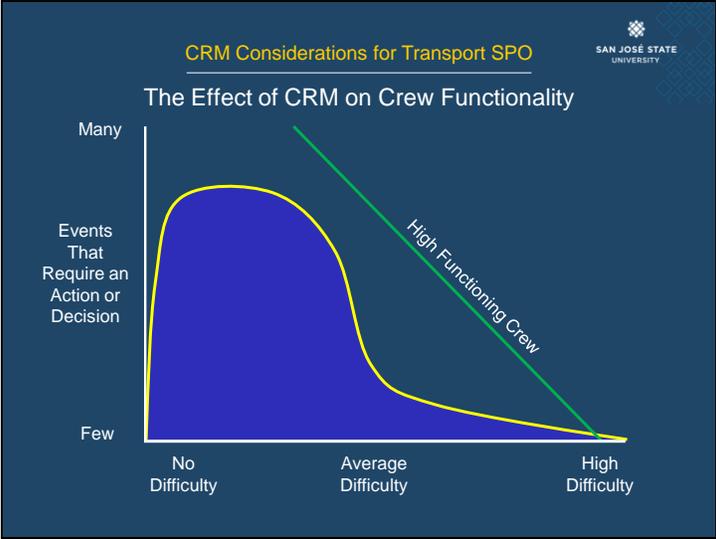
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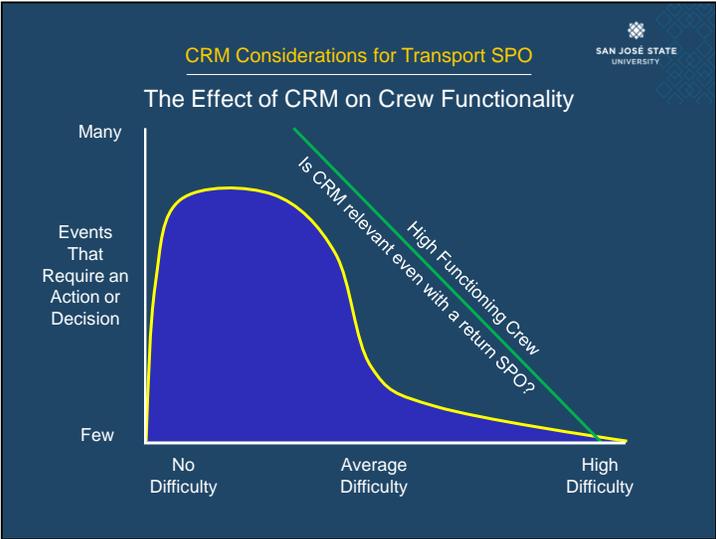
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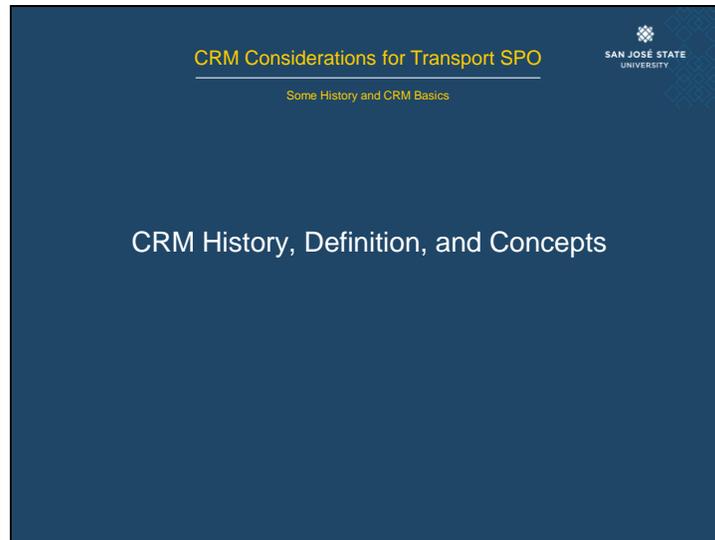
CRM Considerations for Transport SPO
Some History and CRM Basics
SAN JOSÉ STATE UNIVERSITY

CRM History, Definition, and Concepts

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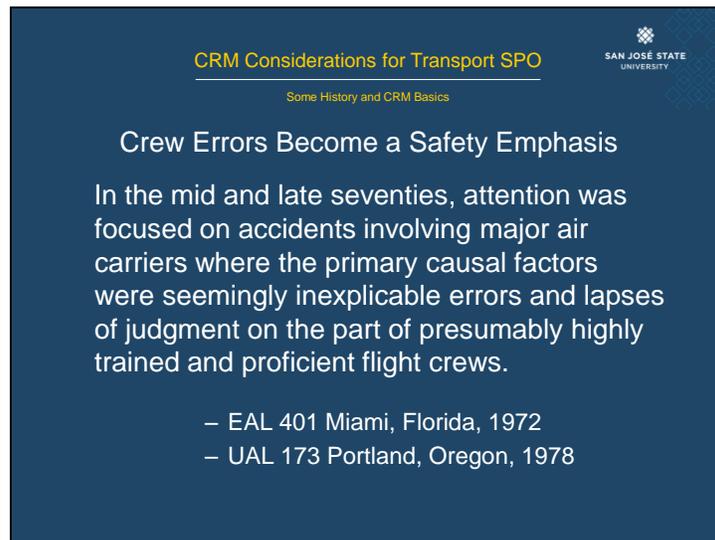
CRM Considerations for Transport SPO
Some History and CRM Basics
SAN JOSÉ STATE UNIVERSITY

Crew Errors Become a Safety Emphasis

In the mid and late seventies, attention was focused on accidents involving major air carriers where the primary causal factors were seemingly inexplicable errors and lapses of judgment on the part of presumably highly trained and proficient flight crews.

– EAL 401 Miami, Florida, 1972
– UAL 173 Portland, Oregon, 1978

(Koteskey) Slide 35

(Koteskey) Slide 36

(Koteskey) Slide 37

(Koteskey) Slide 38

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(Koteskey) Slide 39

(Koteskey) Slide 40

(Koteskey) Slide 41

CRM Considerations for Transport SPO
Some History and CRM Basics

The Basics:

• Commonly Trained CRM Skills

• Threat and Error Management

(Koteskey) Slide 42

CRM Considerations for Transport SPO
Some History and CRM Basics

Commonly Trained CRM Skills

• Decision making
• Adaptability / Flexibility
• Mission Analysis
• Monitoring and Correcting
• Communication
• Leadership
• Assertiveness
• Situation Awareness

(Koteskey) Slide 43

(Koteskey) Slide 44

(Koteskey) Slide 45

(Koteskey) Slide 46

(Koteskey) Slide 47

CRM Considerations for Transport SPO

Some History and CRM Basics

The duties and responsibilities of managing the "project" of getting an airline flight safely planned, flown, and recovered, are most of what pilots do every day.

They do this as part of, and in concert with, a complex web of teams.

(Koteskey) Slide 48

CRM Considerations for Transport SPO

Some History and CRM Basics

CRM research and training has embraced this philosophy and may provide some rich insight as we begin to explore SPO for transport aircraft.

(Koteskey) Slide 49

(Koteskey) Slide 50

(Koteskey) Slide 51

(Koteskey) Slide 52

(Koteskey) Slide 53

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(Koteskey) Slide 55

(Koteskey) Slide 56

(Koteskey) Slide 57

(Koteskey) Slide 58

(Koteskey) Slide 59

(Koteskey) Slide 60

(Prasse) Slide 1

(Prasse) Slide 2

(Prasse) Slide 3

ACARS – A Communications Breakthrough for Aviation Spurs Change in the 3-Man Crew

- The Aircraft Communications Addressing and Reporting System (ACARS) was developed by ARINC as a solution for saturated voice channels and to expand system capacity for ATC.

- Following test phases and trials in 1967, the FAA decided that "*general-purpose data link had no near-term ATC applications*". [1]

Thus, ACARS was shelved until…

(Prasse) Slide 4

ACARS and the 2-Man Crew

- Launch Customer – Piedmont Airlines 1978

- Piedmont known in the industry as forward-thinking and innovative with leading edge technology (e.g., first to use TCAS) , explored ideas on how to realize savings by operating the B737 with a two-man crew. [2]

- FAA would not certify Piedmont for two-man operations unless the airline demonstrated continuous "*reliable and rapid communications*" in FAR 121.99 so Piedmont asked ARINC for a designated network.

(Prasse) Slide 5

(Prasse) Slide 6

(Prasse) Slide 7

SPO and the Air Carrier

- There are many types of operations within the air carrier to examine concerning SPO:
  - Aircraft Automated Systems and Performance
  - Flight Operations and Pilot Requirements,
  - Maintenance Operations Control Center (MOCC)
  - System Operations Control Center (SOCC),
    - **Aeronautical Operational Control (AOC) and the dispatcher**
- This presentation will narrow approach to SPO and focus on AOC and the dispatcher, applying criteria already established today in ATM performance-based standards.

(Prasse) Slide 8

Required Total System Performance (RTSP)

- RTSP – Performance-based standards that pertain to Air Traffic Management (ATM) [4]

- Originally attributed to **Required Navigation Performance (RNP)**
  - Performance-based navigation (PBN) has been applied to oceanic separation criteria such as RNP10 or RNP4 [5]

- RTSP incorporates all functions of CNS/ATM: (Communications/Navigation/Surveillance in ATM)

  Required Communications Performance (RCP)
  Required Navigation Performance (RNP)
  Required Surveillance Performance (RSP)

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(Prasse) Slide 9

Required SPO Systems & Performance (RSSP)

In order to standardize requirements for SPO the following might be considered:

RSSP – Required SPO Systems and Performance

Develop the criteria to establish the standards required for SPO operating within a whole system from the air carrier to air traffic control.

RSSP areas to be considered: Technology
Procedures
Organizational
Human Factors
Security

(Prasse) Slide 10

Two Possibilities for SPO Operations

1. **Use of Unmanned Aircraft Systems (UAS) technology with remotely piloted operations to back-up SPO**
2. **Advanced AOC without a remotely piloted back-up UAS**

(Prasse) Slide 11

SPO Supported by UAS Operations

Technology in place today that can enable a systems safety back-up to Single Pilot Operations with a UAS. Flights eventually can be fully autonomous and fly a programmed profile from A to B with the SPO as the primary monitor.

Definitions:

Unmanned Aircraft System (UAS) – FAA term that reflects all the complex systems associated with the UAV such as the ground stations involved in the process.   The UAS operations must be compliant with the same regulations and procedures of flights operated with a crew on board.

Optionally Piloted Aircraft (OPA) – FAA term for an aircraft that is being controlled from the ground even when there is a pilot on board.

(Prasse) Slide 12

However...

The future of SPO with an UAS in commercial aviation is foreseeable and would be the safest option but have the highest costs.

Are the inherent risks (with one highly trained pilot who must undergo additional physical and mental health screening plus computer proficiency in addition to airmanship proficiency) manageable to fly without a UAS?

(Prasse) Slide 13

(Prasse) Slide 14

(Prasse) Slide 15

(Prasse) Slide 16

(Prasse) Slide 17

(Prasse) Slide 18

(Prasse) Slide 19

Required Performance Applications with Data Link (8)

Enroute Separation: 5NM DL
Navigation: RNAV/RNP1
Surveillance: Radar or
     ADS–B with Mode S
     (60 times a second)
Communication:
     VDL Mode 2 support
     ACARS/CPDLC/ATN2
        RCP10/V
        RCP/120D

- 50/50 or 30/30 w/ATOP
- RNP10 or RNP4
- ADS–C RSP180
     periodic rate 27mins
     periodic rate 14mins

- RCP400/V + RCP240D

Future Domestic Airspace	Oceanic Airspace w/ATOP

(Prasse) Slide 20

Automatic Dependent Surveillance – Broadcast (ADS–B) with Mode S (9)

- Automatically transmits position & velocity vector from GPS or FMS on the aircraft to other ADS–B equipped stations.
- Implementation in Domestic Airspace will update position once every second – 60 times per minutes vs. radar once every 5–7 seconds

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(Prasse) Slide 21
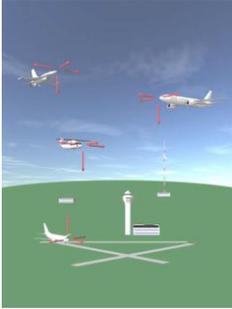
Final Thoughts

- Advanced AOC Systems would significantly save in crew costs by enabling a SPO and require the dispatcher to assume a higher degree of responsibility as a controller and co-pilot.
- Advanced AOC Systems will enhance operational efficiency while reducing human error.
- Implement Required SPO Systems and Performance (RSSP) to establish SPO framework and coordinate world-wide into a seamless global system .
- Performanced-Based criteria in Communications & Surveillance will be the guidelines for approving SPO with such mediums as CDDLC, DPDLC and similar systems to Ocean21.

(Prasse) Slide 22

Establishing Advanced AOC Systems for Single Pilot Operations

Questions?

(Prasse) Slide 23

(Prasse) Slide 24

Notes from slides cont.

- **Slide 15**: **3–Way Communication.** Currently dispatcher does communicate through company data link systems to flight but not with RCP standards. CPDLC in the U.S. is routed by ARINC or SITA through the NADIN network. If a flight can send a message to a controller directly, there is no reason why a dispatcher should not be able to do the same. Currently performance groups, such as the Performanced–Based Aviation Rule–Making Committee – Communications Work Group (PARC CWG) are shaping communication standards with ICAO guidance material Global Operational Data Link (GOLD) and new documents such as Satellite Voice Guidance Material (SVGM). Some trials underway with new SATCOM using Iridium Data Link – FANS 1/A over Iridium (FOI) are with Cargo Lux, Continental (now United), Hawaiian, and UPS. The benefits of Iridium are a lower cost solution to Inmarsat, draws less power on the aircraft, lighter in weight, and has global coverage including the polar regions.

- **Slide 16**: **Surveillance.** Ocean21 here shows the ADS–C reports presented to a controller's situation display as flight data blocks to provide enhanced situational awareness and the potential for reduced separation. On the left are the electronic flight strips and other ATM functions such as Automatic conflict probe, Trajectory conformance monitoring, ADS–C, ADS–B, CPDLC, Micro–EARTS (Microprocessor–based enroute automated radar tracking system, and Traffic–load monitoring. Ocean21 by Lockheed is not the only design out there although it was the one that won the contract with the FAA for Oceanic ATM. Other companies have similar prototypes such as ARINC, SABRE, Boeing, Flight Explorer, Jeppessen, and more. And worth mentioning are the systems, some most likely by Raytheon, for the UAS operations that we don't know about.

- **Slide 17**: Issues: How many SPO flights are safely controlled by the dispatcher at one time?
  Are SPO flights mixed in with a dispatcher's other fights in the airline's system?

- **Slide 18**: ATOP – Advance Technologies and Oceanic Procedures, used with Ocean21 by Oakland, Anchorage and NYC Oceanic Centers. VHF Data Link (VDL) Mode 2 – digital data link for CPDLC. Single European Sky rule requires all new aircraft flying in Europe to be CPDLC compliant after Jan. 1, 2014 with Aeronautical Telecommunications Network (ATN) 2 standard.
  Oceanic RTSP: RNP10 – 50/50nm lateral separation criteria RCP 400 with ADS–C 27mins periodic rate. RNP4 – 30/30nm lateral separation criteria with RCP240 with ADS–C 14 mins periodic rate – CPDLC must be received within 210 seconds 95% of the time and 240 seconds 99.95 of the time. ADS –C RSP180 – position of aircraft must be received within 90 seconds 95% of the time and within 180 seconds 99.9% of the time.

- **Slide 19:** FAA deadline to have the U.S. ADS–B equipped by 2013 and all aircraft equipped with ADS–B OUT by 2020. However, in order for ADS–B to realize it's full potential, operators will need to equip sooner than 2020. Australia, the leader in ADS–B deployment, has continent–wide coverage of it's enroute airspace and in the process of determining how to proceed with ADS–B for lower altitudes.
  VDL Mode 4 – enables data link with ground stations and other aircraft. Trials in Europe with ADS–B and VDL Mode 4 underway.

Notes from slides cont.

