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A Validated Task Analysis of the Single Pilot Operations Concept

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January 2015

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Acronyms

ASL ..... above sea level
ATC ..... Air Traffic Control
ATIS ..... Automatic Terminal Information Service
CA ..... Captain
CDU ..... computer display unit
ConOps ..... concept of operations
CRM ..... Crew Resource Management
CTA ..... Cognitive Task Analysis
DA ..... Dedicated Assistance
FDDRL ..... Flight Deck Display Research Laboratory (NASA Ames Research Center)
FO ..... First Officer
ft ..... feet
FY ..... fiscal year
GO1 ..... Ground Operator 1
GO2 ..... Ground Operator 2
GO3 ..... Ground Operator 3
ILS ..... Instrument Landing System
NAS ..... National Airspace System
NASA ..... National Aeronautics and Space Administration
NextGen ..... Next Generation Air Transportation System
OBP ..... On-Board Pilot
PF ..... pilot flying
PM ..... pilot monitoring
PNG ..... pilot not flying
SME ..... subject matter expert
SPO ..... Single Pilot Operations

A Validated Task Analysis of the Single Pilot Operations Concept

Cynthia A. Wolter[1] and Brian F. Gore[2]

Executive Summary

The current day flight deck operational environment consists of a two-person Captain/First Officer crew. A concept of operations (ConOps) to reduce the commercial cockpit to a single pilot from the current two pilot crew is termed Single Pilot Operations (SPO). This concept has been under study by researchers in the Flight Deck Display Research Laboratory (FDDRL) at the National Aeronautics and Space Administration's (NASA) Ames (Johnson, Comerford, Lachter, Battiste, Feary, and Mogford, 2012) and researchers from Langley Research Centers (Schutte et al., 2007). Transitioning from a two pilot crew to a single pilot crew will undoubtedly require changes in operational procedures, crew coordination, use of automation, and in how the roles and responsibilities of the flight deck and ATC are conceptualized in order to maintain the high levels of safety expected of the US National Airspace System. These modifications will affect the roles and the subsequent tasks that are required of the various operators in the NextGen environment. The current report outlines the process taken to identify and document the tasks required by the crew according to a number of operational scenarios studied by the FDDRL between the years 2012-2014.

A baseline task decomposition has been refined to represent the tasks consistent with a new set of entities, tasks, roles, and responsibilities being explored by the FDDRL as the move is made towards SPO. Information from Subject Matter Expert interviews, participation in FDDRL experimental design meetings, and study observation was used to populate and refine task sets that were developed as part of the SPO task analyses. The task analysis is based upon the proposed ConOps for the third FDDRL SPO study. This experiment possessed nine different entities operating in six scenarios using a variety of SPO-related automation and procedural activities required to guide safe and efficient aircraft operations. The task analysis presents the roles and responsibilities in a manner that can facilitate testing future scenarios. Measures of task count and workload were defined and analyzed to assess the impact of transitioning to a SPO environment.

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1.0 Introduction

When dealing with complex system redesigns such as the proposed Single Pilot Operations (SPO) in the National Airspace System (NAS) in the United States, it is necessary to evaluate the impact that the redesign will have on the roles and responsibilities of all of the agents operating within the system. This analysis can take many forms, including empirical simulations of the environment experiencing the complex redesign, semi-structured task analyses of the redesigned environment, and / or computational modeling to generate predictions of the impact of the redesigned systems on the baseline operational environment (among other approaches). In order to fully understand the effect that new system designs have on the system performance, and on all of the agents within the system, documenting the tasks that are currently required for the safe operation of the system and comparing this baseline task analysis with the tasks required in the redesigned system provides insight into potential problem areas for the redesigned system. The objective of the current research was to conduct a task analysis (iteratively validate/refine sets of tasks) associated with likely SPO environments to measure the impact of transitioning to SPO from current-day operations based on the simulations being completed out of the FDDRL over the past three years.

The current-day flight deck operational environment consists of a two-person Captain/First Officer (CA/FO) crew. A concept of operations to reduce the commercial cockpit from the current two-pilot crew to a single pilot is termed Single Pilot Operations. This concept has been under study by researchers in the Flight Deck Display Research Laboratory (FDDRL) at the National Aeronautics and Space Administration's (NASA) Ames Research Center (ARC) (Johnson, Comerford, Lachter, Battiste, Feary, and Mogford, 2012) and Langley Research Center (LaRC) (Schutte et al., 2007). The ARC FDDRL research focuses on air-ground integration issues, while the LaRC research focuses on flight deck design issues. Both the ARC and LaRC research teams foresee that transitioning from a two-pilot crew to a single-pilot crew will undoubtedly require changes in operational procedures, crew coordination, in use of automation, and in how the roles and responsibilities of the flight deck and Air Traffic Control (ATC) are conceptualized in order to maintain the high levels of safety expected of the U.S. National Airspace System (NAS). The work consisted of: conducting a detailed task analysis of candidate FDDRL scenarios, refining existing current day approaches to reflect the roles/responsibilities of proposed SPO entities, and augmenting the SPO scenarios to include responses to off nominal scenarios using the full implementation of the augmented number of ground based operators. In performing this work, the task analysis team reviewed relevant literature, interviewed subject matter experts with active commercial aviation

1.1 The Task Analysis

A task analysis is the process whereby the tasks to safely fly the aircraft with automation are analyzed, documented and outlined (Kirwan & Ainsworth, 1992). The task analysis is a methodology covering a range of techniques to describe, and in some cases evaluate, the human-machine and human-human interaction in systems. It is often described as the study of what an operator (or team) is required to do in terms of actions or cognitive processes to achieve a specific system state. Typically, it is characterized by a hierarchical decomposition of how a goal-directed task is accomplished, including a detailed description of activities, task and element durations, task frequency, task allocation, task complexity, environmental conditions, necessary clothing and equipment, and any other unique factors involved in, or required for, one or more people to perform a given task (Kirwan & Ainsworth, 1992).

One type of task analysis, the Cognitive Task Analysis (CTA) identifies all of the critical cognitive tasks that the operator is required to perform with the automation (Diaper, 1989; Zachary, Ryder, &

Hicinbothom, 1998). CTA is a family of methods and tools for gaining access to the mental processes that organize and give meaning to observable behavior. CTA methods describe the cognitive processes that underlie the performance of tasks and the cognitive skills needed to respond adeptly to complex situations. Knowledge is elicited through in-depth interviews and observations about cognitive events, structures, or models. Often the people who provide this information are *subject matter experts* (SMEs)—people who have demonstrated high levels of skill and knowledge in the domain of interest (Klein, 2000). The CTA is a complement to traditional task analysis as it adds the capability for designing for the unanticipated by describing the constraints on behavior rather than solely describing the behavior. These approaches feed into a concept-verification phase, where the research concept is verified by a human-system engineer, and preparations are made to implement the results from the task analyses into a model form (Gore, 2008).

1.2 Current Day Operations

The traditional roles of the cockpit operators are defined as Captain (CA) and First Officer (FO) roles. The CA is the main pilot of the aircraft and the one who remains ultimately responsible for the aircraft, its passengers, and the crew. The CA sits in the left seat of the cockpit. The FO is the second pilot of an aircraft. The FO sits in the right-hand seat in the cockpit. One pilot is designated the "pilot flying" (PF) and the other the "pilot not flying" (PNF), or "pilot monitoring" (PM), alternating during each flight phase as necessary. Even when the FO is the flying pilot, the CA is in command and has legal authority of the aircraft. The amount of time either pilot is in control of the aircraft is near equal in normal operations, as the PF designation is passed back-and-forth throughout any given flight. In typical day-to-day operations, the essential job tasks are distributed fairly equally but final decisions always remains with the CA (pilot-in-command). Some have defined the shared roles in the cockpit as being *Aviate*, *Navigate*, *Communicate*, and *Systems Management* (Billings, 1997). Modifications to the manner that this shared cockpit is implemented might be necessary in SPO.

1.3 Single Pilot Operations

In SPO, it is entirely possible that multiple operators and entities will be required to guide the safe transport of the aircraft (Johnson et al., 2012). In this proposed distribution of roles and responsibilities in the SPO environment, a division of tasks between 9 entities will be explored: an On-Board Pilot (OBP), Ground Operator 1 (GO1), Ground Operator 2 (GO2), Ground Operator 3 (GO3), each with their own operator-specific automation (Flight Deck Automation, Ground Automation 1, Ground Automation 2, and Ground Automation 3), and Air Traffic Control. In this SPO iteration, the GOs would be fully trained pilots capable of flying the aircraft alone in the event that incapacitation of the OBP pilot. Three experiments conducted by the FDDRL will illustrate the basis for the scenario-based tasks that were included in the task analysis and the manner that it was created in an iterative fashion.

1.4 Single Pilot Operations Background Research

In the first SPO study conducted by Johnson, Comerford, Lachter, Battiste, Feary, and Mogford (2012), pairs of pilots were asked to complete simulated flight segments in each of two conditions: Co-located, and remote. The pilots were purposely presented with a critical situation that required problem solving. The situation was one in which the crew encountered severe weather during their flight and needed to divert to an alternate airport. Scenarios added complexity to the diversion task, such as the amount of fuel onboard to support planned or unplanned diversions and system failures such as anti-skid that required the crew to recalculate landing weights and distances.

The co-located condition required that pilots work together in a two-person flight simulator, a scenario that corresponded to current-day conditions. The remote condition required that the right and left seats of the cockpit be placed in different rooms, a scenario that represented one version of a SPO concept. The crew in the remote condition version of the SPO concept was allowed to communicate freely, however they could not see each other, observe each others' body language or point to information like weather cells on the navigation display. The interaction of the crew would be impacted by this change to SPO and part of the current task was to identify how the tasks would change as a function of such SPO operations.

A second SPO study evaluated the use of Crew Resource Management (CRM) indicators and shared charts to aid both ground and air-based pilots' communication and to enhance collaboration (Lachter, Brandt, Battiste, Ligda, Matessa & Johnson, 2014). Along with nominal, current-day baseline trials, pilots were separated as a distributed crew, with the CA on the flight deck and the FO on the ground, serving as dispatch with limited support to the OBP for multiple company aircraft. The concept of requesting Dedicated Assistance (DA) was also explored, both with the assistance of automation (CRM tools) and without. This study also presented a situation in which the pilots encountered severe weather that necessitated a diversion to an alternate airport.

A third SPO study focused on the transition between actively controlling multiple aircraft to actively controlling a single aircraft during dedicated assistance (see Johnson et al., in press). Two crew configurations were studied to identify the optimal allocation of responsibilities. In the SPO Hybrid condition, one GO performing dispatch duties to the distressed aircraft, along with other company aircraft, would transition to a dedicated assistant (ground-based FO) when requested by the OBP of the distressed aircraft. Their other nominal aircraft was automatically handed off to other GOs. In the SPO Specialist condition, a Specialist GO was waiting, on call, for a dedicated assistance request by an OBP of any distressed aircraft. The distressed aircraft was then automatically handed off from the "dispatch" GO to the Specialist GO.

1.5 Single Pilot Operations Candidate Roles

A review of the requirements in the above-described studies augmented the 2013 task analysis of SPO scenario manipulations (Wolter & Gore, 2013). Finer level of detail and validation came from subsequent interviews and collaboration with SMEs (C. Wolter, B. Gore, V. Battiste & R. Kotesky, personal communication, January 30, 2013, and May 16, 2013; C. Wolter. R. Kotesky & W. Preston, personal communication, April 22, 2014). In this paper, we explore the differences between a nominal SPO flight and off-nominal SPO flights that require DA, all of which begin with the same flight plan into Denver. In nominal operations, the OBP would be in sole control of decision-making and flying tasks, only relying on the GO for dispatch information and communication with maintenance and company personnel. In off-nominal operations, the OBP can request DA where the GO becomes a ground-located FO.

In this case, PF and PNF designations would vary between the OBP and the GO, with possible multiple mid-flight reassignments until the OBP releases DA. Most settings and radio communications would remain solely PNF responsibilities. Current CA specific tasks would remain the same and would always fall to the OBP. Both human operators would continually monitor instruments and radio communications, as well as perform crosschecks when notified of a change via voice or automation, and verify that the environment is consistent with their internal schema.

Due to a "separated cockpit", automation will play a large role in notifying the OBP and GO of any changes so that either could verify without undue radio congestion. The current mode of Dispatch or

DA would determine the type of automation available. In the DA mode, automation would notify a human operator if their ground or air-based counterpart had made changes such as: radio frequency, altitude, heading, speed, altimeters, computer display unit (CDU) inputs/executions, entering/exiting holds, approach mode, speed brake, landing gear, touchdown zone elevation, or flaps. In the Dispatch mode, automation would monitor the GO for conformance and notify if an aircraft needs assistance or has not been checked up on for a specified period of time. Automation will also notify parties of emergency situations when an aircraft reaches flight-based touch-points, such as when an aircraft passes below 18,000 ft. Advancements in automation may relieve the human operators of some tasks such as getting the current Automatic Terminal Information Service (ATIS), setting altimeters, loading expected arrival information and clearances from ATC. A major notable difference between the current day and the SPO environment is the shift to 'communication-cued' crosschecks (verbal or automated) rather than 'movement-cued' crosschecks that occur in a shared cockpit. Automation will need to account for these overt and covert characteristics associated with a human "good crew member." Automation that mimics the characteristics of a "good crew member" can lead to increased efficiencies; which in turn lead to increased spare capacity to deal with unforeseen events.

For the all SPO flights analyzed, there is a task decomposition of two candidate roles and responsibilities for the ground operators. In the Hybrid off-nominal condition, a GO who is serving as dispatcher with limited OBP support to 10 aircraft, will hand-off 9 of their aircraft to other GOs when DA is requested by an OBP of a distressed aircraft. They will then perform both dispatch tasks and FO tasks for the distressed aircraft. In the Specialist off-nominal condition, a GO who is serving as dispatcher with limited OBP support to 10 aircraft, will hand-off a distressed aircraft to a specialist GO when DA is requested by the OBP of that aircraft. The specialist GO will then perform both dispatch tasks and FO tasks for the distressed aircraft.

1.6 Research Objectives

The objective of this research was to iteratively validate/refine sets of tasks associated with likely SPO environments to measure the impact of transitioning to SPO from current day operations. The tasks identified in the task analysis are linked together in a string of both sequential and parallel nodes. These nodes represent networks that can then be used to analyze different scenarios and task assignments for their impact on workload, efficiency, and safety. Possessing such task analyses allows researchers to explore the degree to which the location and roles of pilots (co-located or remote) impact the ability of the crew to work as an effective, separated, two-person crew as compared to a co-located two-person crew. Potential SPO ConOps were measured by task count and task workload to assess the impact of the transition.

2.0 Method

For the current research, task decompositions that included both the task analysis and a semi-structured CTA of six scenarios (described below) of a planned approach into Denver starting at 37,000 ft Above Sea Level (ASL) with the crew operating under (a) current-day rules, (b) SPO Hybrid rules, or (c) SPO Specialist rules, were completed. Each rule set was tested in either nominal approach to land or an off-nominal condition requiring the dynamic replanning of an alernate airport was completed. The task network analyses are represented with task decomposition spreadsheets and task networks.

2.1 Scenarios

Scenario 1a. Current Day Nominal: Instrument Landing System (ILS) approach into Denver runway 16L.