- **Slide 20**: Single Pilot Operations (SPO) are not new – what is new is applying it to Commercial Aviation and large jet transport that will interface within the National Airspace. SPO may possibly be just a stepping–stone to a Commercial Unmanned Aerial Systems (UAS) – a topic that the FAA currently is requesting public input on selection for 6 UAS test sites to collect data for a safe civilian UAS integration into the NAS.
  And this integration is actually already happening as with the Global Hawk flights flying above the Pacific track system. One pilot recently enroute to Hawaii relayed that a voice came up on their VHF Guard 121.5 "Any Station, Any Station – this is Global Hawk123 (actual callsign omitted here) descending from above F600 down to F450 due operational necessity." The pilots were then simply amazed to see the contrails of the flight and the Global Hawk just above them – so close as a matter of fact that they took pictures. There was no loss of separation but they expressed how astounding it was to see this unmanned aircraft in their airspace and to hear a human voice on their radio from a pilot transmitting on the ground! It is this advanced technology in use today – the automation on the aircraft and on the ground – that will be the cornerstone for commercial aviation's advanced AOC systems in the future.

E.7. Mr. Steve Boyd's Presentation Slides

(Boyd) Slide 1

(Boyd) Slide 2

(Boyd) Slide 3

Part 25 Regulatory requirements

Sec. 25.1523 Minimum flight crew.

The minimum flight crew must be established so that it is sufficient for safe operation, considering—

(a) The workload on individual crewmembers;

(b) The accessibility and ease of operation of necessary controls by the appropriate crewmember; and

(c) The kind of operation authorized under Sec. 25.1525.

[The criteria used in making the determinations required by this section are set forth in Appendix D.]

Appendix D was the major change from CAR 4b

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3   3

(Boyd) Slide 4

Regulatory requirements (cont.)

• **Appendix D (issued in 1965) provides the Criteria for determining minimum flight crew.**

a. *Basic workload functions.* **The following basic workload functions are considered:**
   (1) Flight path control.
   (2) Collision avoidance.
   (3) Navigation.
   (4) Communications.
   (5) Operation and monitoring of aircraft engines and systems.
   (6) Command decisions.

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4   4

(Boyd) Slide 5

Workload factors (Appendix D)

b. *Workload factors.* The following workload factors are considered significant when analyzing and demonstrating workload for minimum flight crew determination:

(1) The accessibility, ease, and simplicity of operation of all necessary flight, power, and equipment controls.

(2) The accessibility and conspicuity of all necessary instruments and failure warning devices. The extent to which such instruments or devices direct the proper corrective action is also considered.

(3) The number, urgency, and complexity of operating procedures.

(4) The degree and duration of concentrated mental and physical effort involved in normal operation and in diagnosing and coping with malfunctions and emergencies.

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5   5

(Boyd) Slide 6

Workload factors (Appendix D) cont.

(5) The extent of required monitoring of systems.

(6) The actions requiring a crewmember to be unavailable at his assigned duty station.

(7) The degree of automation provided in the aircraft systems to afford (after failures or malfunctions) automatic crossover or isolation of difficulties to minimize the need for flight crew action.

(8) The communications and navigation workload.

(9) The possibility of increased workload associated with any emergency that may lead to other emergencies.

(10) Incapacitation of a flight crewmember whenever the applicable operating rule requires a minimum flight crew of at least two pilots.

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6   6

(Boyd) Slide 7

First, normal operations…

- It's likely that additional automation could be introduced that would mitigate workload for a single pilot.
- NextGen will provide some verbal comm and nav relief, but will also shift some ATO controller monitoring tasks to pilots.
- More complex and heavily "populated" airspace will add cognitive and task load

However, normal operations are not the critical issue!

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7   7

(Boyd) Slide 8

System safety

25.1309…

(b) The airplane systems and associated components, considered separately and in relation to other systems, must be designed so that—

(1) The occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable, and

(2) The occurrence of any other failure condition which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable.

(c) Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards.

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8   8

(Boyd) Slide 9

Guidance on system safety

(1) **Minor: Failure conditions which would not significantly reduce airplane safety, and which involve crew actions that are well within their capabilities. Minor failure conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload…**

(2) **Major: Failure conditions which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions the extent that there would be, for example, --**

    (i) A significant reduction in safety margins or functional capabilities, a significant increase in crew workload or in conditions impairing crew efficiency…; or

    (ii) In more severe cases, a large reduction in safety margins or functional capabilities, higher workload or physical distress such that the crew could not be relied on to perform its tasks accurately or completely…

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9   9

(Boyd) Slide 10

More on the guidance…

- **For catastrophic conditions, the failures must be extremely improbable**
  - Not expected to happen in the life of the fleet
  - Typically once per billion flight hours (1E-09)
- **For severe major (i.e. hazardous) conditions**
  - Typically once per 10 million FH (1E-07)
- **For major conditions**
  - Typically once per 100K FH (1E-05)

Note: these standards are for hardware failures only, not those that are caused by software design errors.

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10   10

(Boyd) Slide 11

(Boyd) Slide 12

(Boyd) Slide 13

(Boyd) Slide 14

(Boyd) Slide 15

Flight crew errors

- **Mitigating flight crew errors**
  - While we often hear about flight crews making errors, but we don't often talk about the safety that flight crew members add.
  - Many errors by one pilot are identified and addressed by the other pilot.
  - CRM is specifically intended to maximize this benefit.
  - A single pilot will not have another pilot helping to manage errors.
  - The proposed new flight crew error rule (25.1302) has a requirement for design features that support error management.

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15   15

(Boyd) Slide 16

Pilot "failure"

- **Appendix D requires that the design account for an incapacitated pilot.**
- **Pilot incapacitation is not frequent, but it does occur with some regularity.**
  - Unconsciousness or death
  - Severe acute illness
- **A single pilot transport with an incapacitated pilot is an *ad hoc* UAS with hundreds of passengers on board!**
- **However, as recent events have shown, a simple inability to fly the airplane is NOT the worst case scenario of pilot incapacitation**

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(Boyd) Slide 17

3/27/12: Jet Blue pilot "meltdown"

- During the flight, the First Officer (FO) became concerned about Capt's bizarre behavior. As the A320 departed Kennedy Int'l, the Capt reportedly told the FO to take the controls and work the radio. He then began ranting incoherently about religion, saying "things just don't matter," and he eventually yelled over the radio at air traffic controllers.
- Concerned, the FO suggested that an off-duty captain join them in the cockpit, and Capt "abruptly left the cockpit to go to the forward lavatory"
- While he was gone, the FO ushered the off-duty captain into the cockpit, locked the door and when the Capt returned, pounding on the door to be admitted, the FO used the public address system to ask passengers to restrain the erratic pilot and they obliged.

How would this pilot incapacitation event have played out if the Capt were the only pilot in the flight deck?

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17   17

(Boyd) Slide 18

Dealing with a mentally incapacitated pilot

- **In case of psychological breakdown, one pilot may need to wrest control of the airplane from the other.**
- **In a single pilot transport, would the systems be expected to do that?**
- **Current design practices are based on a premise that the pilot can take control from a malfunctioning (not just failed) system. The system safety assessments often depend on that mitigation.**
- **Reversing that premise would…**
  - Require a total rethink of how airplane systems are designed
  - Would introduce new potentially catastrophic system failures that would also prevent the pilot from intervening

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18   18

(Boyd) Slide 19

Our top priorities and my thoughts…

- **Safety –**
  - So far, there is no apparent safety benefit to be gained from single pilot designs, and it is likely to be very difficult to even approach a safety-neutral design.
  - Compliance with current regulatory requirements may not be feasible.
  - The FAA's stated goal is to continually <u>increase</u> the level of safety.
- **National Airspace System (NAS) capacity –**
  - It seems highly unlikely that going to a single pilot design would increase our ability to push more airplanes through the system, and…
  - Given the change in air traffic management strategy embodied in NextGen (more aircraft-centric), single pilot ops may actually compromise that goal.

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(Boyd) Slide 20

As you go forward with this discussion…

- **The starting premise of a single pilot transport research effort should be (to borrow from Hippocrates): "First, do no harm."**
- **The initial questions to be answered: What benefit is being sought? Why?**
- **The next question: "Is a single pilot transport design the best, most effective, or even a plausible approach for achieving that goal, given the need to increase aviation safety and NAS capacity?**
- **Then ask: Is a single pilot design likely to solve more problems than it creates? Will we be better or worse off?**

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20   20

E.8.   Mr. Greg Potter's Presentation Slides

(Potter) Slide 1

(Potter) Slide 2

(Potter) Slide 3

(Potter) Slide 4

(Potter) Slide 5

(Potter) Slide 6

(Potter) Slide 7

(Potter) Slide 8

(Potter) Slide 9

(Potter) Slide 10

(Potter) Slide 11

(Potter) Slide 12

(Potter) Slide 13

(Potter) Slide 14

(Potter) Slide 15

(Potter) Slide 16

(Workgroup 1: Comerford) Slide 1

(Workgroup 1: Comerford) Slide 2

(Workgroup 1: Comerford) Slide 3

A Quick (Anonymous) Vote

- *Purpose*: To obtain a general sense of opinions represented by this group

- Only 8 Present for Vote

- Asked for personal, informed opinion at present time

- **General Categories Presented**
  - Need 2 Traditional Pilots
  - Strive for 1 Pilot
  - Strive for 1 Pilot on Ground and 1 Pilot in Air
  - Strive to Move Directly from 2 Pilots to None

(Workgroup 1: Comerford) Slide 4
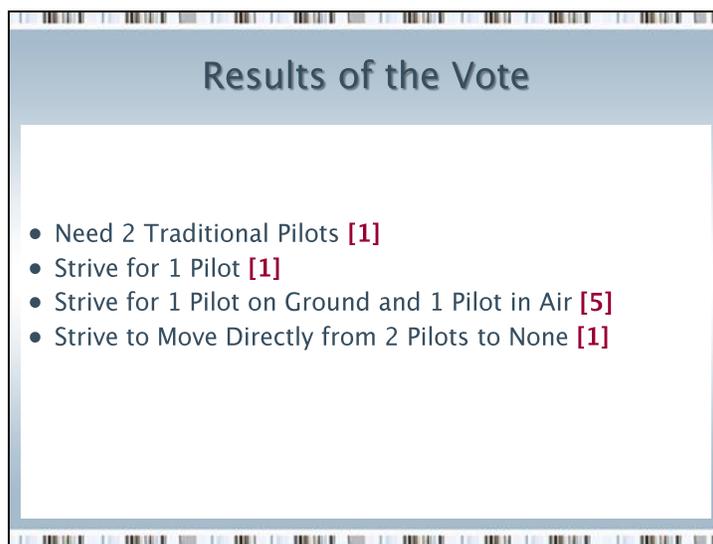
Results of the Vote

- Need 2 Traditional Pilots [1]
- Strive for 1 Pilot [1]
- Strive for 1 Pilot on Ground and 1 Pilot in Air [5]
- Strive to Move Directly from 2 Pilots to None [1]

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(Workgroup 1: Comerford) Slide 5

Initial Approach

- Presented participants with 2 questions to consider as we reviewed the sheet summarizing typical flight deck crew responsibilities:
  1. How would functions/tasks be affected by removing a crew member?
  2. How might a new allocation strategy be used to counter the effects identified in #1.

BUT…
They wouldn't let us ignore the elephant in the room…

PILOT INCAPACITATION

(Workgroup 1: Comerford) Slide 6
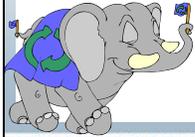
Pilot Incapacitation

- Most participants felt this issue is *extremely important*.
  - It affects *every* item on the list of responsibilities.
  - Statistics comparing single-pilot vs. two-pilot crew were striking (e.g., Michael Norman's presentation)

- Several remarks were noted that suggest we may be overemphasizing this issue.

(Workgroup 1: Comerford) Slide 7
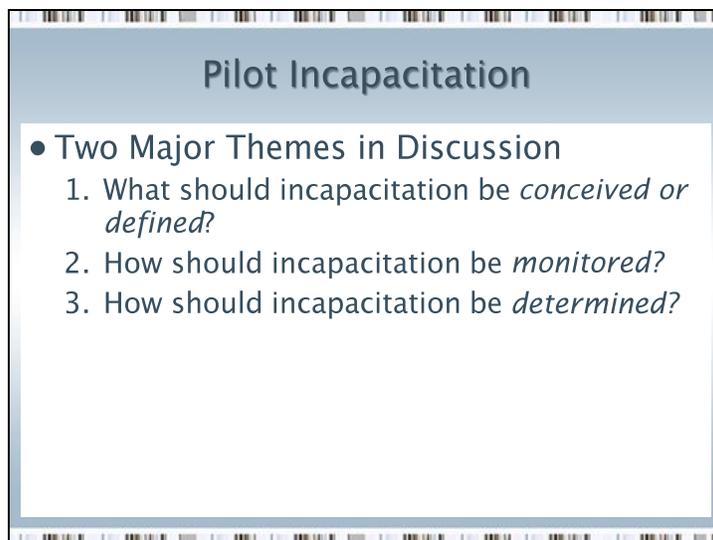
Pilot Incapacitation

- Two Major Themes in Discussion
    1. What should incapacitation be *conceived or defined*?
    2. How should incapacitation be *monitored?*
    3. How should incapacitation be *determined?*

(Workgroup 1: Comerford) Slide 8
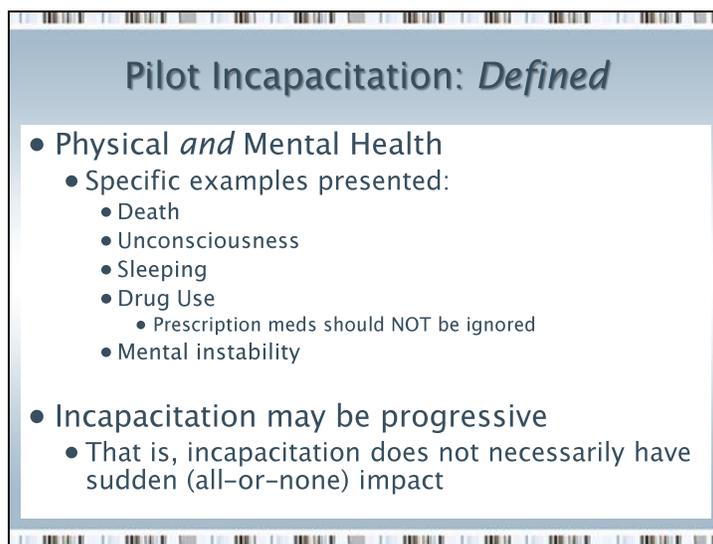
Pilot Incapacitation: *Defined*

- Physical *and* Mental Health
    - Specific examples presented:
        - Death
        - Unconsciousness
        - Sleeping
        - Drug Use
            - Prescription meds should NOT be ignored
        - Mental instability

- Incapacitation may be progressive
    - That is, incapacitation does not necessarily have sudden (all-or-none) impact

(Workgroup 1: Comerford) Slide 9
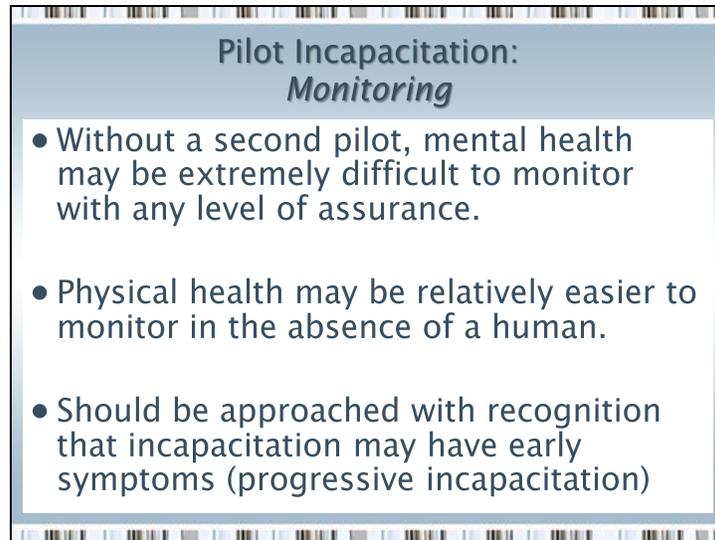
Pilot Incapacitation:
Monitoring

- Without a second pilot, mental health may be extremely difficult to monitor with any level of assurance.

- Physical health may be relatively easier to monitor in the absence of a human.

- Should be approached with recognition that incapacitation may have early symptoms (progressive incapacitation)

(Workgroup 1: Comerford) Slide 10
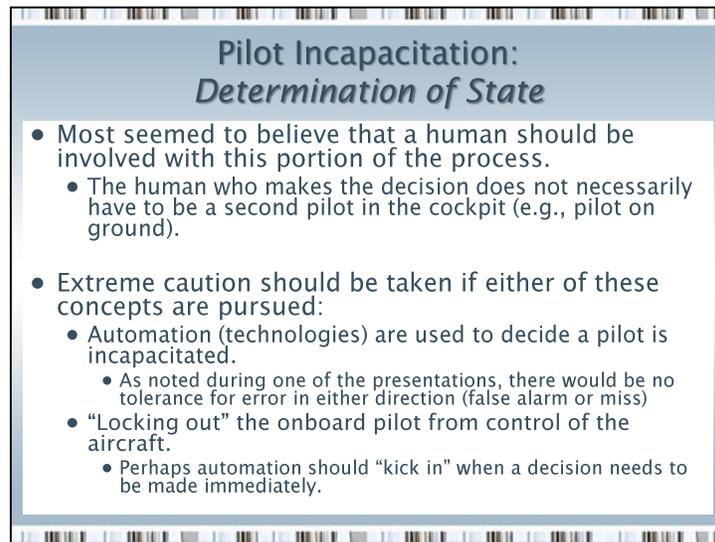
Pilot Incapacitation:
Determination of State

- Most seemed to believe that a human should be involved with this portion of the process.
  - The human who makes the decision does not necessarily have to be a second pilot in the cockpit (e.g., pilot on ground).

- Extreme caution should be taken if either of these concepts are pursued:
  - Automation (technologies) are used to decide a pilot is incapacitated.
    - As noted during one of the presentations, there would be no tolerance for error in either direction (false alarm or miss)
  - "Locking out" the onboard pilot from control of the aircraft.
    - Perhaps automation should "kick in" when a decision needs to be made immediately.
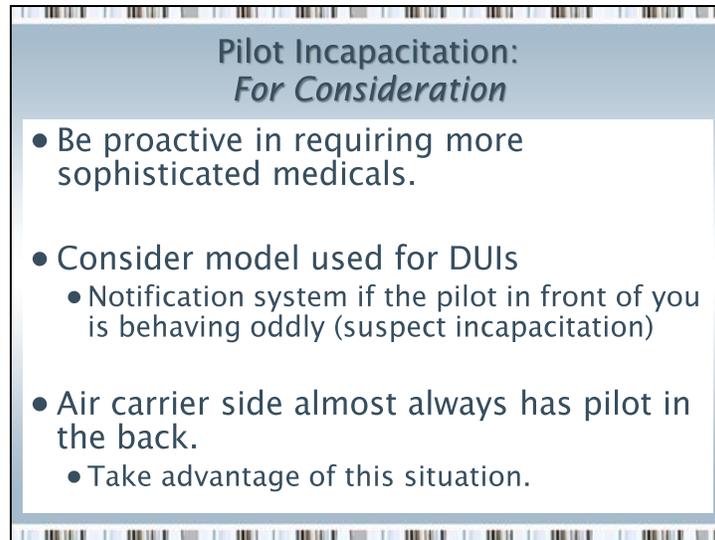
Pilot Incapacitation:
For Consideration

- Be proactive in requiring more sophisticated medicals.

- Consider model used for DUIs
  - Notification system if the pilot in front of you is behaving oddly (suspect incapacitation)

- Air carrier side almost always has pilot in the back.
  - Take advantage of this situation.

(Workgroup 1: Comerford) Slide 12
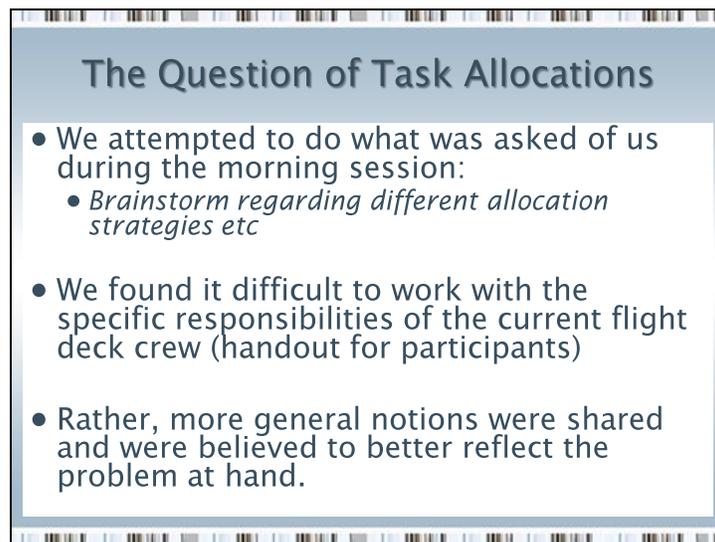
The Question of Task Allocations

- We attempted to do what was asked of us during the morning session:
  - *Brainstorm regarding different allocation strategies etc*

- We found it difficult to work with the specific responsibilities of the current flight deck crew (handout for participants)

- Rather, more general notions were shared and were believed to better reflect the problem at hand.

(Workgroup 1: Comerford) Slide 13

(Workgroup 1: Comerford) Slide 14

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(Workgroup 1: Comerford) Slide 15

Research Directions & Suggestions

- Generally, we were surprised at the amount of literature review that was suggested when all was said and done.

- Other than this general observation, the following slides represent the numerous research areas that were discussed, in no particular order.

(Workgroup 1: Comerford) Slide 16
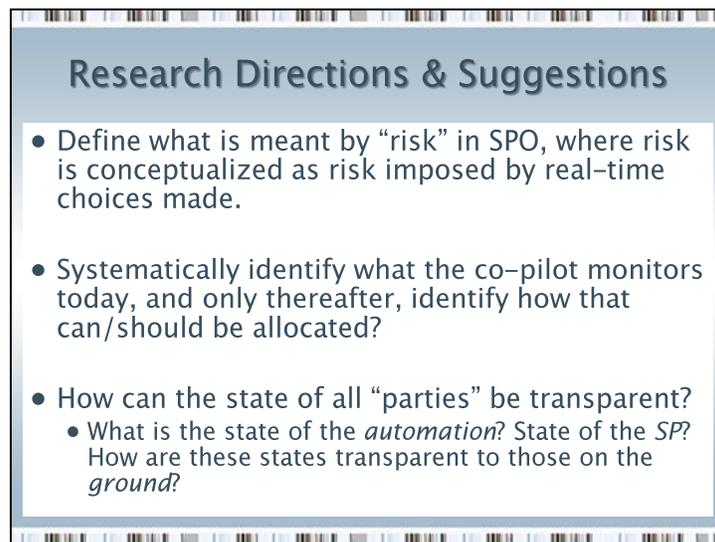
Research Directions & Suggestions

- Define what is meant by "risk" in SPO, where risk is conceptualized as risk imposed by real-time choices made.

- Systematically identify what the co-pilot monitors today, and only thereafter, identify how that can/should be allocated?

- How can the state of all "parties" be transparent?
  - What is the state of the *automation*? State of the *SP*? How are these states transparent to those on the *ground*?

(Workgroup 1: Comerford) Slide 17

(Workgroup 1: Comerford) Slide 18

(Workgroup 1: Comerford) Slide 19

Research Directions & Suggestions

- Poll aviation community to determine which, if any, Single Pilot scenario for Part 121 operations is viable.

- Explore the military domain and leverage off of their experience in single-pilot/dual-pilot vehicle operations

- Assess political/passenger acceptance issues of Single-Pilot 121 ops.

(Workgroup 1: Comerford) Slide 20
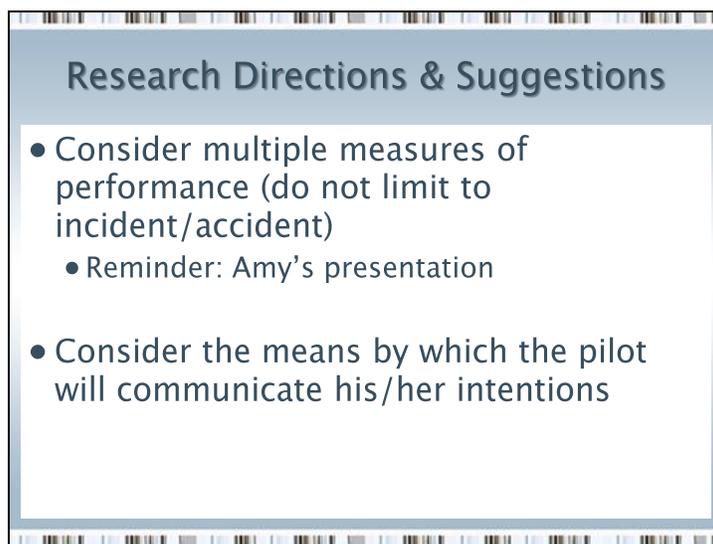
Research Directions & Suggestions

- Consider multiple measures of performance (do not limit to incident/accident)
  - Reminder: Amy's presentation

- Consider the means by which the pilot will communicate his/her intentions

E.10. Workgroup 2: Dr. Kim-Phuong L. Vu's Presentation Slides

(Workgroup 2: Vu) Slide 1

(Workgroup 2: Vu) Slide 2

(Workgroup 2: Vu) Slide 3

Function Allocation

- If the "second pilot" is automation
  - What roles do the single pilot take on from that traditionally assigned to the second pilot?
  - What roles should the automation be assigned?
    - Automation needs to have the ability to do everything
      - The second pilot does (coordination and monitoring)
      - The primary pilot does (incapacitation)
- How adaptive does the automation have to be?
  - Is there an optimal balance?
  - Can it be dynamic? Who determines the level?
  - How accepting are insurance agencies and other stake holders?
- It was consensus of the group, that the most likely "second pilot" would be automation in most situations, although human SMEs can brought in to consult on particular problems

Single Pilot Operations - Technical Interchange Meeting

(Workgroup 2: Vu) Slide 4

Automation as the "second" pilot

- Qualities of and Design Considerations for Automation
  - Should *essentially* never be wrong
  - Intuitive to use
  - Decision support tool
    - Trajectory
    - Systems management
    - Coordination
    - Control interface
  - Interact with primary pilot in same manner as a human co-pilot
    - Voice control
    - Respond to human instruction (checklist in 2 mins)
    - Anticipate pilot needs (present relevant information)
    - Trade-off tasks with pilot
    - Cross verification
    - Coordinate with all systems and report to pilot
    - CRM capable
    - Public acceptance

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(Workgroup 2: Vu) Slide 5

Research Issues: Design

- What are the Ergonomics of a SP cockpit?
  - How to capitalize on ergonomics?
  - Display-control layout
  - Information Display (multimodal?)
  - Menu structure
  - Musculoskeletal disorders
  - Flight deck layout (where would FAA or line-check airmen sit?)
- What Biological considerations need to be taken into account?
  - Autopilot when leaving cockpit: How long can pilot be absent?
  - Boredom
  - Fatigue
  - Social interaction
- What Environmental consideration need to be addressed?
  - Separate cockpit for lost of cabin pressure
  - Interruptions and distractions

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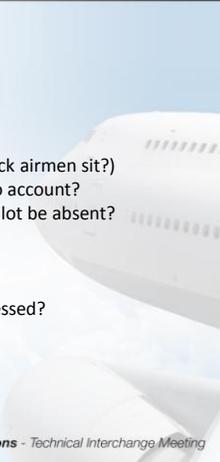
(Workgroup 2: Vu) Slide 6

Research Issues: Human-Computer Interaction

- Who are we Designing for?
  - Pilots
  - Novices
- What is the basis of the Interaction?
  - Cooperative/Query/Challenge
  - Interruptions
- What is an acceptable System response time?
- How would a Voice interface be implemented?
  - Dialogue component
  - Natural vs. controlled natural language
  - Context
- How often does the Human need interact with the automation?
- What are the best Icons/labels/color coding warnings to use?
- When to alert pilots and how?
- Digital vs. analog (ani-digi) – include trend information in the display?
- What level of automation transparency/level of info being reported by automation to pilot query is ideal?

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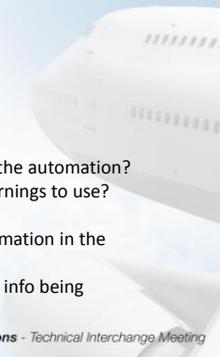
(Workgroup 2: Vu) Slide 7

Research Issues: NextGen Impacts

- Does the level of precision required by NextGen determine the functional allocation?
- What are the limitations of having a human operator in the system?
- Does SPO influence acceptable boundary levels?
- How does the interdependence of systems in NextGen will impact the development of SPO?
- Is SPO even feasible in NextGen, especially in off-nominal situations?

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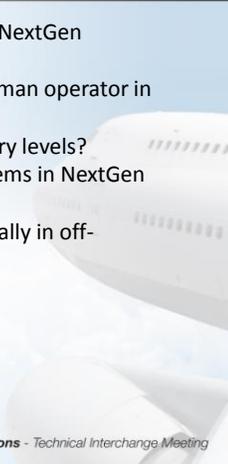
(Workgroup 2: Vu) Slide 8

Research Issues: Training

- For the different F/A what are the minimum training regulations?
- How does automation affect awareness?
- What can single pilots do without more automation? Do we need more automation?
- What should the system do in absence of the pilot? What is the role of automation in an emergency?
- What should be included in CRM training?
- How do we train pilots for unexpected events
  - Training situation assessment and decision making skills
  - Balance between emergency procedure training vs. creativity
  - Embedded training during flight
- How to prevent skill degradation?
- What are the new teamwork skills required?

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(Workgroup 2: Vu) Slide 9
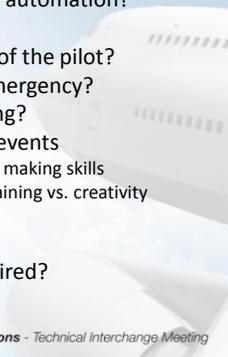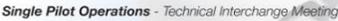
Research Issues: Training (con't)

- How do we select and train new pilot?
- Does training differ by flight length?
- Cultural issues – what are the impact of cultural influences on automation acceptance
  - As an example: flying with somebody that you are in an argument with – there is very little interaction, and that makes the trip "miserable" (is that similar to what it would be like flying with just a computer?)
  - Trust in automation by given cultures
- Are there any task combinations that are unmanageable in a single pilot environment? Can we train to mitigate the detrimental impacts of multitasking?

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(Workgroup 2: Vu) Slide 10
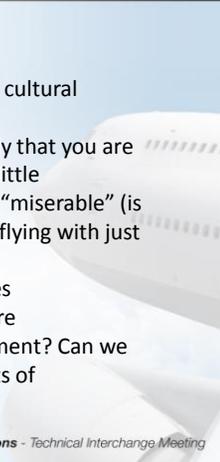
Research Issues: Communication

- There needs to be research on voice controlled automation
- What can technology support?
  - Natural Language vs. Controlled natural language
  - Type of speech (let's start down)
  - Variability of commands
  - Training issues?
- Can voice analyses be used as an indicator of stress?
- Can the system recognize when the pilot does not understand and adapt to the pilot?
- What is the role of dialogue and context?
- Can we use of research from other literature to support development?
  - Space exploration
  - Automobile industry

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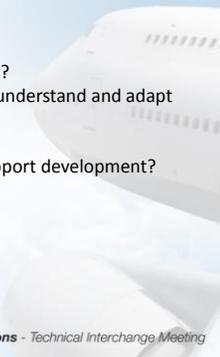
Research Issues: Trust and Acceptability

- What are the overall benefits of SPO? Does this debate warrant dollars over the money that could be provided to second pilots?
- Do we need to survey the public? Are they accepting of FAA certification?
- Where will the pushback come from?
    - Professional communities
    - Unions
- How would a zero tolerance policy for accidents affect the feasibility of SPO?