The first task analysis scenario began before the top of descent at 37,000 ft ASL, near the YANKI waypoint. The crew included a CA and a FO. For this flight, the CA had the role of PF and the FO that of the PNF. CA/FO specific tasks are noted (see Figure 1a and Appendix A).

Scenario 1b. Current Day Off-Nominal: Planned ILS approach into Denver runway 16L with a diversion to Cheyenne runway 27L.

The second task analysis began before the top of descent at 37,000 ft ASL, near the YANKI waypoint. During the descent into Denver, a severe weather hold was initiated at LANDR at 17,000 ft and the crew discussed and decided on their alternate landing points. The crew included a CA and a FO. For this flight, the CA had the role of PF and the FO that of the PNF. CA/FO-specific tasks are noted (see Figure 1b and Appendix B).

Scenario 2a. SPO Hybrid Nominal: ILS approach into Denver runway 16L.

The third ask analysis began before the top of descent at 37,000 ft ASL, near the YANKI waypoint. The crew included an OBP, a company GO (GO1), flight deck automation, and ground automation. Two additional GOs, their ground automations, and ATC are also represented in the analysis. The OBP was always the CA of the flight. The GOs each monitored 10 aircraft, provided limited support, and primarily performed dispatch duties for their assigned aircraft. The GOs were available for DA support but DA was not initiated in this scenario (see Figures 1a, 2a, and Appendix C).

Scenario 2b. SPO Hybrid Off-Nominal: Planned ILS approach into Denver runway 16L with a diversion to Cheyenne runway 27L.

The fourth task analysis began before the top of descent at 37,000 ft ASL, near the YANKI waypoint. During the descent into Denver, a severe weather hold was initiated at LANDR at 17,000 ft and the crew discusses and decides on their alternate. The crew included an OBP, a company GO (GO 1), flight deck automation, and ground automation. Two additional GOs, their ground automations, and ATC are also represented in the analysis. The OBP was always the CA of the flight. The GOs each monitored 10 aircraft, provided limited support, and primarily performed dispatch duties for their assigned aircraft. The GOs were available for DA support, which was requested by the OBP of “NASA01.” GO 1 then released their other aircraft to the other GOs and offered dedicated support to NASA01 until DA was no longer needed and released by the OBP. During DA, GO also performed dispatch duties for NASA01 (see Figures 1b, 2b, and Appendix D).

Scenario 3a. SPO Specialist Nominal: ILS approach into Denver runway 16L.

The fifth task analysis began before the top of descent at 37,000 ft ASL, near the YANKI waypoint. The crew included an OBP, a company GO (GO 1), a Specialist GO, and their automations. One additional GO, their ground automation, and ATC are also represented in the analysis. The OBP was always the CA of the flight. The GOs each monitored 10 aircraft, provided limited support, and primarily performed dispatch duties for their assigned aircraft. The Specialist GO was "offline" and available for DA support but DA was not initiated in this scenario (see Figures 1a, 2a, and Appendix E). Because DA was not initiated here, the task assignments for this scenario are fundamentally the same as Scenario 1b above.

Scenario 3b. SPO Specialist Off-Nominal: Planned ILS approach into Denver runway 16L with a diversion to Cheyenne runway 27L.

The sixth task analysis began before the top of descent at 37,000 ft ASL, near the YANKI waypoint. During the descent into Denver, a severe weather hold was initiated at LANDR at 17,000 ft and the crew discusses and decides on their alternate. The crew included an OBP, a company GO (GO 1), a Specialist GO, and their automations. One additional GO, their ground automation, and ATC are also represented in the analysis. The OBP was always the CA of the flight. The GOs monitored 10 aircraft, provided limited support, and primarily performed dispatch duties for their assigned aircraft. The Specialist GO was "offline" and available for DA support, which was requested by the OBP of "NASA01." The GO then released NASA01 to the Specialist GO but retained their other aircraft. The Specialist GO offered dedicated support to NASA01 until DA was no longer needed and released by the OBP back to the GO. During DA, the Specialist GO would also perform dispatch duties for the distressed aircraft (see Figures 1b, 2c, and Appendix F).

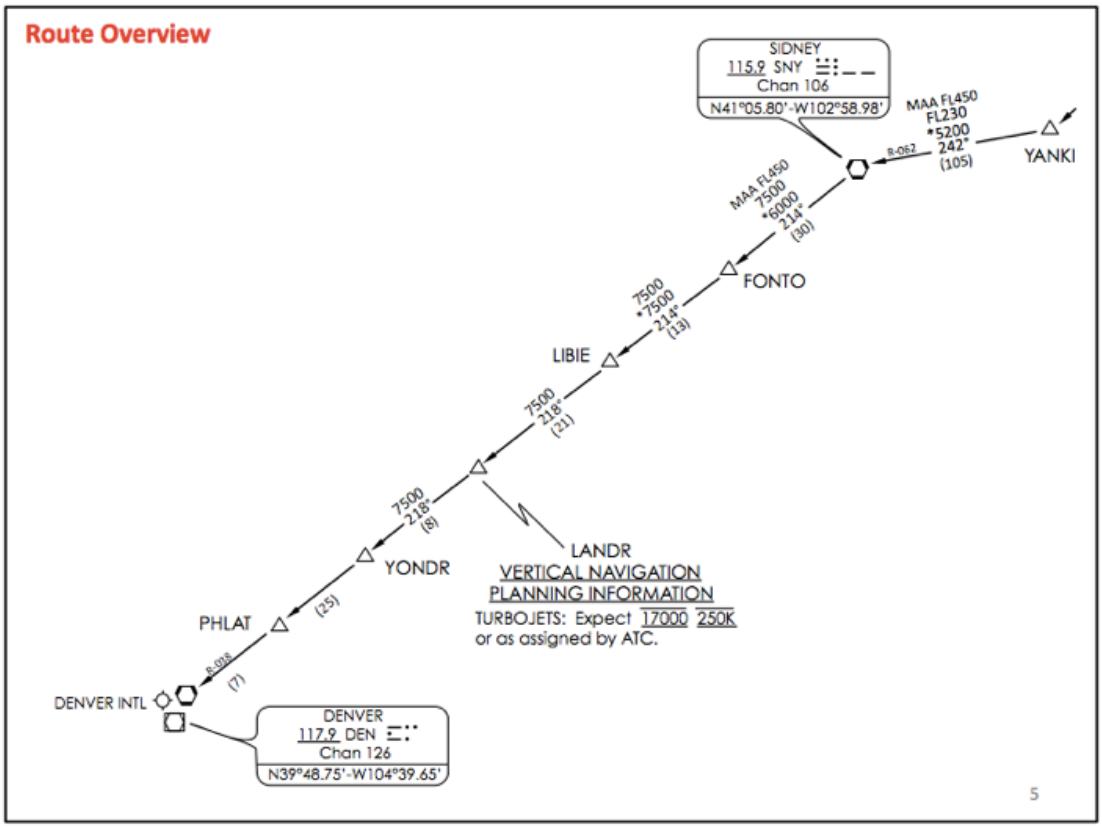

Figure 1a. Denver approach (nominal).

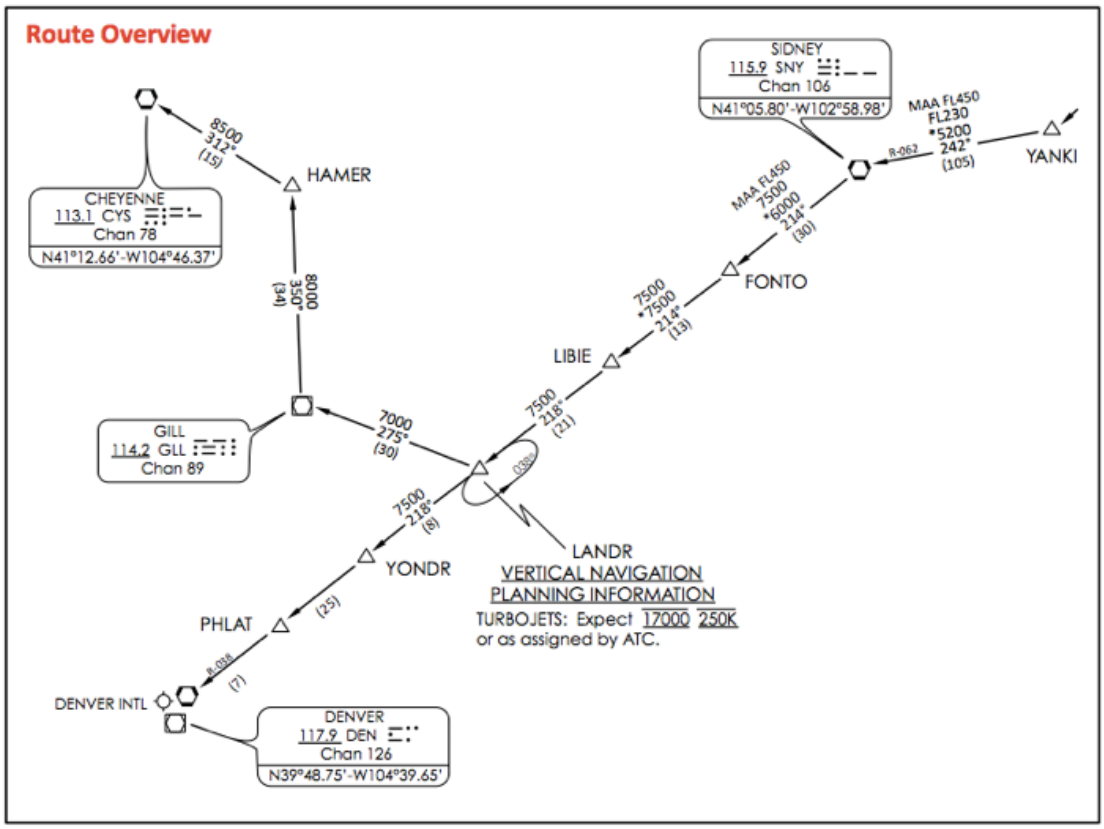

Figure 1b. Divert to Cheyenne approach (off-nominal).

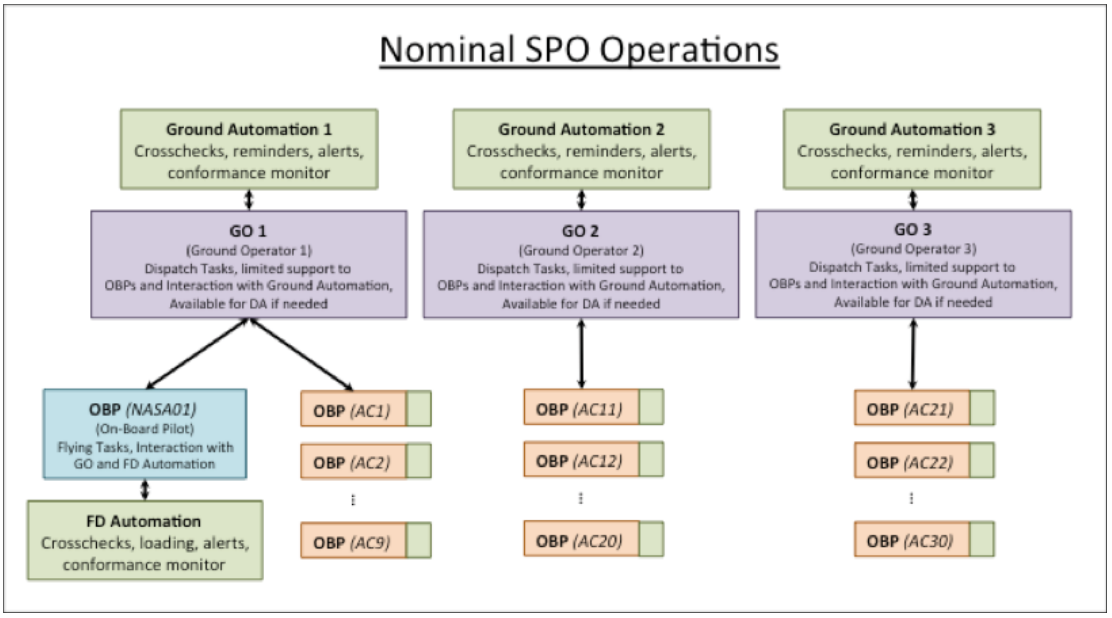

Figure 2a. Nominal SPO operations.

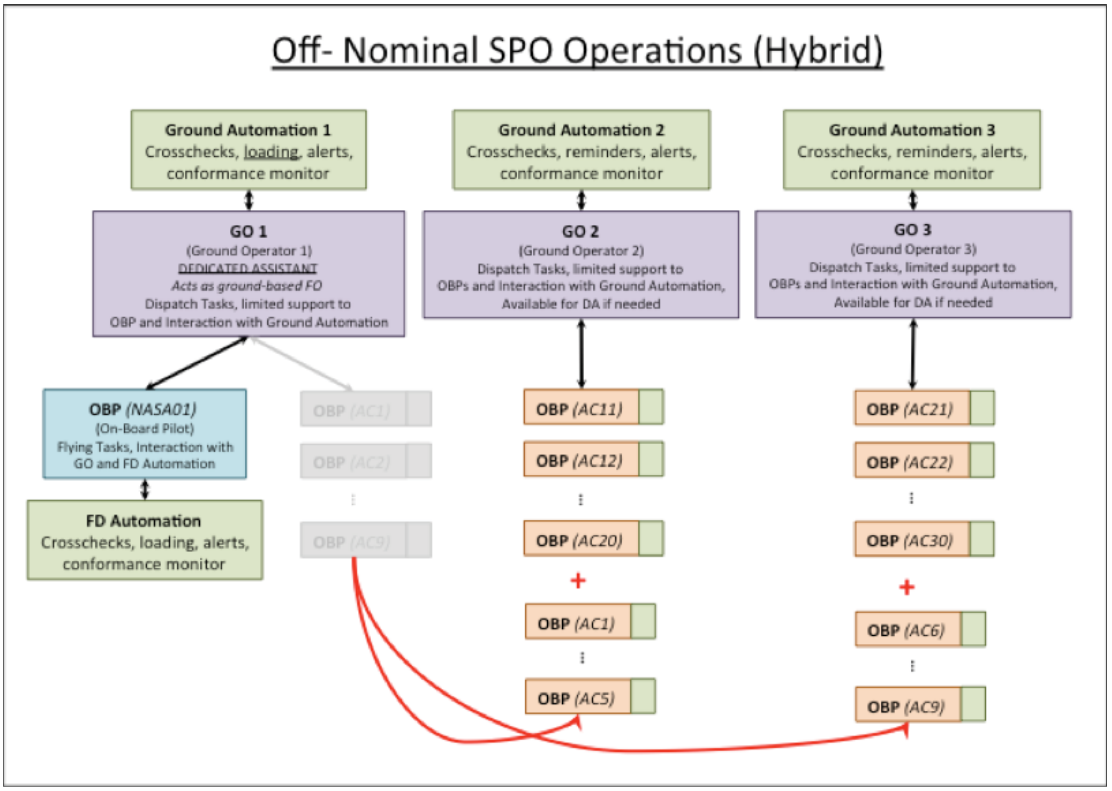

Figure 2b. Off-nominal SPO hybrid operations.