Single Pilot Operations - *Technical Interchange Meeting*
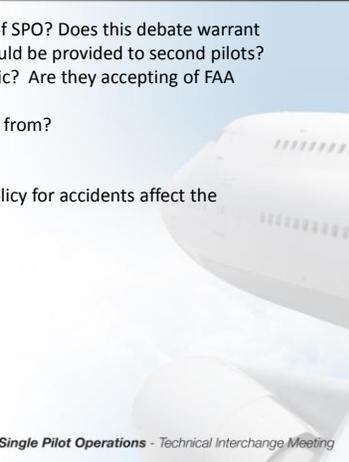
E.11. Workgroup 3: Dr. Michael Feary's Presentation Slides

(Workgroup 3: Feary) Slide 1

(Workgroup 3: Feary) Slide 2

(Workgroup 3: Feary) Slide 3

Breakout Group 3 General Topics

- AOC/FOC/Dispatch
  - Roles and responsibilities
    - Nextgen is going to require more authority of dispatch and may directly interact with ATC
    - Where to draw the line between strategic and tactical
    - New training and procedure requirements - Problems today
    - If unable to comply, won't be allowed in airspace (class B, and ABV FL340) – declining weather
    - Can ask to speak to pilot on duty today – call MOCC
- New Allocation strategies
  - E.g. Extra pilot could be MEL item for certain weather minima
  - Automation as default, pilot to respond to off-nominal
- Accountability
  - Peer pressure for professionalism of other crew member
  - FOQA may help but not replace
  - Shared perception of pilot having responsibility
- Changes in regulatory process
  - Insurance companies are more restrictive in some cases. More closely connected to financial costs, should they be consulted?
  - What should the government be responsible for?

Single Pilot Operations - *Technical Interchange Meeting*

(Workgroup 3: Feary) Slide 4

Breakout Group 3 Research Challenges

- System Centric Performance
  - ATC doesn't necessarily know how many pilots are on board today, but they do profile flights and change requests accordingly
- Need predictive measures
  - Today's environment isn't accepting of incidents and accidents particularly in part 121 pax
- Automation
  - byproduct of automation is to increase high workload, decrease low workload
  - SPO may rely on automation, and therefore exacerbate this problem
- Complexity measures
  - What are the elements of complexity that drive the ability of a single pilot managing the aircraft?
  - How do you know what the limit is and when it has been exceeded?
- Backup pilot availability
  - Frequently deadheading/commuting/positioning pilots are on flights today
- Physiological measures for SP
  - How to know when human is failing (incapacitation)?
  - Medical screening changes?
  - What about cognitive measures?
  - State of the art is not ready

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(Workgroup 3: Feary) Slide 5

Breakout Group 3 Research Challenges (cont'd)

- Error data
  - Don't know how many incidents and accidents have been prevented by second pilot
  - Types and impacts of errors
- What data is available on differences in SPO today
  - Feeling that 2007 report may not be comparing similar populations (differences in pilots cert., equipment, operations, not just 3 of crew)
- Training changes are not well understood yet
  - New paradigm – how do first officers receive soft skills training?
  - Training for FOC/AOC/dispatch – technical, cultural, organizational. Evidence of conflicts with dispatch functions today. Need to develop a level of trust with AOC dealing directly with ATC/ATM
- Nextgen
  - Less flexibility, more tightly constrained. Off-nominal operations will have more impact. This will increase already high workload for these events, perhaps impacting SPO more.
- Effect on ability to diagnose problems
  - Not sure of effect today

Single Pilot Operations - *Technical Interchange Meeting*

(Workgroup 3: Feary) Slide 6
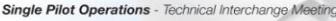
Breakout Group 3 SPO Areas of Interest

- Tasks that may be more vulnerable with SPO? (particularly if something fails because it's dependent on automation)
  - Preflight
    - Walkaround and management of systems
    - Verification of fitness to fly
  - Taxi
  - Preparing for arrival and approach
  - Amended clearances (particularly close in)
  - Closely Spaced Parallel Approaches
  - Optimized Profile Descent
  - In-trail procedures
  - Merging and Spacing
  - Diversions and rerouting
    - Medical, Mx, Operational, weather
  - Rapid Decompression
  - Delegated Separation
  - Length of flight
  - Emergency Evacuation
    - May need another crewmember to – or different training for cabin crew
  - Diagnosis of System Failures

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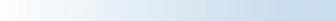
Implementation Thoughts

- For Implementation AK is a good place to start
  - Ocean 21, lots of single pilot operations
- Phased implementation
  - Study 135 ops in more detail
  - 121 cargo operators
  - 121 VFR passenger flights (short hops)
  - Fractionals
- Would be useful to have union involvement early, not just pilot unions

**Single Pilot Operations** - *Technical Interchange Meeting*

(Workgroup 4: Mogford) Slide 1

(Workgroup 4: Mogford) Slide 2

(Workgroup 4: Mogford) Slide 3

Strategy

- Aircraft will be able to fly themselves
- Single pilot on board (PoB) with flight deck automation (FDA) could handle normal operations
  - Aviating, navigating, communicating, and monitoring tasks
  - Following air traffic control instructions
  - Managing departure and arrival
- PoB and FDA could also handle some non-normal conditions
  - Engine out
  - See and avoid
  - Tactical weather situations

Single Pilot Operations - *Technical Interchange Meeting*

(Workgroup 4: Mogford) Slide 4

Strategy

- Flight would be monitored by an "Enhanced" Airline Operations Center (EAOC)
- EAOC includes ground and airborne personnel and automation (decision support and data)
- More extreme non-normal events could be managed by the PoB, FDA, "Cabin Commander," and EAOC
  - Air interruptions (extreme weather, flight mechanical, FDA problems, security issues)
  - Pilot and/or FDA may need help in high workload situations
  - May be FDA failure states to cope with
  - Specialize skills or information may be required

Single Pilot Operations - *Technical Interchange Meeting*

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(Workgroup 4: Mogford) Slide 5

(Workgroup 4: Mogford) Slide 6

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(Workgroup 4: Mogford) Slide 7

(Workgroup 4: Mogford) Slide 8

(Workgroup 4: Mogford) Slide 9

(Workgroup 4: Mogford) Slide 10

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(Workgroup 4: Mogford) Slide 16

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(Workgroup 4: Mogford) Slide 19

Research Topics

- Harbor pilot model? (Local expert at airport)
  - Due to problems with transmission delays at remote facilities
  - Work for FAA and not airline?
- Develop criteria and measures through which SPO concepts/technology can be evaluated and affect FAA standards
- Validate standards using concept development and simulation
- Conduct evaluation of second pilot for error trapping
  - Human can be instrumental in overcoming problems
  - Use ASRS?

Single Pilot Operations - Technical Interchange Meeting

(Workgroup 4: Mogford) Slide 20

The End

Thanks for the opportunity to collaborate on the topic of Single Pilot Operations

Breakout Group 4

Single Pilot Operations - Technical Interchange Meeting

Appendix F: Organization of Findings with References

The following outline was used to organize the feedback received throughout the entire TIM and was used to generate the "Analysis and Summary of Findings" section of this document. This outline is included because **it includes the section of the document where the information can be found within its original context and offers information regarding the frequency with which an idea was mentioned**. For example, see the first bullet below this paragraph that contains content (i.e., "A systematic, but limited, analysis…"). If the reader were interested in seeing the context of the said information, the reader would refer to the line below the entry. There, the reader would find that the information can be found in Section 5.6.2 of this document. Because only one section of the document is referenced, this particular thought was relayed only once. See Section 3.3 of this document for a more thorough description of the manner in which the findings of this meeting were analyzed and summarized.

- **General Thoughts Regarding a Move to SPO**
  - **General, Potential *Advantages* in Moving to SPO**
    - **Financial Cost**
      - A systematic, but limited, analysis of real-world data was performed. New costs associated with SPO were not addressed (e.g., new training required, certification and development costs, etc.). Given the limitations, if we assume a 20-year service life for the aircraft, data show that the aggregate flight crew cost per cockpit seat over the life of the aircraft, world-fleet-wide to be $6.8 trillion, which is potentially a significant percentage of the market value of the new aircraft (i.e., 54% of $12.6 trillion). Therefore, in reducing the requirement for one pilot, we may see economic benefit.
        - *References*: Sections 5.6.2
      - Due to increased flexibility
        - A move to SPO would yield an increase in revenue, an increase in the number of travelers served, and an unchanged demand for pilots.
          - *References*: Sections 5.3.2
        - Flexibility would be increased in terms of scheduling pilots and the pilot pool would be functionally increased without an absolute increase in the number of pilots.
          - *References*: Sections 4.2
      - Reduces cost for training and accommodations.
        - *References*: Sections 5.3.2

- **Feality**
  - General mention that SPO is feasible.
    - *References*: Sections 5.3.2, 6.3.2
  - Aircraft can generally fly autonomously as of today.
    - *References*: Sections 5.7.2
  - Embraer is in the process of designing aircraft for the 2020-2025 timeframe with SPO.
    - *References*: Sections 4.5.2
  - Given the fact that optionally piloted vehicles already are in use, there is no reason to believe SPO is not possible.
    - *References*: Sections 5.5.2
  - Other categories (e.g., Part 135) have certification for single pilot.
    - *References*: Sections 4.2, 4.5.2
  - Some events demonstrate that, under emergency circumstances, single pilots with ample experience and/or training are more than able to handle flight (e.g., Captain Sullenberger landing in the Hudson).
    - *References*: Sections 4.5.2
- **Mere exploration of SPO could yield general improvements, whether or not SPO is realized**
  - General mention that mere exploration of SPO may yield advances.
    - *References*: Sections 6.4.2
  - Exploring SPO could yield advances in automation.
    - *References*: Sections 4.4
  - Exploring SPO could yield advances in air-ground coordination.
    - *References*: Sections 4.4
  - Should allow us to consider the value of maintaining the second pilot.
    - *References*: Sections 4.4
  - SPO may be realized any time one pilot, of a two-person crew, becomes incapacitated. Therefore, SPO research would assist current-day operations.
    - *References*: Sections 4.2
- **Pilot Incapacitation**
  - At the workshop, this issue may have been overemphasized and may not impose as much threat to SPO realization as some suggest.
    - *References*: Sections 6.1.2
  - You could make the claim that having two pilots doubles the chances that you will have one pilot become unstable (e.g., as in the case of the JetBlue incident). Therefore, not necessarily a major impediment to SPO.
    - *References*: Sections 6.4.2

- **Public and Stakeholders**
  - Public may gladly accept SPO if it truly results in lasting price reductions.
    - *References*: Sections 6.2.2
  - Public may simply accept SPO if the FAA certifies it. Public not necessarily a barrier.
    - *References*: Sections 6.2.2
  - Public often is adaptable to technological change. Public not necessarily a barrier.
    - *References*: Sections 5.1.2
- **Safety**
  - Data illustrated that accident rates from 3-person crews were higher than accident rates observed today, under two-person crew operations. Therefore, a reduction in crew does not necessarily reduce safety.
    - *References*: Sections 5.3.2
- **SPO in the Context of NextGen**
  - NextGen will provide some technologies that may make the pilot's job easier.
    - *References*: Sections 5.7.2, 6.2.2
    - NextGen technologies will provide verbal communication and navigation relief (e.g., automatically uploading flight plans).
      - *References*: Sections 5.7.2, 6.2.2
- **General *Disadvantages, Challenges, Issues, or Questions* as Related to SPO**
  - **Certification and Development of Requirements**
    - General mention that certification issues need to be addressed.
      - *References*: Sections 4.3
    - Certifiable systems often include dual or triple redundancies.
      - *References*: Sections 5.3.2
    - Consider using performance-based standards.
      - *References*: Sections 5.5.2
      - Historically, an evaluation of equipment and human limitations has guided regulations.
        - *References*: Sections 5.5.2
      - Performance-based standards provide flexibility for new technologies and a structured method (e.g., RTSP for ATM).
        - *References*: Sections 5.5.2
    - Ensure policies do not hinder graceful degradations in the system.
      - *References*: Sections 5.7.2
      - Example: would be more effective if we have a pilot calling for assistance when he or she is beginning to feel drowsy rather than having the pilot fall asleep.
        - *References*: Sections 5.7.2
    - How could technology be used to mitigate certification risk to reduced crew operations?
      - *References*: Sections 5.6.2

- Need direction as an aviation community
  - Need to clearly identify the operations we are targeting.
    - Need to identify the size of aircraft, the number of passengers, whether we are discussing Part 95, Part 121, and/or other parts of the federal aviation regulations, and whether we are addressing freight, passenger or both type of carriers.
      - *References*: Sections 6.4.2
  - Need to identify issues and topics that are unique to SPO (vs. general principles of design).
    - *References*: Sections 6.2.2
  - Need to scope the problem.
    - *References*: Sections 6.1.2
  - Will the aircraft be designed to fly only in single-pilot mode or will they be designed to operate under either single- or dual-pilot mode?
    - *References*: Sections 6.2.2
  - Would the design approach assume the user is a well-trained pilot or a novice?
    - *References*: Sections 6.2.2
- Need to identify a feasible approval process.
  - *References*: Sections 4.3
- Reducing the crew to a single pilot will likely elevate the hazard category for many failure conditions, requiring much more robust designs.
  - *References*: Sections 5.7.2
- Requires the development of a new concept of operations
  - *References*: Sections 4.2, 4.3, 6.1.2
  - Creating such a document will allow for feedback from all interested parties early in the process.
    - *References*: Sections 6.1.2
- Risk analysis must be considered because it is part of the certification process.
  - *References*: Sections 5.3.2
  - "Risk" needs to be defined for SPO, where risk is conceptualized as risk imposed by real-time choices made.
    - Can help beyond certification. Can help with research and development.
      - Example: one attendee mentioned previous work on an emergency landing planner integrated with the flight management system; the software would take into account various routes to nearby runways, along with weather, to provide pilots with a summary of the risks associated with each route. In this case, risk information was provided in real time.
        - *References*: Sections 6.1.2

- Specific FAA Guidance and Requirements
  - Advisory Circular 25.1523 documents data associated with pilot incapacitation and attributes them to SPO. (See section on Pilot Incapacitation, below). This documentation may suggest that the FAA would be reluctant to certify SPO.
    - *References*: Sections 5.6.2
  - Current safety assessments often assume and depend on the notion that a pilot can take control from a malfunctioning (not just failed) system. With SPO, this assumption becomes problematic.
    - *References*: Sections 5.7.2
    - With SPO, an incapacitated pilot does not allow us to work under this assumption.
      - *References*: Sections 5.7.2
    - Under SPO, this premise would also need to be addressed in the reverse (i.e., aircraft systems can take control of the aircraft from a pilot that is "malfunctioning" or has "failed"). In considering a reversal of the said premise, we would need to completely rethink how airplane systems are designed. In addition, we would need to consider the introduction of new, potentially catastrophic system failures in which the pilot would be prevented from intervening.
      - *References*: Sections 5.7.2
  - FAA guidance currently presumes that modern avionics add complexity and increase workload.
    - *References*: Sections 5.9.2
  - FAA guidance currently assumes that aircraft working under one set of regulations is more complex than another (e.g., FAR Part 25 vs. FAR Part 23), and that assumption is unfounded.
    - *References*: Sections 5.9.2
  - FAR Part 25, which defines airworthiness standards for transport category airplanes, does not exclude the possibility of SPO, but it does address workload.
    - *References*: Sections 5.6.2, 5.7.2
  - Must address oxygen requirements for the single pilot above flight level 35,000.
    - *References*: Sections 6.1.2, 6.4.2
  - Nothing can be found in the advisory circulars and regulations that prohibit single-pilot operations, but if you read the verbiage, you will find an implied reluctance on the part of FAA (i.e., there is an assumption of 2 pilots in language used).
    - *References*: Sections 5.6.2, 5.7.2
  - Software is placed in categories related to its criticality because there is no way to attach a probability to a software design error. Therefore, software is very expensive to build because of the level of scrutiny it undergoes. The level of automation, complexity, and integration needed for a single-pilot transport

will exacerbate the problem of difficult-to-identify design errors and high cost of critical software.
- *References*: Sections 5.7.2
- The thresholds for workload need to be defined through some form of measurement, and this threshold would need to be identified for all relevant parties in the NAS (e.g., pilot, dispatcher, etc.).
  - o *References*: Sections 6.4.2
  - o Consider whether or not workload should be monitored in real-time for all relevant parties in the NAS.
    - *References*: Sections 6.4.2
- We have metrics to "tap" many of the areas that are regulated (e.g., workload). However, we do not have a good metric of complexity.
  - o *References*: Sections 5.7.2
  - o When we speak about complexity, do we mean complexity of the automation system, complexity of the pilot's tasks or job, or complexity of the overall system?
    - *References*: Sections 6.3.2
- Would single-pilot duty requirements be something akin to a 2 X 2 X 8 rule, such that SPO would be restricted to two-engine aircraft with two take-offs and landings and under 8 hours flight time?
  - o *References*: Sections 5.5.2, 6.4.2
- **Are non-technical issues more challenging than the technical issues in the case of SPO?**
  - *References*: Sections 5.7.2
- **Compare "what we can do," "what is certifiable," and "what makes economic sense." The place where those answers overlap represents what we should do.**
  - *References*: Sections 6.4.2
- **Communications**
  - Need to identify which agents in the NAS communicate with whom and when.
    - o *References*: Sections 6.4.2
    - o May be desirable to allow direct communication between dispatch and ATC, in order to offset pilot workload.
      - *References*: Sections 6.3.2
    - o Might become an important requirement for the pilot to communicate to ATC that the aircraft is operated by a single pilot.
      - *References*: Sections 6.3.2
  - We will need to examine the necessary communications required to advance the standard crew size from two to one.
    - o *References*: Sections 5.5.2, 5.6.2
    - o Need enhanced data link
      - *References*: Sections 5.6.2
    - o Need persistent, broadband communication
      - *References*: Sections 6.4.2