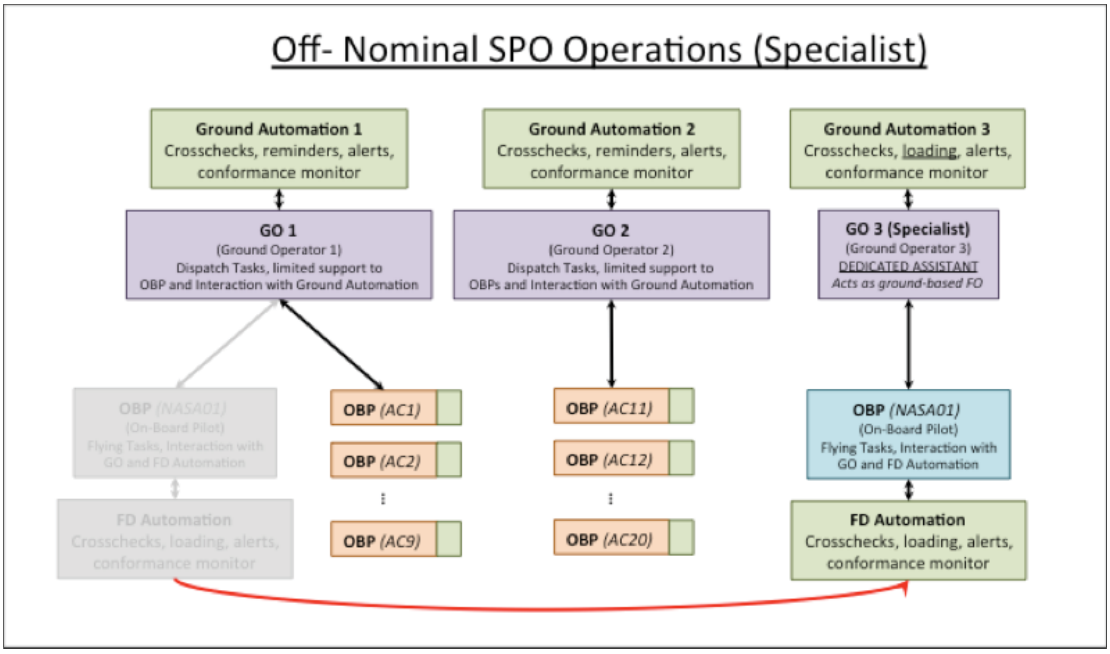

Figure 2c. Off-nominal SPO specialist operations.

2.2 Task Representations

Due to the complexity of the operational domains, two task representations were created to convey the details associated with each approach-to-land rule set. This breakdown was necessary given the complexity of the tasks required to safely land an aircraft and to illustrate the tasks that shifted from the well-established and safe concept of operations to the new concept of operations. Possessing such a breakdown allows a baseline operational standard to be compared with a next generation set of tasks. These representations of the tasks include a task decomposition spreadsheet and a task network model representation.

1. *Task decomposition spreadsheet.* The task decomposition spreadsheet is an Excel™ listing of the tasks and their sequential location per entity. The task decomposition was created to describe each task and operator roles in a more detailed, organized, in-depth manner to illustrate the task flow and the operator responsibilities. This complex representation of the task network allows for a more evolved understanding of both the malleable and rigid associations between tasks (see Figure 3a).

2. *Micro Saint Sharp task network.* Micro Saint Sharp™ is a platform for visualizing the task network linearly and identifying trouble spots where there is an increased task load due to the proposed SPO environment. By creating validated task groups, a fluid reorganization of task orders for analysis based on a given scenario can be developed. A difficulty level to each task could be assigned to better understand which tasks are suitable for redistribution to another human operator or to automation (see Figure 3b).

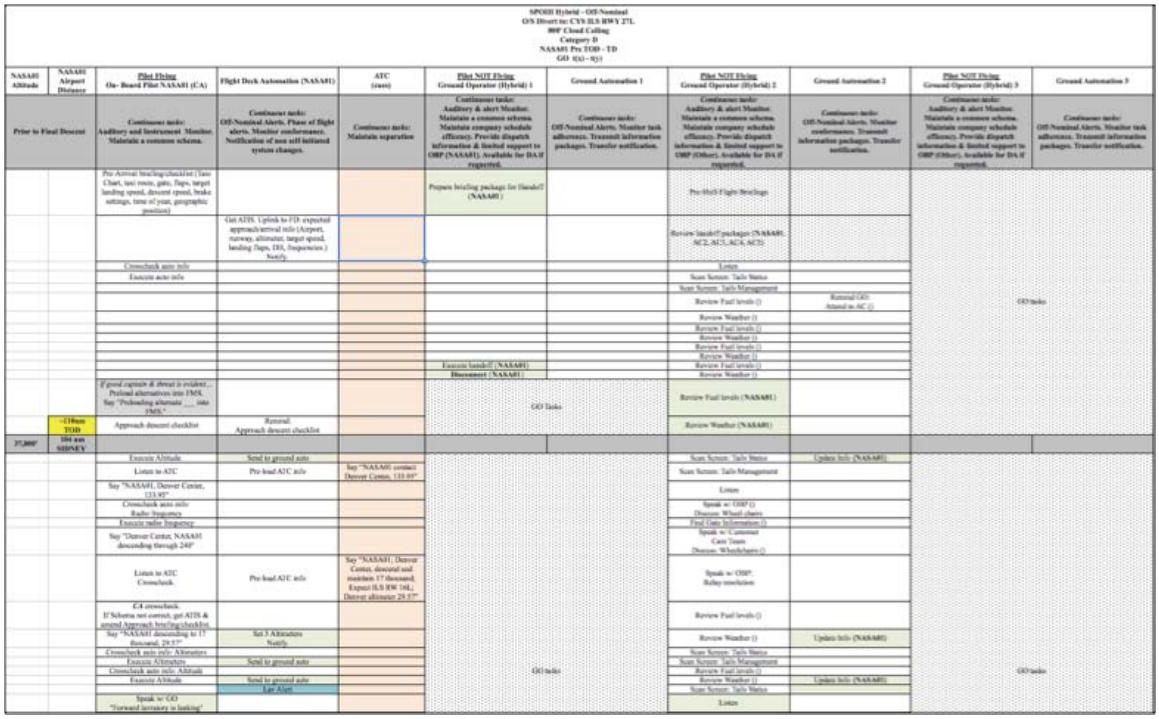

Figure 3a. Task decomposition spreadsheet example.

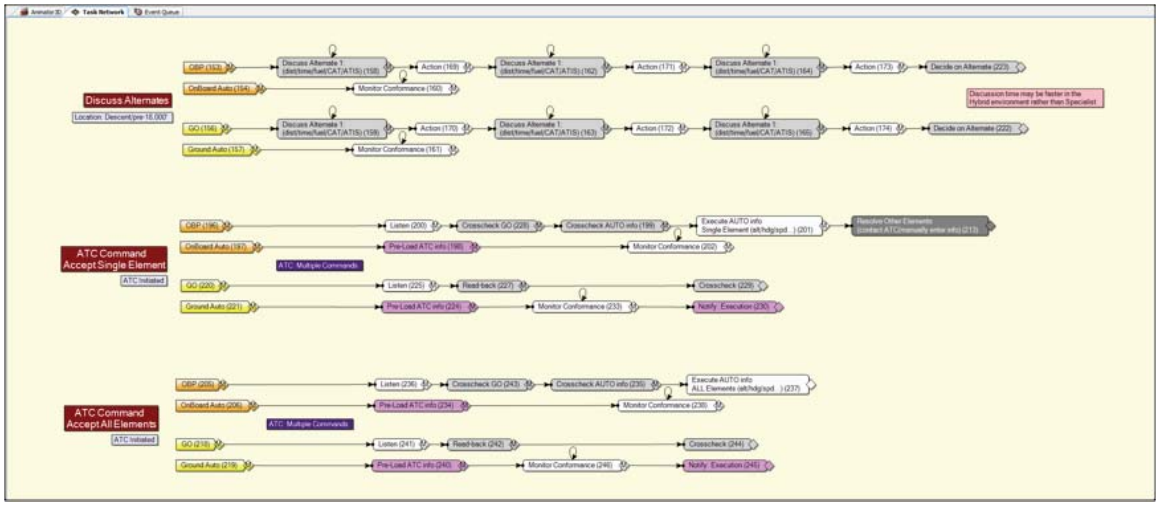

Figure 3b. Micro Saint Sharp task network example.

2.3 Concept Verification and the Impact of SPO on Operator Roles and Responsibilities

The task analyses were performed to determine the task differences between the current day and the proposed SPO descent and approach to land phases of flight, in addition to the changes in procedures when the crew is given divert commands from ATC regarding specific significant events (e.g., airport closure). Specific variables of interest included the number of communications, amount/role of automation, number of crosschecks and their impact on crew coordination. The analysis process began with a pre-existing current-day task analysis of a descent into Denver as well as a Divert to Cheyenne due to weather including entering and exiting a hold, deciding to divert to Cheyenne, and to safely land the aircraft. This was altered to represent the tasks required when operator roles are modified in the SPO environment with an OBP, GOs, operator-specific automation, and sometimes a Specialist GO (see Figures 2a, 2b, and 2c). This preliminary representation of significant event scenarios was populated through direct observation of the first and second SPO studies (Johnson et al., 2012; Lachter et al., 2014), observation of, and participation in, the creation of the third SPO study (see Johnson et al., in press), SME evaluations and interviews (C. Wolter, B. Gore, V. Battiste & R. Kotesky, personal communication January 30, 2013 and May 16, 2013; C. Wolter. R. Kotesky & W. Preston, personal communication April 22, 2014) and published reports of anticipated NextGen tasks and operator errors (Gore, Hooey, Mahlstedt, & Foyle, 2013; Gore, Hooey, Haan, Socash, Mahlestedt, & Foyle, 2013; Gore, Hooey, Haan, Bakowski, & Mahlstedt, 2011).

The most insight into the NextGen SPO ConOps was gained through active participation in the third SPO study design meetings. The ideas developed through this iterative simulation development process were fed into the task analysis. Reactions to the Hybrid and Specialist roles from the participants from the third SPO study were also used to further refine the analysis. The task analysis completed in FY14 follows the proposed ConOps from the third SPO study, and presents the roles and responsibilities in a manner that can facilitate generating future FDDRL testing scenarios as well as provide insight into the most efficient use of the crew resource as roles are reassigned. Specifically, the 2013 task analysis was augmented to include a more complex divert scenario based on a specific scenario also used in the third SPO study (see Johnson et al., in press). The previously explored single pilot-on-board role and responsibilities built upon the SPO first-of-its-kind task decomposition (Wolter & Gore, 2013) to define and incorporate a completely new entity (operator and operator role) based upon current dispatch operations.

Gaps identified in previous task analyses were filled by first creating new task analysis spreadsheets, including new entities, tasks, roles, and responsibilities being explored by the FDDRL lab. Multiple iterations of the analyses revealed potential for improvement through task allocation to a different entity. After final scenarios were chosen and populated with high-level tasks, the tasks were refined and decomposed through comparison with SPO-concept reports, and a series of SME interviews. There were three interview sessions conducted where three SMEs (one current CA, one former air traffic controller, and an ATC specialist) reviewed six spreadsheets of very detailed tasks and task orders to represent each scenario. The spreadsheets were organized by altitude and airport distance for the primary aircraft (NASA01), human operator tasks (PNF and PF) with CA assignment, automation tasks, and ATC communications. Using SME input, the task decomposition spreadsheet was modified to be more representative of the proposed SPO environment (see Figure 3a and Appendices A, B, C, D, E, and F).

An alternate set of roles and responsibilities for the crew, that focused on the impact of greater reliance on automation, both on the flight deck, and on the ground was created through SME

interviews. The preliminary analysis revealed a large increase in the number of tasks to be completed in the newest proposal of SPO ConOps, which indicated that on-board pilots and ground operators would need extra assistance from automation if they were to maintain a similar level of workload as previously proposed in the SPO ConOps.

Both representations went through a series of edits to create both an accurate representation of a current-day environment, and a task distribution capable of representing a future SPO concept. The tasks were expanded into higher-level task groups or events such as Weather Rerouting, Maintenance Issues, and Gate Connections. These tasks groups were then entered into the Micro Saint Sharp program as individual networks, providing a flexible means to create new scenarios and identify problem areas by evaluating the task count and the workload (defined below) associated with the group (see Figure 3b and Appendices G, H, and I).

A number of operator specific task groups for the GO are addressing maintenance issues, delays, security threats, customer care, and the complex dedicated assistance change in role. The nominal handoffs during a shift change, off-nominal Hybrid handoffs, off-nominal Specialist handoffs, as well as the handoff that occurs once dedicated assistance is released has been represented in the present analysis. In this representation, automation has been delegated the following tasks; crosschecks, notifications (for both OBP and GO if there is an issue detected such as non-compliance with the issued clearance), reminding (e.g., complete landing checklist at a certain altitude, execute new clearance, check on aircraft passing 18,000 ft, or "have you checked on this aircraft lately?"), and logging flight deck activity to continuously create briefing packages to ease handoffs.

2.4 Role and Responsibility Considerations

A review of previous SPO studies revealed that when separated, the aircraft's crew performs additional communications to preserve a consistent mental map of the approach and the candidate divert options (Lachter et al., 2014). These additional communications highlighted a potential area of concern implementing a SPO-like condition; if the crew needed to take immediate action, fewer cognitive, attentional, or even coordinated resources to safely land the aircraft may be available for the crew as they are occupied getting to a consistent mental map. As the crew work to become coordinated, their attentional resources are occupied to a greater extent than if they were already coordinated. This suggests that additional tasks cannot be added to the crew. To alleviate extra communications and radio congestion, the use of CRM tools and shared displays were analyzed (Lachter et al., 2014). Although the automation support was helpful for preserving a consistent mental map, even more automation in different forms may be required. Exploring dedicated assistance revealed potential problem areas for the GO during the transition from handling multiple aircraft to handling one distressed aircraft. The method for the transition would need to be streamlined and defined in detail to ensure the distressed aircraft would receive the level of assistance required.

Automation tasks were based on theoretical advancements in technology currently being tested in a laboratory setting for this task analysis. Here, automation has delegated many typical FO tasks as well as "good crew traits" such as crosschecking. The OBP/**CA** needs to be able to maintain ultimate control of the aircraft, yet have enough confidence to only crosscheck and execute the information that the flight deck automation has supplied.

A specific SPO ConOps-related gap and research issue was identified for the Ground Operator and a problem aircraft's dispatch tasks. There has been a lack of information on the impact on the dispatch

tasks once dedicated assistance is initiated. Based on our observations and task counts, the optimal role allocation may be for the original GO to retain their dispatch duties for the DA aircraft, assuming there is a moderate- to high-level of automation available to provide some task relief. This can alleviate some of the issues relating to "coming-in-cold" in the Specialist conditions by retaining an operator already familiar with the distressed aircraft.

2.5 Task Count and Workload

The task count and the workload associated with the tasks identified through a task analysis can be easily generated once a vetted set of tasks has been created. The task count is simply the number of tasks that the entity is responsible to complete, while the workload associated with the task is related to the attentional load required by the task.