- **Conflict between Agents (Human-Human or Human-Automation Conflict)**
  - Method must be developed that allows for the identification of a conflict state
    - *References*: Sections 5.1.2
    - Conflict state identification especially important when between a human agent and automation.
      - *References*: Sections 5.1.2
    - After the conflict is identified, the method of managing the conflict also must be identified.
      - *References*: Sections 5.1.2
- **Design of Aircraft**
  - Perhaps the cockpit should be treated separately in terms of loss of cabin pressure (i.e., to ensure the single pilot can maintain a pressurized environment).
    - *References*: Sections 6.2.2
    - However, this arrangement might pose concern in terms of ethics.
      - *References*: Sections 6.2.2
  - With the presence of the second pilot also comes the notion of dual systems on board, which often are independent (if one fails, you can access the other). With single-pilot designs, you lose the second channel on some systems.
    - *References*: Sections 5.7.2
- **Ergonomics of the Single-Pilot Cockpit**
  - Recognize that the amount of information that was once presented to two sets of eyes can now be presented to only one.
    - *References*: Sections 6.2.2
  - When designing the cockpit, consider the following characteristics:
    - display-control layout, icons, labels, color-coding, choice of digital, analog, or mixed information, inclusion of trend information where appropriate, the information display (whether it will be multi-modal or not), menu structures within displays, and musculoskeletal disorders.
      - *References*: Sections 6.2.2
- **Feasibility**
  - Feasibility of SPO is an "open question" with arguments on "both sides."
    - *References*: Sections 4.2, 4.4, 5.1.2
- **Financial Cost**
  - Are we certain SPO would yield savings?
    - General identification of the question.
      - *References*: Sections 5.1.2
    - Is cost savings certain in light of the research, development, certification, and training that would be required to implement SPO?
      - *References*: Sections 6.2.2, 6.4.2

- Cost-saving alternatives may exist.
  - *References*: Sections 5.6.2, 5.7.2
    - Fewer pilots could be required per seat if there were more efficient scheduling.
      - *References*: Sections 5.6.2
    - Flight crew augmentation requirements could be reduced for long flights (i.e., the need to have two complement crew members on board aircraft could be reduced to one complement crew member).
      - *References*: Sections 5.6.2
- **Is one pilot a logical stepping stone on the way to zero pilots?**
  - *References*: Sections 4.1, 4.3, 5.3.2, 5.5.2
- **Legal Issues**
  - The legal and policy requirements must be identified.
    - *References*: Sections 4.3
  - Accountability
    - Assuming an increase in automation, would the single pilot continue to have as much responsibility for flight safety?
      - *References*: Sections 6.1.2
    - Automation failures could be conceived as occurring at the design, manufacturing, installation, maintenance, training, or operations stage.
      - *References*: Sections 5.1.2
    - We need to develop an "automation policy" to guide design, operation, and management of highly automated systems.
      - *References*: Sections 5.1.2
    - What we are really doing is giving the authority to the designer when automation is involved. The designer must make assumptions/forecasts about what conditions exist in flight, and they may not be qualified to do so.
      - *References*: Sections 5.1.2
- **Pilot Availability at Duty Station**
  - Accommodating actions and procedures requiring a pilot to be unavailable at his/her assigned duty station (i.e., observation of systems, emergency operation of any control, emergencies in any compartment, passenger or cabin crew management, and lavatory visits on long flights) may be a challenge.
    - *References*: Sections 5.6.2
  - Aircraft may need to react to the pilot being away from duty station in the same way it reacts to an incapacitated pilot. The same state results (i.e., pilotless aircraft).
    - *References*: Sections 6.4.2
  - How long can the pilot be absent before the automation should be "concerned" (i.e., move into a mode in which pilot incapacitation is assumed or attempt to query crew members)?
    - *References*: Sections 6.2.2

- **Pilot Incapacitation**
  - General identification of the pilot incapacitation issue
    - *References*: Sections 5.5.2, 5.6.2, 6.1.2, 6.2.2, 6.3.2, 6.4.2
  - Data regarding pilot incapacitation
    - Advisory Circular 25.1523 documents that, from 1980 to 1989,:
      - 262 pilot incapacitation events occurred in FAR Part 91 operations, with 180 fatalities. All of the fatalities were attributed to single-pilot operation.
        - *References*: Sections 5.6.2
      - in FAR Part 135 operations, 32 occurrences of pilot incapacitation were documented, with 32 fatalities. All of these fatalities also were attributed to single-pilot operation.
        - *References*: Sections 5.6.2
      - in FAR Part 121 operations, 51 cases of pilot incapacitation were documented, in which normal recovery of the aircraft was achieved by the second pilot.
        - *References*: Sections 5.6.2
    - Cases of pilot incapacitation for accident and incident data from January 1987 through December 2006.
      - FAR Part 91 results in 144 pilot incapacitation events per billion hours
        - *References*: Sections 5.6.2
      - FAR Part 135 operations results in 57 events per billion hours flown
        - *References*: Sections 5.6.2
      - FAR Part 121 results in 10 events per billion hours flown
        - *References*: Sections 5.6.2
      - We must work to see these and related statistics change in a positive manner before reducing the number of pilots.
        - *References*: Sections 6.1.2
    - FAA data suggest pilot incapacitation occurs approximately 1/month
      - *References*: Sections 5.3.2
    - If the pilot (as a human being) is considered a system in the aircraft, he or she would not be certified as a reliable system.
      - For the age of 47 (the average age of pilots), the mortality rate is 427 per 100,000 in the population.
      - A second pilot offsets this lack of reliability in the human system.
        - *References*: Sections 5.6.2

- Importance of Pilot Incapacitation Issue
  - Pilot incapacitation is extremely important because it potentially affects every one of a pilot's responsibilities.
    - *References*: Sections 6.1.2
  - Pilot incapacitation is the most significant challenge to certification and conduct of safe, single-pilot, transport category airplane operations.
    - *References*: Sections 5.6.2
    - Because of potential pilot incapacitation, the airplane needs to be able to behave autonomously, and if that could get certified alone, then all other design would essentially be guarding the aircraft against the pilot. Therefore, from a purely design and certification standpoint, it may be easier to design the aircraft for no pilot than for a single pilot.
      - *References*: Sections 5.6.2
- Need to identify when pilot incapacitation has occurred
  - *References*: Sections 5.6.2
  - Allow pilots to report if a nearby pilot is behaving oddly (akin to DUI reporting)
    - NextGen will provide more opportunities for pilots to directly observe the behaviors of other aircraft.
    - *References*: Sections 6.1.2
  - Definition of Pilot Incapacitation
    - A definition of pilot incapacitation should include considerations of both mental and physical health.
      - *References*: Sections 6.1.2
    - Do not ignore subtle pilot incapacitation (e.g., can be caused by a stroke), in which the incapacitated pilot will only show symptoms if prodded (e.g., questioned). Some pilots currently are trained to recognize it.
      - *References*: Sections 5.7.2
    - Pilot incapacitation can be progressive and does not necessarily represent an "all-or-none" state.
      - May exhibit early "symptoms."
        - *References*: Sections 6.1.2
    - Pilot incapacitation might occur if the pilot is:
      - Asleep
        - *References*: Sections 6.1.2, 6.4.2
      - Deceased.
        - *References*: Sections 6.1.2, 6.4.2
      - Experiencing a mental breakdown
        - *References*: Sections 6.1.2, 6.4.2
      - Intoxicated
        - *References*: Sections 6.4.2
      - Unconscious
        - *References*: Sections 6.1.2
      - Under the influence of drugs.
        - Do not ignore prescription drugs.

- - Aviation currently has no system to monitor prescription drug abuse.
      - *References*: Sections 6.1.2
  - Errors in determining pilot incapacitation
    - The determination of pilot incapacitation would have to be error-proof (no more than one failure in a billion flight hours).
      - *References*: Sections 5.6.2
    - Errors could not occur in either "direction."
      - The system should never be allowed to miss a case of incapacitation, and at the same time, should never incorrectly deem a capable pilot as being incapacitated.
        - *References*: Sections 5.6.2, 6.1.2
  - Need real-time monitoring of the pilot.
    - *References*: Sections 5.6.2, 6.1.2
    - Might consider:
      - physiological measures
        - *References*: Sections 6.3.2
        - May be relatively easier to monitor (in the absence of a human) than mental health.
          - *References*: Sections 6.1.2
      - cognitive measures
        - *References*: Sections 6.3.2
      - wakefulness confirmations
        - Might incorporate a "ping" approach to attention and wakefulness management. We could "ping" the pilot every half-hour or hour to serve as a "check in" with the pilot.
          - *References*: Sections 6.1.2, 6.4.2
  - A human should be involved in determining that the pilot is in an incapacitated state.
    - *References*: Sections 6.1.2
    - A human can talk to the pilot, interact directly with the pilot to ascertain his or her condition, and make a judgment regarding incapacitation based on many subtle, yet not easily defined, variables.
      - *References*: Sections 6.1.2

- - - Would not necessarily have to be a second pilot in the cockpit.
      - *References*: Sections 6.1.2
      - Onboard personnel could be quite useful in evaluating and/or validating the state of the single pilot.
        - *References*: Sections 6.1.2, 6.4.2
        - Examples:
          - onboard, commuting pilots
            - *References*: Sections 6.1.2
          - cabin commander
            - *References*: Sections 6.4.2
- - Need *physical* redundancy of two pilots.
    - *References*: Sections 5.3.2
- Proactive Approaches
  - Need enhanced screening of pilots.
    - General identification of issue that medical screening needs to be updated for SPO.
      - *References*: Sections 6.1.2, 6.3.2
    - Consider screening for arteriosclerosis and cerebrovascular disease screening.
      - *References*: Sections 5.6.2
      - These diseases surfaced often during a review of incapacitation cases.
        - *References*: Sections 5.6.2
    - Consider use of a pilot identity detection system (e.g., required fingerprint or retinal scan).
      - *References*: Sections 5.6.2
      - Would recognize those who are not "current" on screenings (e.g., medicals) but also those with malicious intent.
        - *References*: Sections 5.6.2
    - State-of-the-art is not ready to screen for failing pilots to the level required by SPO.
      - *References*: Sections 6.3.2
  - Training
    - Supplemental pilot training might be useful.
      - Example: train pilots to recognize signs of a heart attack.
        - *References*: Sections 6.3.2
- Response to Pilot Incapacitation
  - After an episode of pilot incapacitation, how would the pilot be reinstated as being the agent in control of the aircraft and how much control should be given back?
    - *References*: Sections 6.1.2
    - If the pilot is deemed to be incapacitated, recovers, and asks an automated system for permission to have control, who is ultimately in command of the aircraft? Not the pilot! It's the aircraft.

- • *References*: Sections 6.4.2
  - o Consider a conservative approach. Automation could "kick in" (even if temporarily) when a decision needs to made immediately and pilot *may* be incapacitated.
    - ▪ *References*: Sections 6.1.2
  - o If the pilot is falling asleep or has fallen asleep, the aircraft systems could include a simple warning or alarm in order to alert the pilot (e.g., "Wake up!).
    - ▪ *References*: Sections 6.4.2
    - ▪ See Mercedes Benz "Attention Assist System" as an example.
      - • *References*: Sections 6.4.2
  - o In the case of pilot incapacitation, would the agent who gains control (either automation or another human) fly to the departure or arrival airport or would the aircraft be landed at the closest airport that would allow for a safe landing?
    - ▪ *References*: Sections 6.4.2
  - o Must identify back-up for pilot incapacitation.
    - ▪ *References*: Sections 6.4.2
    - ▪ Might consider the following for back-ups in the case of pilot incapacitation:
      - • flight deck automation
        - o *References*: Sections 6.4.2
      - • ground-based personnel
        - o *References*: Sections 6.4.2
  - o Once pilot incapacitation is recognized by the system, the aircraft would have to be immune from inadvertent inputs by that incapacitated pilot.
    - ▪ *References*: Sections 5.6.2, 6.4.2
  - o Use caution if you:
    - ▪ Have automation deem incapacitation
    - ▪ Lock pilot out of ability to control aircraft
      - • *References*: Sections 6.1.2
- • Specific FAA Guidance and Requirements
  - o Minimum flight crew (i.e., the appendix associated with Sec. 25. 1523) requires that the design account for an incapacitated pilot.
    - ▪ *References*: Sections 5.7.2

- **Pilot Performance (which is separate from experienced workload)**
  - Challenge for single pilot to complete tasks currently performed by two pilots. Examples:
    - Aircraft configuration such as gear and flaps
      - *References*: Sections 5.6.2
    - Aircraft systems monitoring and management
      - *References*: Sections 5.6.2
      - Diagnosis of systems failures
        - *References*: Sections 6.3.2
    - Amended clearances, particularly when close to airport
      - *References*: Sections 6.3.2
    - Checklists
      - *References*: Sections 5.6.2
    - Diversions
      - *References*: Sections 6.3.2
    - Emergency evacuation
      - *References*: Sections 6.3.2
    - Flight guidance and autopilot/autothrottle configuration such as selection of the appropriate mode
      - *References*: Sections 5.6.2
    - Management of passengers and cabin crew
      - *References*: Sections 5.6.2
    - Monitoring of the aircraft state
      - *References*: Sections 5.6.2
    - Monitoring of external hazards
      - *References*: Sections 5.6.2
    - Performing emergency and abnormal procedures
      - *References*: Sections 5.6.2
    - Pre-flight phase, in general
      - *References*: Sections 6.3.2
      - Of particular concern during the pre-flight phase,
        - management of systems tasks
        - verification of fitness to fly
          - May be able to make use of gate agents to assist in this process.
        - "walk around"
    - Preparing for arrival and approach
      - *References*: Sections 6.3.2
    - Rapid decompression
      - *References*: Sections 6.3.2
    - Taxiing to avoid runway incursions
      - *References*: Sections 6.3.2