To measure workload in the six scenarios described, each task was described as having low-, medium-, or high-workload demands. The task-analyst classified the workload classifications using the task analysis and workload as a basis for the categorizations (Hamilton, Bierbaum, & McAnulty, 1994; Hamilton, Bierbaum, & Fulford, 1990; McCracken & Aldrich, 1984). Low-workload tasks have been defined as tasks that are either very short in duration and/or require less attention (i.e., listening tasks, executing tasks, or any task performed by automation). Medium-workload tasks have been defined as tasks that occupy more attentional resources, but are normal tasks that are performed often (i.e., speaking and crosschecking). High-workload tasks have been defined as tasks that are unfamiliar and/or very demanding of attentional resources (i.e., discussing, deciding, and final manual landing). Every task in each scenario was given a corresponding workload level and then counted and recorded (see Figures 4a, 4b, 4c, 4d, 4e, and 4f). For the purposes of relevancy, GO and GO Automation tasks were only counted if they directly related to the flight of NASA01. GO tasks outside of the primary flight have not been adequately discussed at this point to confidently measure their shift from beginning to end.

For a nominal approach into Denver, the task count revealed that the total task number is reduced from 175 tasks performed by three entities to 160 tasks performed by four entities for both the SPO Hybrid and SPO Specialist Nominal condition compared to current day (Figure 4a, 4b, and 4c). The number of tasks performed by the CA/OBP remains at 85 tasks in both current day and SPO, 48.57% & 53.13% of the task total respectively. The workload for the CA/OBP also dropped from current day to SPO: High-workload tasks decreased from 16.47% to 11.76%; medium-workload tasks dropped from 62.35% to 54.12%; and, low-workload tasks increased from 21.18% to 34.12%. Across all entities, the same trend can be seen: High-workload tasks decreased from 11.43% to 7.5%; medium-workload tasks dropped from 66.86% to 33.75%; low-workload tasks increased from 21.71% to 58.75%.

		Current Day Nominal			
		CA	FO	GO	ALL
Low Workload	Total Low	18	18	2	38
	Percent Low	21.18%	21.43%	33.33%	21.71%
Medium Workload	Total Medium	53	61	3	117
	Percent Medium	62.35%	72.62%	50.00%	66.86%
High Workload	Total High	14	5	1	20
	Percent High	16.47%	5.95%	16.67%	11.43%
Total Tasks	Total Tasks	85	84	6	175
	Percent Entity	48.57%	48.00%	3.43%	100.00%

Figure 4a. Current day nominal task count.

		SPO Hybrid Nominal				
		OBP	FD AUTO	GO	GO AUTO	ALL
Low Workload Tasks	Total Low	29	42	8	15	94
	Percent Low	34.12%	100.00%	44.44%	100.00%	58.75%
Med Workload Tasks	Total Medium	46	0	8	0	54
	Percent Medium	54.12%	0.00%	44.44%	0.00%	33.75%
High Workload Tasks	Total High	10	0	2	0	12
	Percent High	11.76%	0.00%	11.11%	0.00%	7.50%
Total Tasks	Total Tasks	85	42	18	15	160
	Percent Entity	53.13%	26.25%	11.25%	9.38%	100.00%

Figure 4b. SPO hybrid nominal task count.

		SPO Specialist Nominal					
		OBP	FD AUTO	GO1	Spec GO	GO AUTOS	ALL
Low Workload Tasks	Total Low	29	42	8		15	94
	Percent Low	34.12%	100.00%	44.44%		100.00%	58.75%
Med Workload Tasks	Total Medium	46	0	8		0	54
	Percent Medium	54.12%	0.00%	44.44%		0.00%	33.75%
High Workload Tasks	Total High	10	0	2		0	12
	Percent High	11.76%	0.00%	11.11%		0.00%	7.50%
Total Tasks	Total Tasks	85	42	18		15	160
	Percent Entity	53.13%	26.25%	11.25%		9.38%	100.00%

Figure 4c. SPO specialist nominal task count.

For an off-nominal approach into Denver with a diversion to Cheyenne, the total tasks increased when comparing current day (237; Figure 4d) to the SPO Hybrid condition (318; Figure 4e) and the SPO Specialist condition (343; Figure 4f.) The number of tasks performed by the CA/OBP increased in both the SPO Hybrid (141, 44.34%) and SPO Specialist (146, 42.57%) conditions as compared to current day (118, 49.79%). The workload intensity trends were similar between all three conditions; High-workload tasks for current day, SPO Hybrid, and SPO Specialist made up 22.88%, 28.37%, and 30.82% of the total CA/OBP tasks respectively; Medium-workload tasks for current day, SPO Hybrid, and SPO Specialist made up 59.32%, 49.65%, and 47.26% of the total CA/OBP tasks respectively; and, Low-workload tasks for current day, SPO Hybrid, and SPO Specialist made up 17.8%%, 21.99%, and 21.92% of the total CA/OBP tasks respectively. The increase in task number between SPO Hybrid and SPO Specialist is notable for future SPO ConOps development.

		Current Day Off-Nominal			
		CA	FO	GO	ALL
Low Workload Tasks	Total Low	27	24	2	53
	Percent Low	22.88%	21.24%	33.33%	22.36%
Med Workload Tasks	Total Medium	70	78	3	151
	Percent Medium	59.32%	69.03%	50.00%	63.71%
High Workload Tasks	Total High	21	11	1	33
	Percent High	17.80%	9.73%	16.67%	13.92%
Total Tasks	Total Tasks	118	113	6	237
	Percent Entity	49.79%	47.68%	2.53%	100.00%

Figure 4d. Current day off-nominal task count.

		SPO Hybrid Off-Nominal				
		OBP	FD AUTO	GO	GO AUTO	ALL
Low Workload Tasks	Total Low	40	58	24	37	159
	Percent Low	28.37%	100.00%	29.27%	100.00%	50.00%
Med Workload Tasks	Total Medium	70	0	47	0	117
	Percent Medium	49.65%	0.00%	57.32%	0.00%	36.79%
High Workload Tasks	Total High	31	0	11	0	42
	Percent High	21.99%	0.00%	13.41%	0.00%	13.21%
Total Tasks	Total Tasks	141	58	82	37	318
	Percent Entity	44.34%	18.24%	25.79%	11.64%	100.00%

Figure 4e. SPO hybrid off-nominal task count.

		SPO Specialist Off-Nominal					
		OBP	FD AUTO	GO1	Spec GO	GO AUTOS	ALL
Low Workload Tasks	Total Low	45	54	9	12	46	166
	Percent Low	30.82%	100.00%	29.03%	18.18%	100.00%	48.40%
Med Workload Tasks	Total Medium	69	0	19	46	0	134
	Percent Medium	47.26%	0.00%	61.29%	69.70%	0.00%	39.07%
High Workload Tasks	Total High	32	0	3	8	0	43
	Percent High	21.92%	0.00%	9.68%	0.00%	0.00%	12.54%
Total Tasks	Total Tasks	146	54	31	66	46	343
	Percent Entity	42.57%	15.74%	9.04%	19.24%	13.41%	100.00%

Figure 4f. SPO specialist off-nominal task count.

3.0 Conclusion

It is certainly a challenge to develop a set of tasks for concepts that are just in their infancy as is the case with the SPO concept. The task analyses completed as part of the present research produced a detailed and verified set of tasks representing a nominal, current-day approach into Denver. This task network is the necessary first step for any NextGen SPO approach scenario development process as it illustrates the most likely baseline task set upon which modifications could be proposed and evaluated for moving from a two-person crew to a single pilot being responsible for the operations of the aircraft. It is imperative that this baseline task analysis be accurate so that incremental changes can be proposed and evaluated in subsequent scenario considerations and an informed decision can be made about the costs and benefits of a next generation concept. Two reasonable and plausible SPO scenarios were defined and populated with detailed tasks, operator assignments, and task orders through a series of SME interviews, reviews of published reports, and participation in ongoing SPO experiments conducted in the FDDRL at NASA Ames Research Center.

Based on SPO concept reports, studies conducted in the FDDRL lab, and task analyses performed thus far, a clearer picture of future NextGen SPO ConOps has been formed. To avoid overloading any single human operator during the approach phase of flight, there is an identified need for more reliance on automation to at minimum perform crosschecks and load flight settings. The approach phase of flight is densely populated with tasks from the top of descent to touchdown, requiring input from multiple operators to safely land the aircraft. If tasks currently being performed by two co-located pilots are all assigned to a single OBP, the task load on that operator becomes too great to reliably perform. With two operators collaborating remotely, communication between them presents an obstacle to overcome. Without the physical cues from being co-located, all communications could be made verbally but would add an impractical amount of additional tasks.

The solution in these analyses was to provide support for crew crosschecks through automated notifications of any operator-initiated changes of the aircraft and shift routine setting tasks to automation. Automation would also act as a “good crew member” by reminding the human operators to attend to items that automation recognizes have not been attended to for a period of time. ConOps specifically relating to DA handoffs and DA changes in roles need to be firmly defined to increase the effectiveness of a ground-based FO. Along with some projected advancements in automation to perform basic uploading from ATC functions, tasks being assumed by all three entities (OBP, GO, and automation) rather than just the OBP alone, will help to alleviate task overload on any single operator—especially in the case of any significant and/or unexpected event. The data derived from these task analyses support these conclusions.

4.0 Future Research

The SPO scenarios defined thus far represent two flight conditions and two potential ways of assigning tasks between entities in a SPO environment. Next steps could include refinement of the existing task analysis based on additional SME evaluations, as well as extending the task analysis to better define the GO roles and responsibilities. A GO-centric analysis may reveal needs that have not yet been defined. The GO-as-dispatch and GO-as-ground-based-FO tasks have not been adequately defined for analysis as they are entirely new roles, and never before studied. Modifications to the existing scenarios include dissecting the FY14 GO tasks to a finer level of detail, and possibly the impact of requesting DA at the beginning of the GO shift, or shift-start compared to DA at when crew are in the middle of their shift, or mid-shift. To accomplish this, a shift-based task analysis of the GO that includes likely tasks, task allocations, and task workloads for a specific period of time would need to be created. The tasks in the FY15 will be designed to parallel future FDDRL studies via communication/collaboration between teams. There will be an impact assessment of required and time-critical flight crew and ATC tasks under SPO technologies and procedures. Impact will be measured by task count and associated task workload changes and the number of task conflicts.

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Appendix A. Task Decomposition Spreadsheet (Current Day Nominal)

Current Day - Nominal DEN ILS RWY 16L 800' Cloud Ceiling Category D						
Altitude	**Airport Distance**	**Pilot Flying (CA)**	**Pilot NOT Flying (FO)**	**FD Automation**	**ATC (cues)**	**Dispatch 1**
Prior to Final Descent		***Continuous tasks: Build a common schema - mainly at cross checks.* Auditory and Instrument Monitor (continue to TD)**	***Continuous tasks: Build a common schema - mainly at cross checks.* Auditory and Instrument Monitor (continue to TD)**		***Continuous tasks:* Maintain separation**	**Continuous Tasks: Maintain company schedule efficency. POC between AC and other entities. Route adjustments and reroutings.**
		Pre-Arrival briefing. (Taxi Chart, taxi route, gate, flaps, target landing speed, descent speed, brake settings, time of year, geographic position)	Monitor PF Pre-Arrival Briefing. Crosscheck.			
		Briefs GSO about procedures and techniques. Say "I'm going to use full reverse on this landing."	Listen.			
		Listen.	Say "Roger"			
		Crosscheck.	Get ATIS. Load expected approach/arrival info (Airport, runway, altimeter, target speed, landing flaps, DH, frequencies.) Notify.			
		Crosscheck.	Set radio and navigation frequencies and final course			
		If good captain & threat is evident… Discuss the threat.				
		If good captain & threat is evident… Preload alternatives into FMS. Say "Preloading alternate ___ into FMS."	If good captain & threat is evident… Crosscheck. Say "Roger."			
	~110nm TOD	Crosscheck.	Read: Approach descent checklist			
37,000'	**104 nm SIDNEY**	Crosscheck.	Set Altitude.			
		Listen to ATC	Listen to ATC		Say "United 573 contact Denver Center, 133.95"	
		Crosscheck.	Say "United 573, Denver Center, 133.95"			
		Crosscheck.	Set radio frequency to 133.95 for Denver Center			
		Crosscheck.	Say "Denver Center, United 573 descending through 240"			
		Listen to ATC Crosscheck.	Listen to ATC Crosscheck.		Say "United 573; Denver Center, descend and maintain 17 thousand; Expect ILS RW 16L; Denver altimeter 29.57"	
		CA crosscheck. If Schema not correct, get ATIS & amend Approach briefing.				
		Crosscheck.	Say "United 573 descending to 17 thousand, 29.57"			
		Set 2 Altimeters.	Set 1 Altimeter.			
		Crosscheck.	Crosscheck.			
				Lav Alert		
			Speak w/ Dispatch "Forward lavratory is leaking"			Listen

Appendix A. Task Decomposition Spreadsheet (Current Day Nominal)

		Listen	Listen			Speak w/ FO (**NASA01**) Confirm request: Maintenance Problem
		Listen	Listen			Speak w/ FO (**NASA01**) Safety inquiry: Maintenance Problem "Do you have any safety concerns?"
			Speak w/ Dispatch "No, have maintenance ready on the ground at DEN."			Listen
						Speak w/ Maintenance (**NASA01**)
		Listen	Listen			Speak w/ FO (**NASA01**) Relay Resolution: "Maintenance will you meet you at the gate"
18,000' 12,650' AGL	**74 nm**	Crosscheck.	Turn on exterior lights			
		Crosscheck.	Check Pressurization.			
		Listen.	Check Altimeters as completed on approach descent checklist. If 777/787 observe ECL items are green. Say "Altimeters are set to 29.57. Approach descent checklist complete"			
11,650' AGL	**61 nm**	Listen to ATC	Listen to ATC		Say "United 573, Fly heading 218, cleared direct PHLAT, direct KIPPR, direct Denver, descend and maintain 10,000, expect runway 16L ILS approach to Denver."	
		Crosscheck.	Say "Roger, United 573, 218, direct to PHLAT, direct DEN, descend and maintain 10,000, expect runway 16L approach."			
		Crosscheck.	Set Altitude.			
		Listen to ATC	Listen to ATC		Say "United 573 contact Denver Approach on 119.3."	
		Crosscheck	Say "Roger, United 573, 119.3."			
		Crosscheck.	Set radio frequency to 119.3 for Denver Approach			
		Crosscheck.	Say "Denver Approach, United 573, one zero thousand with Alpha."			
4,650' AGL	**40 nm**	Listen to ATC	Listen to ATC		Say "Roger, United 573. descend and maintain flight level 8000"	
		Listen	Say "Roger, 8000 for United 573"			
		Crosscheck.	Set Altitude			
		Listen to ATC	Listen to ATC		Say "United 573, turn left heading 270, base leg."	
		Listen.	Say "Roger, heading 270, base leg, United 573"			
		Crosscheck.	Set Heading			
		Command "Flaps 1"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 1.			
		Speed set (210)	Speed confirm (210)			
		Command "Flaps 5"	Listen.			

Appendix A. Task Decomposition Spreadsheet (Current Day Nominal)

		Crosscheck.	Reach flap lever. Set flaps to 5.			
		Listen to ATC	Listen to ATC		Say "United 573, turn left heading 200, maintain 7,000 until established. Maintain 180 kts to LEETS, contact tower on 135.3"	
		Listen.	Say "Roger, left 200, 7,000 until established and 180 until LEETS, contacting Tower at 135.3, United 573"			
		Crosscheck.	Set Heading			
		Crosscheck.	Set Altitude.			
		Crosscheck.	Arm Approach Mode			
		Crosscheck.	Confirm FMA display reads expected			
		Crosscheck.	Set radio frequency to 135.3 for Denver Tower			
2,650' AGL	**32 nm**	Command "Flaps 15"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 15.			
		Speed set (180)	Speed confirm (180)			
		Listen.	Say "Denver Tower, United 573 turning Final for the ILS 16L approach."			
		Listen to ATC	Listen to ATC		Say "United 573, cleared for the ILS 16L approach."	
		Listen.	Say "Roger, cleared for ILS 16L, United 573"			
		Disconnect autopilot.		Aural alert.		
		Command "Gear Down, Landing checklist"	Listen.			
		Crosscheck.	Set landing gear			
		Speed set (146)	Speed confirm (146)			
		CA Arm speed brake.	***FO*** Crosscheck.			
		Confirm "TDZE set"	Set TDZE			
		Command "Flaps 20"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 20.			
1,650' AGL	**7 nm**	Glideslope capture	Confirm capture			
		Crosscheck.	Confirm FMA display reads: LOC & G/S			
		Command "Flaps 25"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 25.			
		Command "Flaps 30"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 30.			
		Crosscheck.	Complete landing checklist. Say "Landing Checklist complete"			
		Crosscheck.	Say "Tower, United 573 for RWY one six left"			
		Listen to ATC	Listen to ATC		Say "United 573 cleared to land RWY one six left"	
		Listen.	Say "Roger, cleared to land RWY one six for United 573"			
1,000' AGL	**3.9 nm**	Listen.	Say "1000 feet"			
		Check stabilized approach status				
		Acquire runway				
		Say "Runway in sight"	Confirm.			

Appendix A. Task Decomposition Spreadsheet (Current Day Nominal)

		Listen.	Say "Approaching DH"			
500' AGL	**~1.5nm**	Listen.	"500 feet"			
		Recheck stabilized approach status				
		Listen.	"100'"			
		Listen.	"50"			
		Listen.	"30"			
		Listen.	"20"			
		Listen.	"10"			
Touchdown						

Appendix B. Task Decomposition Spreadsheet (Current Off-Day Nominal)

Current Day - Off-Nominal Divert to: CYS ILS RWY 27L 800' Cloud Ceiling Category D						
Altitude	**Airport Distance**	**Pilot Flying (CA)**	**Pilot NOT Flying (FO)**	**FD Automation**	**ATC**	**Dispatch 1**
Prior to Final Descent		***Continuous tasks: Build a common schema - mainly at cross checks.*** **Auditory and Instrument Monitor (continue to TD)**	***Continuous tasks: Build a common schema - mainly at cross checks.*** **Auditory and Instrument Monitor (continue to TD)**		***Continuous tasks:*** **Maintain separation**	**Continuous Tasks: Maintain company schedule efficency. POC between AC and other entities. Route adjustments and reroutings.**
		Pre-Arrival briefing. (Taxi Chart, taxi route, gate, flaps, target landing speed, descent speed, brake settings, time of year, geographic position)	Monitor PF Pre-Arrival Briefing. Crosscheck.			
		Briefs GSO about procedures and techniques. Say "I'm going to use full reverse on this landing."	Listen.			
		Listen.	Say "Roger"			
		Crosscheck.	Get ATIS. Load expected approach/arrival info (Airport, runway, altimeter, target speed, landing flaps, DH, frequencies.) Notify.			
		Crosscheck.	Set radio and navigation frequencies and final course			
		If good captain & threat is evident…				
		If good captain & threat is evident… Preload CYS into FMS. Say "Preloading Cheyenne into FMS."	If good captain & threat is evident… Crosscheck. Say "Roger."			
	~110nm TOD	Crosscheck.	Read: Approach descent checklist			
37,000'	**104 nm SIDNEY**	Crosscheck.	Set Altitude.			
		Listen to ATC	Listen to ATC		Say "United 573 contact Denver Center, 133.95"	
		Crosscheck.	Say "United 573, Denver Center, 133.95"			
		Crosscheck.	Set radio frequency to 133.95 for Denver Center			
		Crosscheck.	Say "Denver Center, United 573 descending through 240"			
		Crosscheck.	Crosscheck.		Say "United 573; Denver Center, descend and maintain 17 thousand; Expect ILS RW 16L; Denver altimeter 29.57"	
		CA crosscheck. If Schema not correct, get ATIS & amend Approach briefing.				
		Listen to ATC command.	Listen to ATC command.			
		Crosscheck.	Say "United 573 descending to 17 thousand, 29.57"			
		Set 2 Altimeters.	Set 1 Altimeter.			
		Crosscheck.	Crosscheck.			
				Lav Alert		
			Speak w/ Dispatch "Forward lavratory is leaking"			Listen

Appendix B. Task Decomposition Spreadsheet (Current Off-Day Nominal)

		Listen	Listen			Speak w/ FO (**NASA01**) Confirm request: Maintenance Problem
		Listen	Listen			Speak w/ FO (**NASA01**) Safety inquiry: Maintenance Problem "Do you have any safety concerns?"
			Speak w/ Dispatch "No, have maintenance ready on the ground at DEN."			Listen
						Speak w/ Maintenance (**NASA01**)
		Listen	Listen			Speak w/ FO (**NASA01**) Relay Resolution: "Maintenance will you meet you at the gate"
18,000' 11,879' AGL	**74 nm**	Crosscheck.	Turn on exterior lights			
		Crosscheck.	Check Pressurization.			
		Listen to ATC	Listen to ATC		**Say "All aircraft, Microburst alert at Denver, approaches are temporally discontinued, expect holding for all runways"**	
		Crosscheck.	Load primary alternate Airport (CYS).			
		Discuss probable hold locations & pattern. Discuss fuel state and calculate				
		Crosscheck.	Pre-load probable hold into CDU			
		Locate all alternate approach plates.				
		Discuss Alternate 1 (CYS) (distance/time/fuel/CAT/ATIS) (x2)				
		Action.				
			Action.			
		Discuss Alternate 2 (distance/time/fuel/CAT/ATIS) (x2)				
		Action.				
			Action.			
		Discuss Alternate 3 (distance/time/fuel/CAT/ATIS) (x2)				
		Action.				
			Action.			
		Listen to ATC	Listen to ATC		Say "United 573, hold North of LANDR on 216 radial, left-hand turns. Maintain one seven thousand, expect further clearance in one zero (10) minutes"	
10,879' AGL	**61 nm**	Decide on Cheyenne (CYS) as the alternate. Discuss fuel state and calculate endurance for a hold with CYS as new destination. (Find burn to CYS. Desired CYS landing fuel. Current burn rate. Time/fuel remaining. Crosscheck.)				
		Listen.	Say "United 573 maintaining 17,000', will hold at LANDR"			
		Crosscheck.	Say "Denver Center, United 573 at LANDR, time 15, 17,000'"			
		Crosscheck.	Execute hold.			
		Listen to ATC	Listen to ATC		Say "All aircraft, Tower evacuated due to funnel cloud sighting, divert to other airports."	
		Decide to divert to CYS (the Decide				
		CA: Validates / in agreement with mental map				

Appendix B. Task Decomposition Spreadsheet (Current Off-Day Nominal)

		Action.				
			Action.			
		Listen.	"Denver Center, United 573 request IFR clearance to Cheyenne via direct"			
		Listen to ATC	Listen to ATC		"United 573 standby" "United 573 cleared to Cheyenne via direct GILL, direct Cheyennne"	
		Listen.	Say "Roger, direct GILL, direct Cheyenne, United 573."			
		Crosscheck.	Load CYS as new destination in CDU. Get ATIS. Build a route, Load expected Approach/Arrival Information: Airport, Runway, Altimeter, Speed changes, landing flaps, DH, frequencies. Load LNAV/VNAV.			
		CA: Validates / in agreement with mental map				
		Monitor PF Pre-Arrival Briefing. Crosscheck.	Pre-Arrival briefing. (Taxi Chart, taxi route, gate, flaps, target landing speed, descent speed, brake settings.			
		Listen to ATC	Listen to ATC		Say "United 573 Fly heading 281 GILL, maintain one seven thousand"	
		Crosscheck.	Say "Roger, United 573, 281 to GILL, maintaining 17,000."			
		Listen to ATC	Listen to ATC		Say "United 573, Fly heading 350, Cleared direct HAMER, direct CYS, descend and maintain 10,000, expect runway 27 approach to CYS; Cheyenne altimeter 28.15"	
		Crosscheck.	Say "Roger, United 573, 350, direct to HAMER, direct CYS, descend and maintain 10,000, expect runway 27 approach; altimeter 28.15"			
		Crosscheck.	Execute route.			
		Crosscheck.	Exit hold.			
		CA crosscheck. If Schema not correct, get ATIS & amend Approach briefing.				
		Set 2 Altimeters.	Set 1 Altimeter.			
		Crosscheck.	Crosscheck.			
10,879' AGL	**~70 nm**	Listen.	Say "Denver Center, United 573, Unable, minimum fuel. Request emergency clearance to ____."			
		Listen to ATC	Listen to ATC		Say "United 573 cleared to ___. Descend and maintain 10,000'. Contact ___ on ###.##"	
		Crosscheck.	Say "Roger, United 573, cleared to ___, descending to 10,000', ###.##"			
3,879' AGL	**49 nm**	Listen to ATC	Listen to ATC		Say "United 573 contact Cheyenne Approach on 124.55"	
		Crosscheck.	Say "Roger, United 573, 124.55"			
		Crosscheck.	Set radio frequency to 124.55 for Cheyenne Approach			
		Listen.	Say "Cheyenne Approach, United 573, one zero thousand with Alpha."			

Appendix B. Task Decomposition Spreadsheet (Current Off-Day Nominal)

		Listen to ATC	Listen to ATC		Say "Roger, United 573. descend and maintain flight level 9000"	
		Crosscheck.	Say "Roger, 9000 for United 573"			
		Crosscheck.	Set Altitude.			
2,879' AGL	**15 nm**	Listen to ATC	Listen to ATC		Say "United 573, turn left heading 350, base leg."	
		Crosscheck.	Say "Roger, heading 350, base leg, United 573"			
		Crosscheck.	Set Heading			
		Command "Flaps 1"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 1.			
		Speed confirm (210)	Speed set (210)			
		Command "Flaps 5"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 5.			
		Listen to ATC	Listen to ATC		Say "United 573, turn left heading 280, maintain 7,800 until established. Maintain 180 kts to ZUNUG, contact tower on 118.7"	
		Listen.	Say "Roger, left 280, 7,800 until established and 180 until ZUNUG, contacting Tower at 118.7, United 573"			
		Crosscheck.	Set Heading			
		Crosscheck.	Set Altitude.			
		Crosscheck.	Arm Approach Mode			
		Crosscheck.	Confirm FMA display reads expected			
		Crosscheck.	Set radio frequency to 118.7 for Cheyenne Tower			
1,679' AGL	**15 nm**	Command "Flaps 15"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 15.			
		Speed confirm (180)	Speed set (180)			
		Listen.	Say "Cheyenne Tower, United 573 turning Final for the ILS 27L approach."			
		Listen to ATC	Listen to ATC		Say "United 573, cleared for the ILS 27L approach."	
		Listen.	Say "Roger, cleared for ILS 27L, United 573"			
		Disconnect autopilot.		Aural alert.		
		Command "Gear Down, Landing checklist"	Listen.			
		Crosscheck.	Set landing gear			
		Speed confirm (146)	Speed set (146)			
		CA Arm speed brake.	***FO*** Crosscheck.			
		Confirm "TDZE set"	Set TDZE			
		Command "Flaps 20"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 20.			
1,679' AGL	**5.1 nm**	Glideslope capture	Confirm capture			
		Crosscheck.	Confirm FMA display reads: LOC & G/S			
		Command "Flaps 25"	Listen.			
		Crosscheck.	Reach flap lever. Set flaps to 25.			
		Command "Flaps 30"	Listen.			

Appendix B. Task Decomposition Spreadsheet (Current Off-Day Nominal)

		Crosscheck.	Reach flap lever. Set flaps to 30.			
		Crosscheck.	Complete landing checklist. Say "Landing Checklist complete"			
		Crosscheck.	Say "Tower, United 573 for RWY two seven left"			
		Listen to ATC	Listen to ATC		Say "United 573 cleared to land RWY two seven left"	
		Listen.	Say "Roger, cleared to land RWY two seven for United 573"			
1,000' AGL	**3.9 nm**	Listen.	Say "1000 feet"			
		Check stabilized approach status				
		Acquire runway				
		Say "Runway in sight"	Confirm.			
		Listen.	Say "Approaching DH"			
500' AGL	**~1nm**	Listen.	"500 feet"			
		Recheck stabilized approach status				
		Listen.	"100'"			
		Listen.	"50"			
		Listen.	"30"			
		Listen.	"20"			
		Listen.	"10"			
Touchdown						

Appendix C. Task Decomposition Spreadsheet (SPO Hybrid Nominal)

SPOHH Hybrid - Nominal
NASA01 DEN ILS RWY 16
800' Cloud Ceiling
Category D
NASA01 Pre TOD - TD
GOH t(x) - t(y)