- o Tasks primarily associated with NextGen operations
  - ▪ closely spaced parallel approaches
    - • *References*: Sections 6.3.2
  - ▪ delegated separation
    - • *References*: Sections 6.3.2
  - ▪ in-trail procedures
    - • *References*: Sections 6.3.2
  - ▪ merging and spacing
    - • *References*: Sections 6.3.2
  - ▪ optimized profile descent
    - • *References*: Sections 6.3.2
- o Verbal call-outs
  - ▪ *References*: Sections 5.6.2
- o Verification of visual contact on approaches
  - ▪ *References*: Sections 5.6.2
- • Keep in mind that the pilot is the most capable system in aircraft but is also least reliable.
  - o *References*: Sections 6.4.2
- • Off-nominal events of concern
  - o Enabling a single pilot to conduct complex operating procedures (sometimes simultaneously) in normal, abnormal, and emergency scenarios may be challenging.
    - ▪ *References*: Sections 5.6.2
  - o May reduce ability to handle non-normal events
    - ▪ General identification of non-normal events being a challenge in SPO
      - • *References*: Sections 4.4, 5.3.2, 5.7.2, 6.3.2
- ▪ **Public and Stakeholders**
  - • Attempting to change the size of the crew can become highly politicized and visible.
    - o *References*: Sections 5.7.2
  - • General Public
    - o May decrease perceived safety and increase fear in public eye.
      - ▪ *References*: Sections 4.4, 4.5.2, 5.3.2, 6.2.2, 6.3.2
    - o Perhaps the burden should simply be put on passengers, who can determine whether or not they are willing to fly under SPO if it meant savings for them.
      - ▪ *References*: Sections 6.3.2
    - o Public might be more accepting of SPO if it were limited to short flights.
      - ▪ *References*: Sections 6.3.2
  - • May generate negative reactions from Congress
    - o *References*: Sections 4.5.2, 5.7.2
  - • May generate negative reactions from the media
    - o *References*: Sections 4.5.2

- May generate negative reactions from unions
  - *References*: Sections 4.5.2, 5.7.2, 6.2.2
  - Might be met with "push back" due to potential loss of pilot jobs.
    - *References*: Sections 5.7.2
  - Need to get unions "in the loop."
    - *References*: Sections 6.3.2
  - Need to involve all relevant unions (e.g., pilots, ATC, dispatch).
    - *References*: Sections 6.3.2
- Need to get all stakeholders involved early in the process.
  - *References*: Sections 6.4.2
- Need to get insurance companies involved in the process sooner rather than later.
  - *References*: Sections 6.3.2
- Pilots
  - Pilots' "egos" may be affected by the greater reliance on automation.
    - *References*: Sections 4.5.2
  - Move toward SPO could affect the number or type of individuals interested in flying as a profession.
    - *References*: Sections 4.5.2
  - The extra stress placed on pilots (by having to fly on their own) may affect willingness of pilots (in terms of compensation or otherwise) to accept SPO.
    - *References*: Sections 4.5.2, 6.3.2

- **Safety**
  - General mention that SPO poses safety issues.
    - *References*: Sections 4.4, 5.7.2
  - Accident rates for single-pilot operations in the military were found to be in the order of the rates found for GA, whereas the accident rates for the multi-pilot operations were found to be in the order of rates found for Part 121.
    - *References*: Sections 5.6.2
  - Historical statistics suggest that the presence of two pilots significantly enhances flight safety (by one to two orders of magnitude).
    - *References*: Sections 5.6.2
  - Remain focused on the main goal: safety. It is should not be our primary goal to have a particular number of pilots in the cockpit. Instead, developers should determine the minimum number of pilots necessary in the cockpit in order to reach safety goals.
    - *References*: Sections 6.4.2
  - When GA data are examined to compare single- vs. dual-pilot operations, the data are mixed (some comparisons say no difference, some comparisons suggest dual-pilot operations are safer).
    - *References*: Sections 5.3.2

- **Security**
  - Aircraft would need to react to a pilot with malicious intent in a similar manner to that of an incapacitated pilot.
    - *References*: Sections 6.4.2
  - Consider use of a pilot identity detection system (e.g., required fingerprint or retinal scan).
    - *References*: Sections 5.6.2
    - Would prevent unauthorized person from serving as a pilot.
      - *References*: Sections 5.6.2
  - How would a pilot with malicious intent be detected?
    - *References*: Sections 6.4.2
- **Selection of Pilots**
  - How will selection be handled for single pilots?
    - *References*: Sections 6.2.2
- **Social Interaction Reduced or Removed**
  - May produce boredom, which often produces lack of vigilance/attentiveness.
    - *References*: Sections 5.1.2, 5.3.2, 6.2.2
    - Long flights may be particularly difficult for the single pilot.
      - *References*: Sections 6.2.2, 6.3.2
    - Potential Solutions
      - Encourage pilots to engage in social conversations with ground personnel or onboard flight attendants.
        - *References*: Sections 5.1.2, 6.1.2
      - Limit SPO to relatively short flights.
        - *References*: Sections 5.1.2
    - Removal of peer pressure that encourages professionalism.
      - *References*: Sections 6.3.2
- **SPO in the Context of NextGen**
  - General identification of the two concepts being potentially "at odds."
    - *References*: Sections 4.4, 5.3.2, 6.2.2, 6.3.2
  - Future airspace may be more heavily "populated," which might add cognitive and task load.
    - *References*: Sections 5.7.2
  - May be difficult for a single-pilot aircraft and a reduced controller cadre to safely manage the required precision of NextGen (e.g., tailored arrivals and spacing), especially in complicated or off-nominal situations (e.g., weather factors, emergencies, etc.).
    - *References*: Sections 5.9.2, 6.1.2, 6.2.2, 6.3.2
  - May be difficult to get single-pilot aircraft certified in the context of NextGen.
    - *References*: Sections 5.9.2
  - NextGen research should not, but has been, ignoring the single pilot.
    - *References*: Sections 5.9.2, 6.3.2
  - NextGen will shift some controller monitoring tasks to pilots, which will presumably increase pilot workload.
    - *References*: Sections 5.7.2
  - Single-pilot operators must be able to perform the NextGen-required procedures or risk losing access (as some have suggested).

- o *References*: Sections 5.9.2
- o If two pilots are required for NextGen operations, have we made the system better? Have we made it safer?
- o *References*: Sections 5.9.2
- What additional elements might arise from future (i.e., NextGen) air transport operations, as well as procedural variations world-wide (i.e., responsibility of flight crew versus AOC in determining optimal routing en-route)?
  - o *References*: Sections 5.6.2
- Which NextGen agents will be responsible for strategic and tactical decision making? The answer to this question will impact SPO.
  - o *References*: Sections 6.3.2
- Will SPO change the accepted or expected response times for the single pilot as compared to a two-person crew in NextGen?
  - o *References*: Sections 6.2.2
- **Systems Approach to SPO**
  - Use NAS-Centric not Pilot-Centric Approach
    - o General recommendation to use this approach.
      - *References*: Sections 6.3.2
    - o Failure to utilize this approach may yield research findings that are not realistic.
      - *References*: Sections 6.3.2
      - Example: Current-day ATC "profiles" flights based on the type of flight and sometimes has different expectations for different types of flights (i.e., requests more or less of them).
        - *References*: Sections 6.3.2
    - o How will mixed equipage be addressed by all parties within the NAS (e.g., pilots, dispatch, ATC, etc.)?
      - *References*: Sections 5.5.2, 6.4.2
    - o How will the job of ATC change?
      - *References*: Sections 6.3.2
    - o There are many types of operations to examine for SPO: (1) aircraft automated systems and performance, (2) flight operations and pilot requirements, (3) the maintenance operations control center, and (4) the AOC.
      - *References*: Sections 5.5.2
  - Use System-oriented not Agent-oriented Approach
    - o Example: Two agents in the system (automation or human agents) could be doing what they have been told to do, but an undesirable outcome could be the result of the two actions.
      - *References*: Sections 6.2.2

- **Teamwork (between "agents")**
  - "Challenges" and cross-checking between agents should be made to be systematic and active.
    - *References*: Sections 5.2.2
  - CRM, in particular
    - In order to adopt SPO, we must explore issues related to CRM.
      - *References*: Sections 5.4.2, 5.6.2
      - What new CRM skills, if any, would be required under SPO?
        - *References*: Sections 6.2.2
    - CRM is technically the effective use of *all* available resources. Therefore, CRM is relevant to SPO.
      - *References*: Sections 5.4.2
      - When we ignore concepts related to CRM, we might limit ourselves to considering only aircraft control tasks (e.g., power control, flight control, and navigation).
        - *References*: Sections 5.4.2
  - When there is an exchange of full or partial control, how will we ensure the exchange is graceful?
    - *References*: Sections 6.1.2, 6.4.2
- **Technology and Decision Support Tools**
  - Although not necessarily a "required" technology, we might consider having something akin to FOQA (Flight Operational Quality Assurance). Rather than monitoring pilot reliability and performance, we would monitor automation reliability and performance.
    - *References*: Sections 6.2.2
  - Need to identify the enabling technologies.
    - *References*: Sections 4.3
    - Technologies and decision support tools may need to include:
      - a virtual pilot assistant
        - *References*: Sections 5.6.2
      - automation of complex tasks, like fuel management, should be fully or partially automated.
        - *References*: Sections 5.6.2
      - decision support tools for trajectory-based decisions.
        - *References*: Sections 6.2.2
      - decision support tools for systems management and coordination.
        - *References*: Sections 6.2.2
      - dispatch critical autopilot and auto-throttle.
        - *References*: Sections 5.6.2
      - dispatch having the same view as the flight deck.
        - *References*: Sections 6.3.2
      - effective voice synthesis.
        - *References*: Sections 6.4.2
      - enhanced systems automation.
        - *References*: Sections 5.6.2
      - electronic systems control.
        - *References*: Sections 5.6.2

- enhanced caution and warning system.
  - *References*: Sections 5.6.2
- enhanced external view.
  - *References*: Sections 5.6.2
- enhanced weather radar.
  - *References*: Sections 5.6.2
- intelligent voice recognition.
  - *References*: Sections 5.6.2
- pilot monitoring and recovery system.
  - *References*: Sections 5.6.2
- some form of display and control mirroring (i.e., allowing an agent to view the displays at another agent's station).
  - *References*: Sections 6.4.2
  - What information would need to be shared and in what form?
    - *References*: Sections 6.4.2
- Must be an attempt to identify all of the possible failures.
  - *References*: Sections 5.3.2

- **Training**
  - Ground support (e.g., ATC and AOC) would probably need additional training in terms of the technical, cultural, and organizational changes under SPO.
    - *References*: Sections 6.3.2
  - How will single pilots be trained?
    - *References*: Sections 6.2.2
  - How will we prevent skill degradation in the SPO environment, especially if automated systems are performing relatively more tasks?
    - *References*: Sections 6.2.2
  - Need to include new training component to teach pilots to use voice recognition system.
    - *References*: Sections 6.2.2
  - On long flights in particular, some training could occur while en route, when a pilot may become bored.
    - *References*: Sections 6.2.2
  - The single-pilot cockpit might be different enough from current-day cockpits that we might need to consider whether or not we need to "un-train" some behaviors.
    - *References*: Sections 6.2.2
  - With the loss of the second pilot, the idea of apprentice training is lost.
    - *References*: Sections 5.3.2, 6.3.2
    - Potential alternative: Could begin with an arrangement in which a second pilot observes the "single pilot" before the "single pilot" transitions into single-pilot operations.
      - *References*: Sections 6.3.2
  - Will training need to differ according to flight lengths?
    - *References*: Sections 6.2.2
- **Will SPO generate more problems than it solves?**
  - *References*: Sections 5.7.2

- **Workload**
  - May increase workload of the single pilot.
    - General identification of the issue that workload may increase.
      - *References*: Sections 4.4
  - Particular circumstances that may cause concern:
    - Communications
      - *References*: Sections 5.6.2
    - Navigation
      - *References*: Sections 5.6.2
- **Recommendations for Research in the Assessment of SPO Feasibility**
  - **General Guidance**
    - Assess effects of fatigue and boredom.
      - As an example, the workgroup wondered if fatigue will present the risk of overreliance on automation.
        - *References*: Sections 6.1.2
    - Consider examining SPO in the following order (1) examining FAR Part 135 in a bit more detail and learn what experienced companies have done (e.g., Cessna) in designing single-pilot aircraft; (2) Ask what we need to add to their research and design; (3) examine FAR Part 121 cargo operations; (4) evaluate FAR Part 121 VFR passenger flights (short flights) and fractionals.
      - *References*: Sections 6.3.2
    - Consider incorporating the theoretical framework put forth by Sheridan & Inagaki (2012) in which the automation-human machine relation can be examined.
      - *References*: Sections 5.1.2
    - Consider performing research in a way that includes successively more challenging platforms and proceed in this order (1) use of fast-time models; (2) human-in-the loop simulations; (3) flight trials with SPO-certified GA passenger jets; (4) trials by express mail carriers; and (5) trials by short-distance passenger carriers.
      - *References*: Sections 5.1.2
    - Consider the types of errors that are made in testing.
      - *References:* Section 5.2.2
      - Do not limit the exploration of errors and error types to human agents.
        - *References:* Section 5.2.2
      - Examples
        - Verification and communication errors
          - *References:* Section 5.2.2

- Identify the elements of complexity, the limits of the human in terms of complexity, and the threshold to distinguish when limits have been exceeded.
  - *References:* Section 6.3.2
  - These efforts will allow us to understand how the single pilot will perform in managing the aircraft under various levels of complexity.
    - *References:* Section 6.3.2
    - Will remove the need to equate complexity with aircraft weight.
      - *References:* Section 6.3.2
- Need to define what we mean by "risk" and identify effective predictive measures of risk.
  - *References: Section 6.3.2*
- The thresholds for workload need to be defined through some form of measurement, and this threshold would need to be identified for all parties.
  - *References: Sections 6.4.2*
- Use completely immersive and realistic environments when evaluating SPO. Workload surveys and the like are useful, but they are limited. Surveying pilots often can illuminate relative differences between two conditions. However, in this particular case, we are most interested in absolute workload (i.e., can a single pilot handle the job?).
  - *References: Sections 6.4.2*
- Use a variety of metrics in testing SPO.
  - *References: Sections 5.2.2, 6.1.2*
    - Examples
      - workload, interruptive automation, considerations for boundary conditions, and predictability of the human's work environment
        - *References*: Sections 5.2.2

- **Experimental and Simulation Research**
  - Consider an experiment in which a current, two-person crew might fly with a barrier erected between the two pilots. In this way, they would be able to talk with one another but not see one another. This experiment would allow us to learn about the "body aspect" in communications between the team members and understand the manner in which intentions are relayed.
    - *References*: Sections 5.5.2, 6.1.2
  - Determine what information should be shared, and with whom, if "display and control mirroring" is adopted as a means of sharing information.
    - *References*: Sections 5.5.2, 6.4.2
  - Experiments might be directed at making some of the SPO unknown unknowns merely unknowns.
    - *References*: Sections 5.1.2
  - How could flight test and/or simulation be used to validate technology application to the technical issues? Is this needed?
    - *References*: Sections 5.6.2

- When testing a new display, decision support, control, or the like, consider assessing the following:
  - effects of system errors and random errors
    - *References*: Sections 5.9.2
  - employ SHERPA (Systematic Human Error Reduction and Prediction Approach).
    - *References: Sections 5.9.2*
  - study human responses and the types of failures that occur
    - *References: Sections 5.9.2*
- **Survey Research**
  - Poll the aviation community to determine which, if any, SPO configuration (i.e., method for allocating the second pilot's tasks) is viable.
    - *References*: Sections 6.1.2
    - Ensure all stakeholders are represented.
      - *References*: Sections 6.1.2
  - Public needs to be surveyed to assess whether or not they will accept SPO.
    - *References: Sections 6.1.2, 6.2.2*
- **Large-scale, Real-world Research**
  - NextGen research has ignored the single pilot.
    - *References: Sections 5.9.2*
    - Research should be examining the larger metro-plex regions, as opposed to only hubs. General aviation accounts for a significant amount of traffic in airfields that surround major hubs, and some of this traffic is in the form of business jets with single-pilot operators.
      - *References*: Sections 5.9.2
  - ZAN (Anchorage Center) is a good place to begin examining SPO.
    - In this particular center, AOC already has the capability to speak directly with ATC.
      - *References*: Sections 6.3.2
- **Modeling**
  - A major challenge is how to measure and model the intentions and adaptive behavior of the human so that the computer can "understand."
    - *References: Sections 5.1.2*
  - Consider modeling the workflow of the flight deck as a means to gain insights into the possibility of SPO.
    - *References: Sections 5.2.2*
      - Dr. Pritchett's method could be considered.
        - *References*: Sections 5.2.2
  - Consider work tasks at different levels of abstraction.
    - *References: Sections 5.2.2*
  - If you model any teamwork (e.g., second pilot or team member of the ground), consider the notion that the second team member becomes a part of the first team member's environment, and team members cannot be modeled separately.
    - *References: Sections 5.2.2*
  - Pre-existing models of pilot behavior should be reviewed.
    - *References: Sections 5.1.2*
    - Review relatively newer models of pilot behavior, which take the cognitive components of the piloting task into account.