NASA01 Altitude	NASA01 Airport Distance	Pilot Flying On-Board Pilot NASA01 (CA)	Flight Deck Automation (NASA01)	ATC (cues)	Pilot NOT Flying Ground Operator (Hybrid) 1	Ground Automation 1	Pilot NOT Flying Ground Operator (Hybrid) 2	Ground Automation 2	Pilot NOT Flying Ground Operator (Hybrid) 3	Ground Automation 3
Prior to Final Descent		*Continuous tasks:* **Auditory and Instrument Monitor. Maintain a common schema.**	*Continuous tasks:* **Off-Nominal Alerts. Phase of flight alerts. Monitor conformance. Notification of non self-initiated system changes.**	*Continuous tasks:* **Maintain separation**	**Continuous tasks:** **Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (NASA01). Available for DA if requested.**	*Continuous tasks:* **Off-Nominal Alerts. Monitor task adherence. Transmit information packages. Transfer notification.**	*Continuous tasks:* **Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (Other). Available for DA if requested.**	*Continuous tasks:* **Off-Nominal Alerts. Monitor conformance. Transmit information packages. Transfer notification.**	*Continuous tasks:* **Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (Other). Available for DA if requested.**	*Continuous tasks:* **Off-Nominal Alerts. Monitor task adherence. Transmit information packages. Transfer notification.**
		Pre-Arrival briefing/checklist (Taxi Chart, taxi route, gate, flaps, target landing speed, descent speed, brake settings, time of year, geographic position)			Prepare briefing package for Handoff **(NASA01)**		Pre-Shift Flight Briefings		**GO Tasks (Other AC)**	
			Get ATIS. Uplink to FD: expected approach/arrival info (Airport, runway, altimeter, target speed, landing flaps, DH, frequencies.) Notify.				Review handoff packages **(NASA01**, AC2, AC3, AC4, AC5)			
		Crosscheck auto info					Listen			
		Execute auto info					Scan Screen: Tails Status			
							Scan Screen: Tails Management			
							Review Fuel levels ()	Remind GO: Attend to AC #		
							Review Weather ()			
							Review Fuel levels ()			
							Review Weather ()			
							Review Fuel levels ()			
							Review Weather ()			
					Execute handoff **(NASA01)**		Review Fuel levels ()			
					Disconnect (NASA01)		Review Weather ()			
		If good captain & threat is evident… Preload alternatives into FMS. Say "Preloading alternate ___ into FMS."			**GO Tasks (Other AC)**		Review Fuel levels **(NASA01)**			
	~110nm TOD	Approach descent checklist	Remind: Approach descent checklist				Review Weather **(NASA01)**			
37,000'	**104 nm SIDNEY**	Execute Altitude.	Send to ground auto				Scan Screen: Tails Status	Update Info **(NASA01)**		
		Listen to ATC	Pre-load ATC info	Say "NASA01 contact Denver Center, 133.95"			Scan Screen: Tails Management			
		Say "NASA01, Denver Center, 133.95"					Listen			
		Crosscheck auto info: Radio frequency					Speak w/ OBP () Discuss: Wheel chairs			
		Execute radio frequency					Find Gate Information ()			
		Say "Denver Center, NASA01 descending through 240"					Speak w/ Customer Care Team Discuss: Wheelchairs ()			
		Listen to ATC Crosscheck.	Pre-load ATC info	Say "NASA01; Denver Center, descend and maintain 17 thousand; Expect ILS RW 16L; Denver altimeter 29.57"			Speak w/ OBP: Relay resolution			
		CA crosscheck. If Schema not correct, get ATIS & amend Approach briefing/checklist.					Review Fuel levels ()			
		Say "NASA01 descending to 17 thousand, 29.57"	Set 3 Altimeters Notify.				Review Weather ()	Update Info **(NASA01)**		
		Crosscheck auto info: Altimeters					Scan Screen: Tails Status	Remind GO: Attend to AC ()		
		Execute Altimeters	Send to ground auto				Scan Screen: Tails Management	Update Info **(NASA01)**		
		Crosscheck auto info: Altitude					Review Fuel levels ()			
		Execute Altitude	Send to ground auto				Review Weather ()	Update Info **(NASA01)**		
			Lav Alert				Scan Screen: Tails Status			
		Speak w/ GO "Forward lavratory is leaking"					Listen			
		Listen					Speak w/ OBP **(NASA01)** Confirm request: Maintenance Problem			
		Listen					Speak w/ OBP **(NASA01)** Safety inquiry: Maintenance Problem "Do you have any safety concerns?"			

Appendix C. Task Decomposition Spreadsheet (SPO Hybrid Nominal)

		Speak w/ GO "No, have maintenance ready on the ground at DEN."				Listen		
						Speak w/ Maintenance (**NASA01**) Patch through maintenance (collaboration possible)		
		Listen				Speak w/ OBP (**NASA01**) Relay Resolution: "Maintenance will you meet you at the gate"		
						Review Fuel levels (**NASA01**)		
						Review Weather (**NASA01**)		
18,000' 11,650' AGL	61 nm		Remind: Pressurization			Scan Screen: Tails Status	Notify: Below 18,000' (**NASA01**)	
		Check pressurization				Scan Screen: Tails Management		
			Turn on exterior lights Notify			Speak w/ OBP () Discuss: Gate Connection Problem		
		Crosscheck Lights				Speak w/ OBP () Discuss: Gate Connection Solution		
						Comm: Reservation coordinator Discuss Gate Connections ()		
		Listen to ATC	Pre-load ATC info	Say "NASA01, Fly heading 218, cleared direct PHLAT, direct KIPPR, direct Denver, descend and maintain 10,000, expect runway 16L ILS approach to Denver."		Receive and Understand message (ATC) "Delays at ORD due to weather."		
		Say "Roger, United 573, 218, direct to PHLAT, direct DEN, descend and maintain 10,000, expect runway 16L approach."				Scan Screen: Tails Status		
		Execute Altitude	Send to ground auto			Scan Screen: Tails Management	Update Info (**NASA01**)	
		Execute Heading	Send to ground auto			Review Altitude & Heading ()	Update Info (**NASA01**)	
		Listen to ATC		Say "NASA01 contact Denver Approach on 119.3."		Review Fuel Levels ()		
		Say "Roger, United 573, 119.3."				Review Weather ()		
		Execute Radio	Send to ground auto			Speak w/ OBP () Discuss: Airport/inbound delays	Update Info (**NASA01**)	
		Say "Denver Approach, United 573, one zero thousand with Alpha."			**GO Tasks (Other AC)**	Speak w/ Customer care team Discuss: Delays ()		**GO Tasks (Other AC)**
4,650' AGL	40 nm	Listen to ATC	Pre-load ATC info	Say "Roger, NASA01. descend and maintain flight level 8000"		Speak w/ Reservation coordinator Discuss: Delays ()		
		Say "Roger, heading 350, base leg, NASA01"				Scan Screen: Tails Status	Remind GO: Attend to AC ()	
		Crosscheck AUTO info				Scan Screen: Tails Management		
		Execute Heading	Send to ground auto	Say "NASA01, turn left heading 270, base leg."		Review Altitude & Heading ()	Update Info (**NASA01**)	
		Listen	Remind: Flaps 1			Review Fuel levels ()		
		Reach and set flaps to 1				Review Weather ()		
		Set speed (210)				Review Altitude & Heading ()	Notify: Autopilot disconnect ()	
		Listen	Remind: Flaps 5			Review Fuel levels ()		
		Reach and set flaps to 5.				Review Weather ()		
						Review Weather ()		
		Listen to ATC	Pre-load ATC info	Say "NASA01, turn left heading 200, maintain 7,000 until established. Maintain 180 kts to LEETS, contact tower on 135.3"		Scan Screen: Tails Status		
		Say "Roger, heading 270, base leg, United 573"				Scan Screen: Tails Management		
		Crosscheck auto info: Altitude				Review Altitude & Heading ()		
		Execute Altitude	Send to ground auto			Review Fuel levels ()	Update Info (NASA01)	
		Crosscheck auto info: Heading				Review Weather ()		
		Execute Heading	Send to ground auto			Scan Screen: Tails Status	Update Info (NASA01)	
		Listen	Remind: Arm approach mode			Scan Screen: Tails Management		
		Arm Approach Mode	Send to ground auto			Discuss: Fuel Temperatures ()	Update Info (NASA01)	
		Confirm FMA reads as expected				Scan Screen: Tails Status		
		Crosscheck auto info: Radio frequency				Scan Screen: Tails Management		
		Execute radio frequency	Send to ground auto			Review Fuel levels ()	Update Info (NASA01)	
2,650' AGL	32 nm		Remind: Flaps 15			Review Weather ()		
		Reach and set flaps to 15.				Scan Screen: Tails Status		
		Set speed (180)				Scan Screen: Tails Management		

Appendix C. Task Decomposition Spreadsheet (SPO Hybrid Nominal)

		Say "Cheyenne Tower, NASA01 turning Final for the ILS 27L approach."			GO Tasks (Other AC)	Review Fuel levels ()		GO Tasks (Other AC)
		Listen to ATC		Say "NASA01, cleared for the ILS 16L approach."		Review Weather ()		
		Say "Roger, cleared for ILS 27L, NASA01"				Receive and Understand message (ATC) "……"		
		Disconnect autopilot	Aural alert. Send to ground auto			Identify relevant AC	Update Info (NASA01)	
		Listen	Remind: Landing gear			Scan Screen: Tails Status		
		Set landing gear				Scan Screen: Tails Management		
		Set speed (146)				Speak w/ OBP () Discuss: Security information		
		C4 Arm speed brake				Scan Screen: Tails Status		
		Set TDZE				Scan Screen: Tails Management		
						Listen		
		Listen	Remind: Flaps 20			Speak w/ OBP () Discuss: Fuel temp test		
		Reach and set flaps to 20.				Calculate fuel temp		
1,650' AGL	7 nm	Glideslope capture	Send to ground auto			Send test results/min fuel temp ()	Update Info (NASA01)	
		Confirm FMA display reads: LOC & G/S				Scan Screen: Tails Status	Remind GO: Attend to AC ()	
		Listen	Remind: Flaps 25			Scan Screen: Tails Management		
		Reach and set flaps to 25.				Prepare Outbound for release Check weather ()		
		Listen	Remind: Flaps 30			Prepare Outbound for release Check flight plan ()		
		Reach and set flaps to 30.				Scan Screen: Tails Status		
			Remind: Landing checklist			Scan Screen: Tails Management		
		Indicate landing checklist complete				Review Weather ()		
		Say "Tower, NASA01 for RWY two seven left"				Review Altitude & Heading ()		
		Listen to ATC		Say "NASA01 cleared to land RWY one six left"		Review Fuel levels ()		
		Say "Roger, cleared to land RWY two seven for NASA01"				Review Weather ()		
1,000' AGL	3.9 nm	Listen	"1,000 feet"			Review Altitude & Heading (NASA01)	Notify: Below 1,000' (NASA01)	
		Acquire runway	Send to ground auto			Review Fuel levels (NASA01)	Update Info (NASA01)	
		Listen	"Approaching DH"			Review Weather (NASA01)		
500' AGL	~1nm	Listen	"500 feet"			Scan Screen: Tails Status		
		Recheck stabilized approach status				Scan Screen: Tails Management		
		Listen	"100"			Review Fuel levels ()		
		Listen	"50"			Review Weather ()		
		Listen	"30"			Review Altitude & Heading ()		
		Listen	"20"			Speak w/ OBP () Discuss: Delays		
		Listen	"10"			Find Gate Information ()		
Touchdown								

Appendix D. Task Decomposition Spreadsheet (SPO Off-Hybrid Nominal)

SPOIII Hybrid - Off-Nominal
O/S Divert to: CYS ILS RWY 27L
800' Cloud Ceiling
Category D
NASA01 Pre TOD - TD
GO t(x) - t(y)

NASA01 Altitude	NASA01 Airport Distance	Pilot Flying On- Board Pilot NASA01 (CA)	Flight Deck Automation (NASA01)	ATC (cues)	Pilot NOT Flying Ground Operator (Hybrid) 1	Ground Automation 1	Pilot NOT Flying Ground Operator (Hybrid) 2	Ground Automation 2	Pilot NOT Flying Ground Operator (Hybrid) 3	Ground Automation 3
Prior to Final Descent		*Continuous tasks:* Auditory and Instrument Monitor. Maintain a common schema.	*Continuous tasks:* Off-Nominal Alerts. Phase of flight alerts. Monitor conformance. Notification of non self-initiated system changes.	*Continuous tasks:* Maintain separation	Continuous tasks: Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (NASA01). Available for DA if requested.	*Continuous tasks:* Off-Nominal Alerts. Monitor task adherence. Transmit information packages. Transfer notification.	*Continuous tasks:* Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (Other). Available for DA if requested.	*Continuous tasks:* Off-Nominal Alerts. Monitor conformance. Transmit information packages. Transfer notification.	*Continuous tasks:* Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (Other). Available for DA if requested.	*Continuous tasks:* Off-Nominal Alerts. Monitor task adherence. Transmit information packages. Transfer notification.
		Pre-Arrival briefing/checklist (Taxi Chart, taxi route, gate, flaps, target landing speed, descent speed, brake settings, time of year, geographic position)			Prepare briefing package for Handoff (**NASA01**)		Pre-Shift Flight Briefings		GO Tasks (Other AC)	
			Get ATIS. Uplink to FD: expected approach/arrival info (Airport, runway, altimeter, target speed, landing flaps, DH, frequencies.) Notify.				Review handoff packages (**NASA01**, AC2, AC3, AC4, AC5)			
		Crosscheck auto info					Listen			
		Execute auto info					Scan Screen: Tails Status			
							Scan Screen: Tails Management			
							Review Fuel levels ()	Remind GO: Attend to AC ()		
							Review Weather ()			
							Review Fuel levels ()			
							Review Weather ()			
							Review Fuel levels ()			
							Review Weather ()			
					Execute handoff (**NASA01**)		Review Fuel levels ()			
					Disconnect (**NASA01**)		Review Weather ()			
		If good captain & threat is evident… Preload alternatives into FMS. Say "Preloading alternate ___ into FMS."			GO Tasks (Other AC)		Review Fuel levels (**NASA01**)			
	~110nm TOD	Approach descent checklist	Remind: Approach descent checklist				Review Weather (**NASA01**)			
37,000'	104 nm SIDNEY	Execute Altitude.	Send to ground auto				Scan Screen: Tails Status	Update Info (**NASA01**)		
		Listen to ATC	Pre-load ATC info	Say "NASA01 contact Denver Center, 133.95"			Scan Screen: Tails Management			
		Say "NASA01, Denver Center, 133.95"					Listen			
		Crosscheck auto info: Radio frequency					Speak w/ OBP () Discuss: Wheel chairs			
		Execute radio frequency					Find Gate Information ()			
		Say "Denver Center, NASA01 descending through 240"					Speak w/ Customer Care Team Discuss: Wheelchairs ()			
		Listen to ATC Crosscheck.	Pre-load ATC info	Say "NASA01; Denver Center, descend and maintain 17 thousand; Expect ILS RW 16L; Denver altimeter 29.57"			Speak w/ OBP: Relay resolution			
		CA crosscheck. If Schema not correct, get ATIS & amend Approach briefing/checklist.					Review Fuel levels ()			
		Say "NASA01 descending to 17 thousand, 29.57"	Set 3 Altimeters Notify.				Review Weather ()	Update Info (**NASA01**)		
		Crosscheck auto info: Altimeters					Scan Screen: Tails Status			
		Execute Altimeters	Send to ground auto				Scan Screen: Tails Management	Update Info (**NASA01**)		
		Crosscheck auto info: Altitude					Review Fuel levels ()			
		Execute Altitude.	Send to ground auto				Review Weather ()	Update Info (**NASA01**)		
			Lav Alert				Scan Screen: Tails Status			
		Speak w/ GO "Forward lavratory is leaking"					Listen			
		Listen					Speak w/ OBP (**NASA01**) Confirm request: Maintenance Problem			
		Listen					Speak w/ OBP (**NASA01**) Safety inquiry: Maintenance Problem "Do you have any safety concerns?"			
		Speak w/ GO "No, have maintenance ready on the ground at DEN."					Listen			

Appendix D. Task Decomposition Spreadsheet (SPO Off-Hybrid Nominal)

						Speak w/ Maintenance (**NASA01**) Patch through maintenance (collaboration possible)		
		Listen				Speak w/ OBP (**NASA01**) Relay Resolution: "Maintenance will you meet you at the gate"		
						Review Fuel levels (**NASA01**)		
						Review Weather (**NASA01**)		
18,000' 10,879' AGL	74 nm		Remind: Pressurization			Scan Screen: Tails Status	Notify: Below 18,000' (**NASA01**)	
		Check pressurization				Scan Screen: Tails Management		
			Turn on exterior lights Notify			Speak w/ OBP () Discuss: Gate Connection Problem		
		Crosscheck Lights				Speak w/ OBP () Discuss: Gate Connection Solution		
					GO Tasks (Other AC)	Comm: Reservation coordinator Discuss Gate Connections ()		**GO Tasks (Other AC)**
		Listen to ATC		Say "All aircraft, Microburst alert at Denver, approaches are temporally discontinued, expect holding for all runways"		Notified of wx at DEN, possible hold and divert (NASA01)	Notify: Wx @ DEN	
		Review weather				Review Fuel levels (**NASA01**)		
		Review options				Review Weather (**NASA01**)		
		Decide DA is needed				Scan Screen: Tails Status		
		Say: "DA Request"				Listen DA request (NASA01)		
						Review Altitude (**NASA01**)		
						Review Heading (**NASA01**)		
		Listen				Speak w/ OBP: Confirm DA request (NASA01)		
						Select DA	**Request Confirmation**	
					Receives AC from GO2	**Confirm handoff**	**Handoff all other AC**	**Receives AC from GO2**
		Listen	"Dedicated Assistance"			Listen	Notify: DA MODE	
		Listen				Speak w/ OBP (**NASA01**): "How can I help?"		
		Speak w/ GO: "Locate relevant alternate approach plates and check weather"				Listen		
		Listen				"Roger, locating."		
						Identify alternate airports		
						Locate approach plates (CYS/EGE/COS/GJT/PUB)		
			Load plates			Send plates to NASA01	Send plates to **NASA01** auto	
		Review plates				Locate weather (CYS/EGE/COS/GJT/PUB)		
			Load weather			Send weather to **NASA01**	Send weather to **NASA01** auto	
		Review weather				Review plates		
						Review weather		
		Discuss current state				Discuss current state		
		Agree on preliminary best alternate (CYS)				Agree on preliminary best alternate (CYS)		
		Assign duties: Chart set up, weather review, ATC communication, decision support				Listen.		
		Listen			**GO Tasks (Other AC)**	Confirm duties		**GO Tasks (Other AC)**
			Notify OBP			Load primary alternate Airport (CYS)	Notify **NASA01** auto	
		Crosscheck GO						
		Discuss probable hold locations & pattern. Discuss fuel state and calculate endurance for a hold. (Find burn to DEN. Desired DEN landing fuel. Current burn rate. Time/fuel remaining. Crosscheck.)				Discuss probable hold locations & pattern. Discuss fuel state and calculate endurance for a hold. (Find burn to DEN. Desired DEN landing fuel. Current burn rate. Time/fuel remaining. Crosscheck.)		
			Notify OBP			Pre-load probable hold into CDU	Notify **NASA01** auto	
		Crosscheck GO						
		Discuss Alternate 1 (CYS) (distance/time/fuel/CAT/ATIS) (x2)				Discuss Alternate 1 (CYS) (distance/time/fuel/CAT/ATIS) (x2)		
						Action		
		Action						
		Discuss Alternate 2 (EGE) (distance/time/fuel/CAT/ATIS) (x2)				Discuss Alternate 2 (EGE) (distance/time/fuel/CAT/ATIS) (x2)		
						Action		
		Action						
		Discuss Alternate 3 (COS) (distance/time/fuel/CAT/ATIS) (x2)				Discuss Alternate 3 (COS) (distance/time/fuel/CAT/ATIS) (x2)		
						Action		
		Action						

Appendix D. Task Decomposition Spreadsheet (SPO Off-Hybrid Nominal)

		Listen to ATC	Pre-load ATC info	Say "NASA01, hold North of LANDR on 216 radial, left-hand turns. Maintain one seven thousand, expect further clearance in one zero (10) minutes"		Listen to ATC	Pre-load ATC info	
10,879' AGL	61 nm	Decide on Cheyenne (CYS) as the alternate. Discuss fuel state and calculate endurance for a hold with CYS as new destination. (Find burn to CYS. Desired CYS landing fuel. Current burn rate. Time/fuel remaining. Crosscheck.)				Decide on Cheyenne (CYS) as the alternate. Discuss fuel state and calculate endurance for a hold with CYS as new destination. (Find burn to CYS. Desired CYS landing fuel. Current burn rate. Time/fuel remaining. Crosscheck.)		
		Listen				Say "NASA01 maintaining 17,000', will hold at LANDR"		
		Crosscheck GO				Say "Denver Center, NASA01 at LANDR, time 15, 17,000"		
		Crosscheck ATC info						
		Execute hold	Send to ground auto				Update Info (NASA01) / Notify GO	
						Crosscheck hold		
		Listen to ATC		Say "All aircraft, Tower evacuated due to funnel cloud sighting, divert to other airports."		Listen to ATC		
		Decide to divert to CYS (the Decide piece requires that alternates are removed from consideration by a process of elimination - weather, distance to land, and fuel). Execute Alternate 1 Plan.				Decide to divert to CYS (the Decide piece requires that alternates are removed from consideration by a process of elimination - weather, distance to land, and fuel). Execute Alternate 1 Plan.		
		CA: Validates / in agreement with mental map						
		Action						
						Action		
		Listen. Crosscheck GO				"Denver Center, NASA01 request IFR clearance to Cheyenne via direct"		
		Listen to ATC	Pre-load ATC info	"NASA01 standby" "NASA01 cleared to Cheyenne via direct GILL, direct Cheyennne"	**GO Tasks (Other AC)**	Listen to ATC	Pre-load ATC info	**GO Tasks (Other AC)**
			Load CYS as new destination in CDU. Get ATIS. Build a route, Load expected Approach/Arrival Information: Airport, Runway, Altimeter, Speed changes, landing flaps, DH, frequencies. Load LNAV/VNAV. Notify OBP.				Load CYS as new destination in CDU. Get ATIS. Build a route, Load expected Approach/Arrival Information: Airport, Runway, Altimeter, Speed changes, landing flaps, DH, frequencies. Load LNAV/VNAV. Notify GO.	
		Crosscheck AUTO info				Crosscheck AUTO info		
		Execute route	Send to ground auto				Update Info (NASA01) / Notify GO	
		CA: Validates / in agreement with mental map				Crosscheck route		
		Pre-Arrival briefing. (Taxi Chart, taxi route, gate, flaps, target landing speed, descent speed, brake settings.				Monitor PF Pre-Arrival Briefing. Crosscheck		
		Listen to ATC	Pre-load ATC info	Say "NASA01 Fly heading 281 GILL, maintain one seven thousand"		Listen to ATC	Pre-load ATC info	
		Listen. Crosscheck GO				Say "Roger, NASA01, 281 to GILL, maintaining 17,000."		
		Crosscheck AUTO info						
		Execute Heading	Send to ground auto				Update Info (NASA01) / Notify GO	
						Crosscheck Heading		
		Listen to ATC	Pre-load ATC info	Say "NASA01, Fly heading 350, Cleared direct HAMER, direct CYS, descend and maintain 10,000, expect runway 27 approach to CYS; Cheyenne altimeter 28.15"		Listen to ATC	Pre-load ATC info	
		Listen. Crosscheck GO				Say "Roger, NASA01, 350, direct to HAMER, direct CYS, descend and maintain 10,000, expect runway 27 approach; altimeter 28.15"		
		CA crosscheck. If Schema not correct, get ATIS & amend Approach briefing.						
		Execute route	Send to ground auto				Update Info (NASA01) / Notify GO	
						Crosscheck OBP		
		Exit hold	Send to ground auto				Update Info (NASA01) / Notify GO	
						Crosscheck OBP		

Appendix D. Task Decomposition Spreadsheet (SPO Off-Hybrid Nominal)

			Set 2 cockpit Altimeters Notify NASA01 & GO				Set 1 ground Altimeter Notify GO & NASA01	
		Crosscheck AUTO info				Crosscheck AUTO info		
		Execute Altimeters				Execute Altimeter		
3,879' AGL	49 nm	Listen to ATC	Pre-load ATC info	Say "NASA01 contact Cheyenne Approach on 124.55"		Listen to ATC	Pre-load ATC info	
		Listen. Crosscheck GO				Say "Roger, NASA01, 124.55"		
		Crosscheck AUTO info				Crosscheck AUTO info		
						Execute radio frequency		
		Listen. Crosscheck GO				Say "Cheyenne Approach, NASA01, one zero thousand with Alpha."		
		Listen to ATC	Pre-load ATC info	Say "Roger, NASA01. descend and maintain flight level 9000"	GO Tasks (Other AC)	Listen to ATC	Pre-load ATC info	GO Tasks (Other AC)
		Listen. Crosscheck GO				Say "Roger, 9000 for NASA01"		
		Crosscheck AUTO info						
		Execute Altitude	Send to ground auto				Update Info (NASA01) / Notify GO	
						Crosscheck Altitude		
		Speak w/ GO: "I am ready to release Dedicated Assistance""				Listen		
		Listen				Speak w/OBP: "Confirming Dedicated Assistance release"		
		Speak w/ GO:: "Thanks for the assistance"				Listen		
		Listen				Interact NASA01: "No problem, goodnight."		
		Execute DA release	Send to ground auto				Update Info (NASA01) / Notify GO	
2,879' AGL	15 nm	Listen to ATC	Pre-load ATC info	Say "NASA01, turn left heading 350, base leg."	Gives AC to GO2	Request AC return		Gives AC to GO2
		Say "Roger, heading 350, base leg, NASA01"				Receive other AC		
		Crosscheck AUTO info				Scan Screen: Tails Status		
		Execute Heading	Send to ground auto			Scan Screen: Tails Management	Update Info (NASA01)	
		Listen	Remind: Flaps 1			Review Fuel levels ()		
		Reach and set flaps to 1				Review Weather ()		
		Set speed (210)				Scan Screen: Tails Status		
		Listen	Remind: Flaps 5			Scan Screen: Tails Management		
		Reach and set flaps to 5.				Review Fuel levels ()		
		Listen to ATC	Pre-load ATC info	Say "NASA01, turn left heading 280, maintain 7,800 until established. Maintain 180 kts to ZUNUG, contact tower on 118.7"		Review Weather ()		
		Say "Roger, left 280, 7,800 until established and 180 until ZUNUG, contacting Tower at 118.7, NASA01"				Scan Screen: Tails Status	Remind GO: Attend to AC ()	
		Crosscheck auto info: Altitude				Scan Screen: Tails Management		
		Execute Altitude	Send to ground auto			Review Fuel levels ()	Update Info (NASA01)	
		Crosscheck auto info: Heading						
		Execute Heading	Send to ground auto		GO Tasks (Other AC)	Review Weather ()	Update Info (NASA01)	GO Tasks (Other AC)
		Listen	Remind: Arm approach mode					
		Arm Approach Mode	Send to ground auto			Scan Screen: Tails Status	Update Info (NASA01)	
		Confirm FMA reads as expected				Scan Screen: Tails Management		
		Crosscheck auto info: Radio frequency				Review Fuel levels ()		
		Execute radio frequency	Send to ground auto			Review Weather ()	Update Info (NASA01)	
1,679' AGL	15 nm		Remind: Flaps 15			Scan Screen: Tails Status		
		Reach and set flaps to 15.				Scan Screen: Tails Management		
		Set speed (180)				Review Fuel levels ()		
		Say "Cheyenne Tower, NASA01 turning Final for the ILS 27L approach."				Review Weather ()		
		Listen to ATC		Say "NASA01, cleared for the ILS 27L approach."		Review Altitude & Heading ()		
		Say "Roger, cleared for ILS 27L, NASA01"				Receive and Understand message (ATC) "..."		
		Disconnect autopilot	Aural alert. Send to ground auto			Identify relevant AC	Update Info (NASA01)	
		Listen	Remind: Landing gear			Scan Screen: Tails Status		
		Set landing gear				Scan Screen: Tails Management		
		Set speed (146)				Speak w/ OBP () Discuss: Security information		

Appendix D. Task Decomposition Spreadsheet (SPO Off-Hybrid Nominal)

		C4 Arm speed brake			GO Tasks (Other AC)	Scan Screen: Tails Status		GO Tasks (Other AC)
		Set TDZE				Scan Screen: Tails Management		
						Listen		
		Listen	Remind: Flaps 20			Speak w/ OBP () Discuss: Fuel temp test		
		Reach and set flaps to 20.				Calculate fuel temp		
1,670' AGL	5.1 nm	Glideslope capture	Send to ground auto			Send test results/min fuel temp ()	Update Info **(NASA01)**	
		Confirm FMA display reads: LOC & G/S				Scan Screen: Tails Status		
		Listen	Remind: Flaps 25			Scan Screen: Tails Management	Notify: New Outbound ()	
		Reach and set flaps to 25.				Prepare Outbound for release Check weather ()		
		Listen	Remind: Flaps 30			Prepare Outbound for release Check flight plan ()		
		Reach and set flaps to 30.				Scan Screen: Tails Status	Remind GO: Attend to AC ()	
			Remind: Landing checklist			Scan Screen: Tails Management		
		Indicate landing checklist complete				Scan Screen: Tails Status		
		Say "Tower, NASA01 for RWY two seven left"				Scan Screen: Tails Management		
		Listen to ATC		Say "NASA01 cleared to land RWY two seven left"		Speak w/ OBP () Discuss: Gate Connection Problem		
		Say "Roger, cleared to land RWY two seven for NASA01"				Speak w/ OBP () Discuss: Gate Connection Solution		
1,000' AGL	3.9 nm	Listen	"1,000 feet"			Comm: Reservation coordinator Discuss Gate Connections ()	Notify: Below 1,000' **(NASA01)**	
		Acquire runway	Send to ground auto			Review Altitude & Heading **(NASA01)**	Update Info **(NASA01)**	
		Listen	"Approaching DH"			Review Fuel levels **(NASA01)**		
500' AGL	~1nm	Listen	"500 feet"			Review Weather **(NASA01)**		
		Recheck stabilized approach status				Scan Screen: Tails Status		
		Listen	"100"			Scan Screen: Tails Management		
		Listen	"50"			Review Fuel levels ()		
		Listen	"30"			Review Weather ()		
		Listen	"20"			Speak w/ OBP () Discuss: Airport/inbound delays		
		Listen	"10"			Speak w/ Customer care team Discuss: Delays ()		
Touchdown								

Appendix E. Task Decomposition Spreadsheet (SPO Specialist Nominal)

SPOIII Specialist - Nominal
NASA01 DEN ILS RWY 16
800' Cloud Ceiling
Category D
NASA01 Pre TOD - TD
GOH t(x) - t(y)