- **References**: Sections 5.1.2
- Examples:
  - ACT-R (Johnson-Laird et al.), Air Midas (Corker et al.), D-OMAR (Deutsch & Pew), and the challenges of model credibility with increasing complexity and pace of change (Foyle & Hooey).
    - **References**: Sections 5.1.2
- **Task Analyses**
  - We must carefully examine the tasks of the pilot-not-flying. Only thereafter, can we ask how, or if, we can allocate those tasks.
    - *References: Sections 5.1.2, 6.1.2*
    - Use checklists as a guide during any type of task analysis (or decisions regarding task allocations).
      - *References*: Sections 6.1.2
- **Literature Reviews**
  - DARPA has previously researched an ability to infer intent based on physiological measures. They explored questions such as, "What is the state of the automation, and what is the state of the human?" Thereafter, they examined how to make the information transparent to the operator and/or a human on the ground.
    - *References*: Sections 6.1.2
  - Explore RTSP, a performance-based standard for ATM, as a model for SPO requirements.
    - *References*: Sections 5.5.2
  - Norman's report (Norman, 2007) on SPO should be reexamined because it appeared to group various sub-groups who have different training, procedures, backgrounds, operations, and equipment.
    - *References: Sections 6.3.2*
  - Refer to the literature and/or incident and accident reports in order to explicitly identify how many incidents and accidents have been prevented by a second pilot.
    - *References: Sections 6.1.2, 6.3.2, 6.4.2*
    - In addition, explore the types of errors that have been prevented by a second pilot and the impact of these preventative actions.
      - *References*: Sections 6.3.2
    - One resource to use is the Aviation Safety Reporting System (ASRS) to explore this question.
      - *References*: Sections 6.4.2
  - Refer to the literature and/or incident and accident reports in order to search for cases in which design assumptions may have led to an incident and accident.
    - *References: Sections 6.1.2*
  - Related work conducted by DARPA (Defense Advanced Research Projects Agency) should be reviewed.
    - *References: Sections 5.1.2, 6.1.2*
  - Research the details of a version of a "super AOC" at one major airline, in which two people serve as virtual team members to ongoing flights. One of these jobs is labeled as the "flight operations duty manager." This person is actually a captain on the airline, but in this role, the person is considered an

assistant chief pilot. The role is filled 24 hours a day, and the person is meant to serve as a representative within the AOC for the captain and crew.

- *References: Sections 5.5.2*
  - Review an upcoming report from Kathy Abbott of the FAA.
    - *References: Sections 6.1.2*
  - Review any relevant literature that might exist from NASA's space-related efforts.
    - *References: Sections 6.1.2*
  - Review the work of Mr. Jay Shivley at NASA Ames Research Center. His research provides some guidance as to how tasks can be organized in a meaningful manner.
    - *References: Sections 6.1.2*
  - Review the work put forth by the task force involved in the move from 3 to 2 pilots.
    - *References: Sections 6.1.2*
  - Review the 1981 ASRS (Aviation Safety Reporting System) study that explored the performance of the single pilot under IFR (instrument flight rules).
    - *References: Sections 6.1.2*
  - Review literature to understand SPO as it is being practiced today.
    - *References: Sections 6.3.2*
  - Review literature from the military domain, such that SPO efforts can leverage off of their experience in single- and dual-pilot vehicle operations.
    - *References: Sections 6.1.2*
  - Review insurance-related issues.
    - In particular, learning about the involvement of insurance companies in past development efforts.
      - *References*: Sections 6.1.2
  - Review of the NextGen concept of operations, but the review should be performed "with an eye" for SPO.
    - *References: Sections 6.1.2*
  - Review the body of research on CRM, which dates back to the 1960s and 1970s. Review CRM training of today. Together, these two sources can be used to guide requirements and criteria.
    - *References*: Sections 5.4.2
  - The Mercedes Benz "Attention Assist System," and the related research, might be reviewed in developing systems for SPO.
    - *References: Sections 6.4.2*

- **Concepts Specifically Addressing Configurations for SPO and the Allocation of Responsibilities in SPO**
  - Potential Configurations
    - **1 Pilot, who Inherits the Duties of the Second Pilot**
      - General identification of the 1-pilot configuration
        - *References*: Sections 5.6.2
    - **1 Pilot, with Automation Replacing the Second Pilot**
      - General identification of the 1-pilot/automation configuration.
        - *References*: Sections 4.4, 5.6.2, 6.2.2, 6.3.2
    - **1 Pilot, with a Ground-based Team Member Replacing the Second Pilot**
      - General identification of the 1-pilot-on board/1-human-on-ground configuration.
        - *References*: Sections 4.4, 6.1.2, 6.2.2, 6.3.2
      - Options for Ground-Based Team Members
        - Dispatcher
          - *References*: Section 5.3.2, 5.5.2, 6.1.2
        - Remote pilot
          - *References*: Sections 5.5.2
    - **1 Pilot, with Onboard Personnel as Back-up**
      - General identification of the 1-pilot-on board/1-supporting-human on board configuration.
        - *References*: Sections 4.4, 6.1.2, 6.2.2, 6.3.2
      - Options for the Supporting Human On board
        - A second, qualified crew member on board, but not necessarily in crew compartment.
          - "Deadheading," commuting, or positioning pilots as back-ups.
            - *References*: Sections 6.3.2
        - A second, less qualified crew member on board, but not necessarily in crew compartment at all times.
          - Examples:
            - Flight attendants
              - *References*: Sections 5.1.2, 5.3.2, 6.1.2, 6.4.2
            - Flight marshals
              - *References*: Sections 5.1.2
            - Consider the use of a cabin commander.
              - Could serve to manage in-flight problems within the cabin. Duties would include problems with passengers as well as mechanical problems in the cabin. The single pilot could be relieved of some duties that are expected of pilots today.
                - *References*: Sections 6.4.2

- **Alternatives**
  - A distributed, cooperative team
    - Team might consist of: (1) the single pilot on the flight deck, (2) flight deck automation, (3) a cabin manager, (4) airborne support, (5) a ground support team, including an airport specialist, and (6) ground automation.
      - *References*: Sections 6.4.2
  - An extra pilot could be a MEL (minimum equipment list) item for certain conditions (e.g., when weather minima are questionable).
    - *References*: Sections 6.3.2
- *Strengths* **Associated with Various Configurations**
  - **1 Pilot, with Automation Replacing the Second Pilot**
    - Automation and the Pilot-Automation Interaction
      - Rather than asking what to do when automation fails, we perhaps should be asking how we design it so that it does not fail.
        - *References*: Sections 6.2.2
        - Example: fly-by-wire cannot fail, and we fully rely on it today.
          - *References*: Sections 6.2.2
    - Feasibility
      - Aircraft can essentially fly themselves today.
        - *References*: Sections 6.3.2, 6.4.2
      - Feasible under nominal conditions and some off-nominal conditions.
        - *References*: Sections 6.4.2
    - Technology has decreased the frequency of situations in which there are many events occurring simultaneously that are of high difficulty (as was the case early in aviation's history)
      - *References*: Sections 5.4.2
    - Teamwork (between "agents")
      - With teamwork, comes work associated with managing teams.
        - *References*: Sections 5.2.2
      - Human redundancy (e.g., for error checking) does not always yield better performance because two humans can make the same mistake.
        - *References*: Sections 5.2.2
    - This configuration may be the most likely to be adopted.
      - *References*: Sections 6.2.2
    - Training
      - The benefit of using automation is that you only have to "train" the automation once.
        - *References*: Sections 6.4.2
        - If you have humans performing the same task(s), you have to train numerous people and continually work to ensure they remain proficient.
          - *References*: Sections 6.4.2

- - As a rule of thumb, automation can be used if you can train a new person to perform the task(s).
      - *References*: Sections 6.4.2
  - **1 Pilot, with a Ground-based Team Member Replacing the Second Pilot**
    - Options for Ground-Based Team Members
      - Dispatcher
        - Feasibility
          - General mention of feasibility.
            - *References*: Sections 5.5.2
          - A type of "super AOC" already exists at one major airline.
            - *References*: Sections 5.5.2
      - Remote pilot
        - May be the most favored alternative.
          - *References*: Sections 6.1.2
- **General *Disadvantages, Challenges, Issues, or Questions* in Relation to Various Configurations**
  - **General Thoughts Regarding Allocation Strategies**
    - Any decision that requires direct interaction with or experiencing of the environment should be kept as "close" to the information as possible (i.e., the decision and experience should have a shared location).
      - *References*: Sections 6.1.2
    - Automation will not necessarily be reliable in doing what it's supposed to do, and some sort of human supervision of the systems is vital.
      - *References*: Sections 6.2.2
    - Consider tasks in their context before allocating tasks.
      - *References*: Sections 6.1.2
      - If we distribute tasks that are linked in a meaningful manner, we are probably creating a less effective system.
        - *References*: Sections 6.1.2
    - For those configurations with a distributed team (e.g., remote pilot, use of AOC, etc.), how can the state of all agents in the system be transparent to all other agents?
      - *References*: Sections 6.1.2
    - Ironically, from the perspective of a SPO initiative, the only time you truly find both current-day pilots in control is when there are mechanical or off-nominal issues.
      - When something unexpected occurs in a cockpit, a strict division of labor is typically employed. For example, the Captain might say something akin to "I'm flying the aircraft. You take care of X."
        - *References*: Sections 6.1.2
    - Should allocation strategies differ under nominal and off-nominal conditions?
      - *References*: Sections 6.2.2

- The following tasks should be reserved for the remaining pilot because UAS research has shown the human to outperform automation on most of these activities:
  - any task that requires "experiencing" a state (turbulence and icing).
    - *References*: Sections 6.1.2
  - Because automation might yield skill degradation, an effective guideline might be to avoid automation on any skill that must be maintained by the single pilot.
    - *References*: Sections 6.1.2
  - higher-order decision making (dealing with multiple failures, novel problems, collision avoidance, and strategic planning in general).
    - *References*: Sections 6.1.2
  - some tactical, some strategic tasks
    - A hazard warning is a perfect example of a tactical maneuver that might need to be reserved for the single pilot. If a hazard warning is heard, it would imply that automation has failed in doing its job, and the pilot would need to act.
      - *References*: Sections 6.1.2
  - visual tasks (see-and-avoid tasks, visual separation, looking at onboard weather radar, any visual procedures in the terminal area, pattern recognition)
    - *References*: Sections 6.1.2
  - Tasks suggested as being ones to reserve for the single pilot could be described as ones that:
    - are the difficult tasks, which may make SPO a challenge because none of the difficult tasks could be shared.
    - would require artificial intelligence vs. automation.
      - *References*: Sections 6.1.2
- The level of precision required by NextGen might determine the allocation of functions.
  - *References*: Sections 6.2.2
- The impact on the "aviate" category of tasks would be minimal in a move to SPO.
  - *References*: Sections 6.1.2
- The "navigate" and "communicate" categories represent the tasks of the present-day co-pilot, and the change would probably be most apparent in these two categories.
  - *References*: Sections 6.1.2
- When we re-allocate tasks amongst agents in the system, we may change the nature of the job in ways that are unforeseen. Need to be ready to address the new tasks that may be created by the change in allocations (e.g., new monitoring or communicating tasks may be created by new allocations of tasks).
  - *References*: Sections 6.1.2

- **1 Pilot, who Inherits the Duties of the Second Pilot**
  - Ergonomics
    - What elements could not be transferred due to cockpit design or layout?
      - *References*: Sections 5.6.2
  - Certification and Development of Requirements
    - What elements would violate regulations or standard practice relating to airworthiness and flight certification?
      - *References*: Sections 5.6.2
  - Safety
    - What elements would negatively impact safety if simply given to the pilot flying?
      - *References*: Sections 5.6.2
  - Workload
    - What elements would add to physical or mental workload of the pilot flying?
      - *References*: Sections 5.6.2
- **1 Pilot, with Automation Replacing the Second Pilot**
  - Automation and the Pilot-Automation Interaction
    - General mention that automation presents issues.
      - *References*: Sections 4.2, 5.6.2, 6.1.2
    - A general byproduct of automation is to increase high workload and decrease low workload.
      - *References*: Sections 6.3.2
      - Need to identify these circumstances.
        - *References*: Sections 6.4.2
    - Automation may reduce situation awareness.
      - *References*: Sections 6.2.2
    - Automation must anticipate pilot needs.
      - *References*: Sections 6.2.2
    - Automation must have CRM-like skills.
      - *References*: Sections 6.2.2
    - Automation should be conceived in levels and not be treated as an all-or-none state.
      - *References*: Sections 5.1.2
    - Automation should be approached using several taxonomies.
      - *References*: Sections 6.1.2
    - Automation would need to have the ability to successfully perform *all* tasks.
      - Automation would need to perform the jobs that were previously associated with the first officer (e.g., coordination and monitoring), but it would also need to successfully perform the duties of the primary pilot in cases of pilot incapacitation and the like.
      - *References*: Sections 6.2.2

- Automation could be used to ensure pilots do not get trapped in attention tunneling.
  - *References*: Sections 6.2.2
  - That is, the automation could serve to provide different perspectives on a problem.
    - *References*: Sections 6.2.2
- Automated systems should honor the pilot's priorities.
  - *References*: Sections 6.2.2
- Before adding automation, we should ask what a single pilot is able to do without more automation.
  - *References*: Sections 6.2.2
- Certification and Development of Requirements
  - Because the software has become so complex, one minor coding error in automation could "ripple through" the system and lead to an incomprehensible situation for the pilot. With this configuration, this situation may be worsened because more systems will be added, and some of these systems will be of high criticality because they take the place of the second pilot.
    - *References*: Sections 5.7.2
  - Methods for validating and verifying automation must be identified.
    - *References*: Sections 5.7.2
- Consider a conservative approach to automation in which automation helps only when it's too late for human input (e.g., auto-brake systems in automobiles).
  - *References*: Sections 6.4.2
- Consider whether automation will be passive or active.
  - Would it only respond when queried or would the system actively query (or even challenge) the single pilot?
    - *References*: Sections 6.2.2
  - Should the pilot be alerted only when there is a problem or when there *may* be a problem?
    - *References*: Sections 6.2.2
- Culture Considerations
  - Cultures may vary in terms of the automation acceptance and trust.
    - *References*: Sections 6.2.2
  - Culture could affect the acceptance of various design features (e.g., male or female voice).
    - *References*: Sections 6.2.2
- How transparent should the automated systems be and under what circumstances?
  - *References*: Sections 6.2.2, 6.4.2

- o Humans should not necessarily always be in control.
  - *References*: Sections 5.1.2
  - Should *not* be in control when:
    - the human is inattentive.
      - o *References*: Sections 5.1.2
    - there is little time to respond.
      - o *References*: Sections 5.1.2
    - the human is lacking the knowledge to manage the situation.
      - o *References*: Sections 5.1.2
      - o The human should *not* have authority if he or she does not have ability, the human should not have control if he or she does not have authority, and the human should not have responsibility if he or she does not have control.
        - *References*: Sections 5.1.2
- o Might need to design automation in "levels," such that if a relatively higher level of automation fails, the pilot can move to a lower level of automation and not be left without any assistance.
  - *References*: Sections 5.1.2
- o Need to identify tasks and circumstances under which tasks should:
  - be given to the human.
    - *References*: Sections 6.1.2, 6.2.2, 6.4.2
  - be given to the automation.
    - *References*: Sections 6.1.2, 6.2.2, 6.4.2
  - be shared between the human and automation.
    - *References*: Sections 5.1.2, 6.1.2, 6.4.2
  - be traded between the human and automation.
    - *References*: Sections 5.1.2, 6.1.2, 6.4.2
  - have a dynamic (shared or traded) allocation.
    - *References*: Sections 6.1.2, 6.2.2
    - If the allocation of functions is dynamic, what agent should be given the authority to assign functions?
      - o *References*: Sections 6.2.2
      - o Possibly difficult to certify a system that is programmed to behave in an environment with dynamic function allocation.
        - *References*: Sections 6.2.2
    - A dynamic arrangement may be the best one.
      - o *References*: Sections 6.2.2

- The dynamic arrangement may be the worst one.
  - *References*: Sections 6.1.2
  - Static automated systems would always perform in the same way.
  - Adaptable automated systems are ones that can change based on the human's input.
  - Adaptive automated systems are ones that would change their behaviors autonomously given the context.
  - Any automation that is relatively consistent (i.e., static or adaptable) may be relatively less worrisome than adaptive systems.
    - In the case of adaptive systems, the human would have the added workload associated with "tracking" the automation's current activities (e.g., Should I perform the task or is an automated system already doing that?).
    - *References*: Sections 6.1.2
  - Need an automation coordinator.
    - Should communicate with all systems and with pilot.
      - *References*: Sections 6.2.2
  - Pilot-Automation Communication
    - Automation must interact with the primary pilot in a human-like manner.
      - *References*: Sections 6.2.2
    - Natural communication (e.g., verbal and body language) is lost.
      - *References*: Sections 5.1.2
      - Consider a system that recognizes a pilot's hand or body gestures.
        - *References*: Sections 6.3.2

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- Probably need to include intelligent voice recognition system.
    - *References*: Sections 5.6.2, 6.2.2, 6.3.2, 6.4.2
    - Consider designing a system that can analyze the human's voice and be able to imply that the pilot is stressed.
        - *References*: Sections 6.2.2
    - How will a particular system "know" when the pilot is talking to it?
        - *References*: Sections 6.2.2
    - How will the automation handle interruptions (i.e., interrupting the pilot and/or the pilot interrupting it)?
        - *References*: Sections 6.2.2
    - Like a human, an automated system should be able to communicate exactly what it is doing and how it is accomplishing a task. This behavior would mimic what the first officer does in current-day practice.
        - *References*: Sections 6.2.2
    - Like a human, the system should be able to repeat information.
        - *References*: Sections 6.2.2
        - Such a system would serve to assist the pilot when he/she does not understand initial information or verify information for pilot.
        - In repeating the information, the system should perhaps relay the information more slowly, emphasize particular words, or revert back to the standard/formal manner of communicating a request (as ATC does in these circumstances).
        - *References*: Sections 6.2.2.
    - By communicating via voice, the system could assist the pilot with prospective memory (remembering to engage in planned tasks).
        - *References*: Sections 6.3.2

- Would the voice recognition be in the form of natural language or controlled language, with the latter requiring pre-defined phrases?
  - *References*: Sections 6.2.2
- Pilot and automation must be continually giving feedback to one another to stay synchronized.
  - *References*: Sections 5.1.2
  - Perhaps pilots will be required to communicate their intentions more actively/directly than they do today.
    - *References*: Sections 5.1.2
    - May not need intent inferencing if communication is direct input.
      - *References*: Sections 6.1.2
    - If intent information were directly input into the systems, its validity could be considered high. Therefore, that information could be shared with others in the NAS.
      - *References*: Sections 6.1.2
  - Need enhanced caution and warning systems.
    - *References*: Sections 5.6.2
- The acceptable response time must be identified, such that the automation will be able to infer that the pilot did not hear it, understand it, or is incapacitated.
  - *References*: Sections 6.2.2
  - Will there be boundaries placed on how often the pilot interacts with automated systems? In other words, if the pilot is silent for "too long" should the automated system be alerted that there may be a problem with the pilot?
    - *References*: Sections 6.2.2
- Role of the single pilot would become primarily a "systems manager" whose primary skills are associated with managing the onboard automation.
  - *References*: Sections 6.3.2
  - Why do we need automation at all, if the pilot will be monitoring it anyway?
    - *References*: Sections 6.4.2

- o There are some tasks or scenarios that automation cannot be designed to handle.
  - ▪ Examples:
    - • Prioritizing when multiple systems fail.
      - o *References*: Sections 6.3.2
    - • Smelling an odor which serves as a cue that something is wrong.
      - o *References*: Sections 6.4.2
- o We probably should not discuss "automation" as one concept or one system; we should discuss automation systems, with emphasis on the plural form of system.
  - • *References*: Sections 6.2.2
  - ▪ This language reminds us that we have multiple systems serving to automate different processes.
    - • *References*: Sections 6.2.2
- o When automation fails, it can be catastrophic. Humans can be innovative and deal with novel situations.
  - ▪ *References*: Sections 5.1.2
- o When identifying automation's role, do not limit the process by using only a task-oriented approach to automation. You may miss concepts such as prioritization and urgency.
  - ▪ *References*: Sections 5.4.2
- o With the increase in automation, be sure to avoid "over-proceduralizing" the pilot's job.
  - ▪ *References*: Sections 6.2.2
  - ▪ Allow for some creative decision making.
    - • *References*: Sections 6.2.2
  - ▪ Recent findings have shown that "over-proceduralizing" harms performance and decreases the amount of communication and cooperation between the team members.
    - • *References*: Sections 6.2.2
- • Pilot Incapacitation
  - o Ground personnel (e.g., ATC) would need to be informed of a flight's back-up plan in order to prevent confusion if pilot incapacitation did occur.
    - ▪ *References*: Sections 6.2.2
  - o Treat aircraft as an *optionally* piloted vehicle.
    - ▪ *References*: Sections 5.3.2, 5.5.2
- • Public and Stakeholders
  - o General concern regarding the reaction of stakeholders (e.g., insurance companies) to this configuration.
    - ▪ *References*: Sections 6.2.2
  - o Automation must be in a form that is also acceptable to the public.
    - ▪ *References*: Sections 6.2.2

- Safety
  - Design features would have to restore previous levels of safety (i.e., an equivalent level of safety to dual-piloted operations).
    - *References*: Sections 5.6.2
  - What existing technology could be applied to mitigate technical issues and restore flight safety levels to equivalence with multi-crew operations?
    - *References*: Sections 5.6.2
- Security
  - Need to ensure "hackers" cannot access automated systems.
    - *References*: Sections 6.1.2
- Social Interaction Reduced or Removed
  - To offset boredom, the human and automated systems could behave as two pilots in the sense that they might "trade-off" between them.
    - *References*: Sections 6.2.2
    - For example, two pilots might decide that the first pilot lands on this flight and the second lands on another flight.
      - *References*: Sections 6.2.2
- Teamwork (between "agents")
  - Distribution of tasks among humans lost.
    - *References*: Sections 5.2.2
    - If a problem arises in current-day operations, oftentimes one pilot works on the problem while the other pilot takes responsibility for flying.
      - *References*: Sections 6.3.2
  - Human redundancy (e.g., for error checking) lost
    - *References*: Sections 5.2.2, 5.7.2
  - To compensate for absence of second pilot, may need to include:
    - a virtual pilot's assistant
      - *References*: Sections 5.6.2
    - enhanced external view
      - *References*: Sections 5.6.2
    - enhanced weather radar
      - *References*: Sections 5.6.2
    - a person or system to cross-check the pilot's judgments.
      - Examples:
        - AOC
          - *References*: Sections 6.2.2
        - Automation
          - *References*: Sections 6.2.2

- **1 Pilot, with a Ground-based Team Member Replacing the Second Pilot**
  - Certification and Development of Requirements
    - For any possible situation in which a ground-based human serves to replace tasks formerly performed by a pilot, certification may become problematic.
      - *References*: Sections 6.2.2
  - Compared to an onboard pilot, a remote team member may have:
    - slower response times in urgent situations.
      - *References*: Sections 6.2.2, 6.4.2
    - lower situation awareness.
      - *References*: Sections 6.2.2
  - Communication Issues
    - Quality of the communication channel will be important.
      - *References*: Sections 5.1.2
    - Redundant and non-overlapping channels of communication probably are needed to avoid complete failures in the communication system.
      - *References*: Sections 5.1.2, 5.3.2
    - Time lag in communication must be addressed.
      - *References*: Sections 5.1.2, 6.1.2
    - Ground-based team member would have to possess the ability to interrogate the aircraft systems to receive information.
      - *References*: Sections 6.3.2
  - Might consider a debriefing session following flights. In this way, the single pilot could meet with the ground team and review the lessons learned from each flight.
    - *References*: Sections 6.4.2
  - Need a ground-based team member to be working with several aircraft if cost-savings are to be realized.
    - *References*: Sections 5.1.2
    - Need to identify the number of aircraft any type of ground-based team member would manage.
      - *References*: Sections 6.2.2
  - Need to consider whether a ground-based team member monitors an entire flight or not.
    - *References*: Sections 6.2.2
  - Need to identify the duty cycle for ATC if duties are changed.
    - *References*: Sections 6.4.2
  - Need to identify procedures associated with any ground-based automation failures.
    - *References*: Sections 5.1.2

- Options for Ground-Based Team Member
  - Dispatcher
    - Certification, and Development of Requirements
      - Controller-dispatcher data link communications and dispatcher-pilot data link communications would need to be certified (see Communications below).
        - *References*: Section 5.5.2
      - Would need to have a special dispatcher certification for SPO operations.
        - *References*: Section 5.5.2
    - AOCs may be able to manage much of flight planning, including weather.
      - *References*: Section 6.1.2
    - Communications
      - Challenge with having adequate bandwidth for communication and surveillance systems that support real-time interaction
        - *References*: Section 5.3.2, 6.4.2
      - Would require a highly automated AOC, integrated with the aircraft systems through advanced mediums.
        - *References*: Section 5.5.2
      - Would require 3-way communication
        - *References*: Section 5.5.2
        - Dispatcher's communication with the pilot would have to be in the form of direct links (e.g., primarily with digital data messaging, voice, or streaming video).
          - *References*: Section 5.5.2, 6.4.2
        - Currently, the dispatcher does communicate through company data link systems to flights but not with required communications performance standards.
          - *References*: Section 5.5.2
        - Dispatcher must have direct communications with air traffic control via the same data link modes the aircraft uses.
          - *References*: Section 5.5.2
        - Dispatch must have real-time aircraft situational displays.
          - *References*: Section 5.5.2

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- o Technologies such as the Automatic Dependent Surveillance-Broadcast (ADS-B) would need to be enabled for the dispatcher, such that the dispatcher can receive the same signal as the controller.
  - *References*: Section 5.5.2
- o Dispatcher must be able to interrogate the aircraft systems for real-time flight planning predictions (with 4-D trajectory information).
  - *References*: Section 5.5.2
- o Dispatcher must receive enhanced weather from onboard avionics.
  - *References*: Section 5.5.2
- o The advanced AOC system would need to be integrated into a single display in order to support the higher level of responsibility (e.g., Ocean 21).
  - *References*: Section 5.5.2
- Challenge in terms of the human resources
  - *References*: Section 5.3.2
  - Dispatcher typically can handle around 20, but the number decreases rapidly with non-normal circumstances.
    - o *References*: Section 5.3.2
  - Need to identify the duty cycle for dispatcher if duties are changed.
    - o *References*: Sections 6.4.2
- SPO dispatcher should not have to handle a mixture of flights.
  - *References*: Section 5.5.2
- Training
  - New training for dispatchers would be required.
    - o *References*: Section 5.5.2
- o Remote pilot
  - May need to allow for flexibility in the arrangement for the pool of ground pilots
    - *References*: Sections 5.1.2
    - When circumstances are demanding (e.g., non-normal), the number of aircraft the remote pilot can support may change.
      - o *References*: Sections 5.1.2
  - Need to identify the number of aircraft a remote pilot can manage.
    - *References*: Sections 5.5.2

- Need to identify the duty cycle for a remote pilot.
  - *References*: Sections 5.5.2, 6.4.2
- Need to consider whether the remote pilot monitors an entire flight or not.
  - *References*: Sections 5.5.2
  - Alternatives:
    - Dispatcher monitors the flight and then alerts an on-duty remote pilot when needed.
      - *References*: Sections 5.5.2
- Treat aircraft as a *remotely* piloted vehicle (refer to existing UASs).
  - *References*: Sections 5.3.2
  - Cost
    - Treating the aircraft as an optionally piloted aircraft with remote pilot is the most expensive alternative.
      - *References*: Sections 5.5.2
  - Safety
    - Treating the aircraft as an optionally piloted aircraft with remote pilot is the safest alternative.
      - *References*: Sections 5.5.2
- Pilot Incapacitation
  - Must be mindful of international factors when identifying procedures for pilot incapacitation and consider whether the procedures would work outside of the US.
    - *References*: Sections 6.4.2
    - Is it possible to control an aircraft from halfway around the world?
      - *References*: Sections 6.4.2
- Security
  - Communications between ground and air would need to be fully secured.
    - *References*: Sections 5.3.2, 6.1.2, 6.4.2
  - Because of this risk, this configuration may lead to high publicity.
    - *References*: Sections 5.7.2
  - Yields a new "doorway" for terrorism.
    - *References*: Sections 5.3.2, 5.7.2
- Teamwork (between "agents")
  - CRM, in particular
    - CRM methods need to be identified for a distributed team.
      - *References*: Sections 6.4.2

- o It would not be surprising if single pilots develop an animosity towards ground crews under such a configuration. The onboard pilots may feel they should necessarily be in a superior role because it is their lives and licenses on the line.
  - *References*: Sections 6.3.2
- o Need to address measurement and evaluation of the team's performance, if SPO is meant to include a team that extends beyond the cockpit.
  - *References*: Sections 6.4.2
- Will or should ground-based team member's tasks be combined with that of a regular controller?
  - o *References*: Sections 5.1.2
    - Should probably remain separate from the regular controller's tasks, but we need to consider how these two roles will be integrated, if at all
      - *References*: Sections 5.1.2
- Technology and Decision Support Tools
  - o What types of displays and information will be needed by the ground-based personnel?
    - *References*: Sections 6.1.2

- **1 Pilot, with Onboard Personnel as Back-ups**
  - Aircraft could have simplified types of functions (e.g., "the big red button" or "digital parachute" so to speak) available to allow for several options when considering a backup for an incapacitated pilot.
    - o *References*: Sections 5.3.2
  - Post 9/11 cockpit doors become an issue
    - o *References*: Sections 5.4.2, 6.2.2
  - Training
    - o What type of and how much training would this person need?
      - *References*: Sections 6.2.2

- **Alternatives**
  - A distributed, cooperative team
    - o Consider the use of an airport specialist.
      - Could assist the single pilot with questions or problems specifically related to arrival and departure.
        - *References*: Sections 6.4.2
    - o Consider the use of a cabin commander.
      - Could serve to manage in-flight problems within the cabin. Duties would include problems with passengers as well as mechanical problems in the cabin. The single pilot could be relieved of some duties that are expected of pilots today.
        - *References*: Sections 6.4.2
    - o Consider the use of a wingman (or wingmen).
      - Wingman would be a pre-identified pilot in another, nearby flight. Could assist the single pilot by: (1) providing general operational support to the single pilot, (2) running checklists, (3) navigating around weather and turbulence, especially since they would be

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proximate, (4) monitoring his or her alertness, (5) providing general decision making support, and (6) "checking back in" with the single pilot to ensure resolution of the problem.

- *References*: Sections 6.4.2

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Point of Contact: Walter Johnson, NASA Ames Research Center, MS 262-2, Moffett Field, CA 94035; (650) 604-3667.

14. ABSTRACT

Researchers at NASA Ames Research Center and NASA Langley Research Center are jointly investigating issues associated with potential concepts that might allow a single pilot to operate under conditions that are currently reserved for a minimum of two pilots. On April 10-12, 2012, NASA Ames Research Center hosted a technical interchange meeting in order to gain insight from members of the aviation community regarding single-pilot operations (SPO). Approximately 70 people representing government, academia, and industry attended. The meeting resulted in the identification of some overall costs and benefits associated with SPO. In addition, task allocation strategies that might support SPO were identified. When possible, attendees also identified the particular strengths and weaknesses associated with a given allocation strategy and provided recommendations to consider if a particular strategy were to be adopted. Finally, attendees identified areas of research that might be useful in determining the feasibility of SPO or in conceptualizing and developing an environment that supports SPO.

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