NASA01 Altitude	NASA01 Airport Distance	Pilot Flying On-Board Pilot NASA01 (CA)	Flight Deck Automation (NASA01)	ATC (cues)	Pilot NOT Flying Ground Operator (Hybrid) 1	Ground Automation 1	Pilot NOT Flying Ground Operator (Hybrid) 2	Ground Automation 2	Pilot NOT Flying Ground Operator (Hybrid) 3	Ground Automation 3
Prior to Final Descent		*Continuous tasks:* **Auditory and Instrument Monitor. Maintain a common schema.**	*Continuous tasks:* **Off-Nominal Alerts. Phase of flight alerts. Monitor conformance. Notification of non self-initiated system changes.**	*Continuous tasks:* **Maintain separation**	**Continuous tasks:** **Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (NASA01). Available for DA if requested.**	*Continuous tasks:* **Off-Nominal Alerts. Monitor task adherence. Transmit information packages. Transfer notification.**	*Continuous tasks:* **Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (Other). Available for DA if requested.**	*Continuous tasks:* **Off-Nominal Alerts. Monitor conformance. Transmit information packages. Transfer notification.**	*Continuous tasks:* **Auditory & alert Monitor. Maintain a common schema. Act as First Officer to DA aircraft &provide dispatch information.**	*Continuous tasks:* **Off-Nominal Alerts. Phase of flight alerts. Monitor task adherence. Notification of non self-initiated system changes. Transfer notification.**
		Pre-Arrival briefing/checklist (Taxi Chart, taxi route, gate, flaps, target landing speed, descent speed, brake settings, time of year, geographic position)			Prepare briefing package for Handoff **(NASA01)**		Pre-Shift Flight Briefings		**GO Tasks (Other AC)**	
			Get ATIS. Uplink to FD: expected approach/arrival info (Airport, runway, altimeter, target speed, landing flaps, DH, frequencies.) Notify.				Review handoff packages **(NASA01**, AC2, AC3, AC4, AC5)			
		Crosscheck auto info					Listen			
		Execute auto info					Scan Screen: Tails Status	Remind GO: Attend to AC ()		
							Scan Screen: Tails Management			
							Review Fuel levels ()			
							Review Weather ()			
							Review Fuel levels ()			
							Review Weather ()			
							Review Fuel levels ()			
							Review Weather ()			
					Execute handoff **(NASA01)**		Review Fuel levels ()			
					Disconnect (NASA01)		Review Weather ()			
		If good captain & threat is evident… Preload alternatives into FMS. Say "Preloading alternate ___ into FMS."			**GO Tasks (Other AC)**		Review Fuel levels **(NASA01)**			
	~110nm TOD	Approach descent checklist	Remind: Approach descent checklist				Review Weather **(NASA01)**			
37,000'	**104 nm SIDNEY**	Execute Altitude.	Send to ground auto				Scan Screen: Tails Status	Update Info **(NASA01)**		
		Listen to ATC	Pre-load ATC info	Say "NASA01 contact Denver Center, 133.95"			Scan Screen: Tails Management			
		Say "NASA01, Denver Center, 133.95"					Listen			
		Crosscheck auto info: Radio frequency					Speak w/ OBP () Discuss: Wheel chairs			
		Execute radio frequency					Find Gate Information ()			
		Say "Denver Center, NASA01 descending through 240"					Speak w/ Customer Care Team Discuss: Wheelchairs ()			
		Listen to ATC Crosscheck.	Pre-load ATC info	Say "NASA01; Denver Center, descend and maintain 17 thousand; Expect ILS RW 16L; Denver altimeter 29.57"			Speak w/ OBP: Relay resolution			
		CA crosscheck. If Schema not correct, get ATIS & amend Approach briefing/checklist.					Review Fuel levels ()			
		Say "NASA01 descending to 17 thousand, 29.57"	Set 3 Altimeters Notify.				Review Weather ()	Update Info **(NASA01)**		
		Crosscheck auto info: Altimeters					Scan Screen: Tails Status			
		Execute Altimeters	Send to ground auto				Scan Screen: Tails Management			
		Crosscheck auto info: Altitude					Review Fuel levels ()			
		Execute Altitude	Send to ground auto				Review Weather ()	Update Info **(NASA01)**		
		Speak w/ GO "Forward lavratory is leaking"					Listen			
		Listen					Speak w/ OBP **(NASA01)** Confirm request: Maintenance Problem			
		Listen					Speak w/ OBP **(NASA01)** Safety inquiryt: Maintenance Problem "Do you have any safety concerns?"			
		Speak w/ GO "No, have maintenance ready on the ground at DEN."					Listen			

Appendix E. Task Decomposition Spreadsheet (SPO Specialist Nominal)

						Speak w/ Maintenance (**NASA01**) Patch through maintenance (collaboration possible)		
		Listen				Speak w/ OBP (**NASA01**) Relay Resolution: "Maintenance will you meet you at the gate"		
						Review Fuel levels (**NASA01**)		
						Review Weather (**NASA01**)		
18,000' 11,650' AGL	**61 nm**		Remind: Pressurization			Scan Screen: Tails Status	Notify: Below 18,000' (**NASA01**)	
		Check pressurization				Scan Screen: Tails Management		
			Turn on exterior lights Notify			Speak w/ OBP () Discuss: Gate Connection Problem		
		Crosscheck Lights				Speak w/ OBP () Discuss: Gate Connection Solution		
						Comm: Reservation coordinator Discuss Gate Connections ()		
		Listen to ATC	Pre-load ATC info	Say "NASA01, Fly heading 218, cleared direct PHLAT, direct KIPPR, direct Denver, descend and maintain 10,000, expect runway 16L ILS approach to Denver."		Receive and Understand message (ATC) "Delays at ORD due to weather."		
		Say "Roger, United 573, 218, direct to PHLAT, direct DEN, descend and maintain 10,000, expect runway 16L approach."				Scan Screen: Tails Status	Remind GO: Attend to AC ()	
		Execute Altitude	Send to ground auto			Scan Screen: Tails Management		
		Execute Heading	Send to ground auto			Review Altitude & Heading ()		
		Listen to ATC		Say "NASA01 contact Denver Approach on 119.3."		Review Fuel Levels ()		
		Say "Roger, United 573, 119.3."				Review Weather ()		
		Execute Radio	Send to ground auto			Speak w/ OBP () Discuss: Airport/inbound delays		
		Say "Denver Approach, United 573, one zero thousand with Alpha."				Speak w/ Customer care team Discuss: Delays ()		
4,650' AGL	**40 nm**	Listen to ATC	Pre-load ATC info	Say "Roger, NASA01. descend and maintain flight level 8000"	**GO Tasks (Other AC)**	Speak w/ Reservation coordinator Discuss: Delays ()		**GO Tasks (Other AC)**
		Say "Roger, heading 350, base leg, NASA01"				Scan Screen: Tails Status		
		Crosscheck AUTO info				Scan Screen: Tails Management		
		Execute Heading	Send to ground auto	Say "NASA01, turn left heading 270, base leg."		Review Altitude & Heading ()		
		Listen	Remind: Flaps 1			Review Fuel levels ()		
		Reach and set flaps to 1				Review Weather ()		
		Set speed (210)				Review Altitude & Heading ()	Notify: Autopilot disconnect ()	
		Listen	Remind: Flaps 5			Review Fuel levels ()		
		Reach and set flaps to 5.				Review Weather ()		
		Listen to ATC	Pre-load ATC info			Review Weather ()		
		Listen to ATC	Pre-load ATC info			Scan Screen: Tails Status		
		Say "Roger, heading 270, base leg, United 573"		Say "NASA01, turn left heading 200, maintain 7,000 until established. Maintain 180 kts to LEETS, contact tower on 135.3"		Scan Screen: Tails Management		
		Crosscheck auto info: Altitude				Review Altitude & Heading ()		
		Execute Altitude	Send to ground auto			Review Fuel levels ()		
		Crosscheck auto info: Heading				Review Weather ()		
		Execute Heading	Send to ground auto			Scan Screen: Tails Status		
		Listen	Remind: Arm approach mode			Scan Screen: Tails Management		
		Arm Approach Mode	Send to ground auto			Discuss: Fuel Temperatures ()		
		Confirm FMA reads as expected				Scan Screen: Tails Status		
		Crosscheck auto info: Radio frequency				Scan Screen: Tails Management		
		Execute radio frequency	Send to ground auto			Review Fuel levels ()		
2,650' AGL	**32/7 nm**		Remind: Flaps 15			Review Weather ()		
		Reach and set flaps to 15.				Scan Screen: Tails Status		
		Set speed (180)				Scan Screen: Tails Management		
		Say "Cheyenne Tower, NASA01 turning Final for the ILS 27L approach."				Review Fuel levels ()		

Appendix E. Task Decomposition Spreadsheet (SPO Specialist Nominal)

		Listen to ATC		Say "NASA01, cleared for the ILS 16L approach."	GO tasks (Other AC)	Review Weather ()		GO Tasks (Other AC)
		Say "Roger, cleared for ILS 27L, NASA01"				Receive and Understand message (ATC) "……"		
		Disconnect autopilot	Aural alert. Send to ground auto			Identify relevant AC		
		Listen	Remind: Landing gear			Scan Screen: Tails Status	Remind GO: Attend to AC ()	
		Set landing gear				Scan Screen: Tails Management		
		Set speed (146)				Speak w/ OBP () Discuss: Security information		
		C4 Arm speed brake				Scan Screen: Tails Status		
		Set TDZE				Scan Screen: Tails Management		
						Listen		
		Listen	Remind: Flaps 20			Speak w/ OBP () Discuss: Fuel temp test		
		Reach and set flaps to 20.				Calculate fuel temp		
1,650' AGL	7 nm	Glideslope capture	Send to ground auto			Send test results/min fuel temp ()		
		Confirm FMA display reads: LOC & G/S				Scan Screen: Tails Status		
		Listen	Remind: Flaps 25			Scan Screen: Tails Management		
		Reach and set flaps to 25.				Prepare Outbound for release Check weather ()		
		Listen	Remind: Flaps 30			Prepare Outbound for release Check flight plan ()		
		Reach and set flaps to 30.				Scan Screen: Tails Status		
			Remind: Landing checklist			Scan Screen: Tails Management		
		Indicate landing checklist complete				Review Weather ()		
		Say "Tower, NASA01 for RWY two seven left"				Review Altitude & Heading ()		
		Listen to ATC		Say "NASA01 cleared to land RWY one six left"		Review Fuel levels ()		
		Say "Roger, cleared to land RWY two seven for NASA01"				Review Weather ()		
1,000' AGL	3.9 nm	Listen	"1,000 feet"			Review Altitude & Heading (**NASA01**)	Notify: Below 1,000' (**NASA01**)	
		Acquire runway	Send to ground auto			Review Fuel levels (**NASA01**)		
		Listen	"Approaching DH"			Review Weather (**NASA01**)		
500' AGL	~1nm	Listen	"500 feet"			Scan Screen: Tails Status		
		Recheck stabilized approach status				Scan Screen: Tails Management		
		Listen	"100"			Review Fuel levels ()		
		Listen	"50"			Review Weather ()		
		Listen	"30"			Review Altitude & Heading ()		
		Listen	"20"			Speak w/ OBP () Discuss: Delays		
		Listen	"10"			Find Gate Information ()		
Touchdown								

Appendix F. Task Decomposition Spreadsheet (SPO Specialist Off-Nominal)

SPOIII Specialist - Off-Nominal
O/S Divert to: CYS ILS RWY 27
800' Cloud Ceiling
Category D
NASA01 Pre TOD - TD
GO t(x) - t(y)

NASA01 Altitude	NASA01 Airport Distance	Pilot Flying On-Board Pilot NASA01 (CA)	Flight Deck Automation (NASA01)	ATC (cues)	Pilot NOT Flying Ground Operator (Assistant) 1	Ground Automation 1	Pilot NOT Flying Ground Operator (Assistant) 2	Ground Automation 2	Pilot NOT Flying Ground Operator (Specialist)	Ground Automation 3
Prior to Final Descent		*Continuous tasks:* Auditory and Instrument Monitor. Maintain a common schema.	*Continuous tasks:* Off-Nominal Alerts. Phase of flight alerts. Monitor task adherence. Notification of non self-initiated system changes.	*Continuous tasks:* Maintain separation	Continuous tasks: Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (NASA01). Available for DA if requested.	*Continuous tasks:* Off-Nominal Alerts. Monitor task adherence. Transmit information packages. Transfer notification.	*Continuous tasks:* Auditory & alert Monitor. Maintain a common schema. Maintain company schedule efficency. Provide dispatch information & limited support to OBP (Other). Available for DA if requested.	*Continuous tasks:* Off-Nominal Alerts. Monitor task adherence. Transmit information packages. Transfer notification.	*Continuous tasks:* Auditory & alert Monitor. Maintain a common schema. Act as First Officer to DA aircraft &provide dispatch information.	*Continuous tasks:* Off-Nominal Alerts. Phase of flight alerts. Monitor task adherence. Notification of non self-initiated system changes. Transfer notification.
		Pre-Arrival briefing/checklist (Taxi Chart, taxi route, gate, flaps, target landing speed, descent speed, brake settings, time of year, geographic position)			Prepare briefing package for Handoff (NASA01)		Pre-Shift Flight Briefings		Offline	
			Get ATIS. Uplink to FD: expected approach/arrival info (Airport, runway, altimeter, target speed, landing flaps, DH, frequencies.) Notify.				Review handoff packages (**NASA01**, AC2, AC3, AC4, AC5)			
		Crosscheck auto info					Listen			
		Execute auto info					Scan Screen: Tails Status	Remind GO: Attend to AC ()		
							Scan Screen: Tails Management			
							Review Fuel levels ()			
							Review Weather ()			
							Review Fuel levels ()			
							Review Weather ()			
							Review Fuel levels ()			
							Review Weather ()			
					Execute handoff (NASA01)		Review Fuel levels ()			
					Disconnect (NASA01)		Review Weather ()			
		If good captain & threat is evident... Preload alternatives into FMS. Say "Preloading alternate ___ into FMS."			GO tasks (Other AC)		Review Fuel levels (NASA01)			
	~110nm TOD	Approach descent checklist	Remind: Approach descent checklist				Review Weather (NASA01)			
37,000'	104 nm SIDNEY	Execute Altitude.	Send to ground auto				BEGIN SPO III scenario events	Update Info (**NASA01**)		
		Listen to ATC		Say "NASA01 contact Denver Center, 133.95"			Scan Screen: Tails Status			
		Say "NASA01, Denver Center, 133.95"					Scan Screen: Tails Management			
		Set Radio.					Speak w/ OBP () Discuss: Wheel chairs			
							Find Gate Information ()			
		Say "Denver Center, NASA01 descending through 240"					Comm: Customer care team Discuss: Wheelchairs ()			
		Listen to ATC Crosscheck.	Pre-load ATC info	Say "NASA01; Denver Center, descend and maintain 17 thousand; Expect ILS RW 16L; Denver altimeter 29.57"			Review Fuel levels ()			
		C4 crosscheck. If Schema not correct, get ATIS & amend Approach briefing/checklist.					Review Weather ()			
		Say "NASA01 descending to 17 thousand, 29.57"	Set 3 Altimeters Notify. Send to ground auto.				Scan Screen: Tails Status	Remind GO: Attend to AC ()		
		Crosscheck 3 Altimeters.					Scan Screen: Tails Management			
		Crosscheck Altitude					Review Fuel levels ()			
		Execute Altitude.	Send to ground auto				Review Weather ()	Update Info (**NASA01**)		
		Speak w/ GO "Forward lavratory is leaking"					Listen			
		Listen					Speak w/ OBP (**NASA01**) Discuss: Maintenance Problem "Do you have any safety concerns?"			
		Speak w/ GO "No, have maintenance ready on the ground at DEN."					Listen			
		Listen					Speak w/ OBP (**NASA01**) Discuss: Maintenance Solution "Roger, contacting maintenance"			
							Speak w/ Maintenance (**NASA01**) Patch through maintenance (collaboration possible)			
		Listen					Speak w/ OBP (**NASA01**) "Maintenance will you meet you at the gate"			
							Review Fuel levels (**NASA01**)			
							Review Weather (**NASA01**)			
18,000' 10,879' AGL	74 nm						Scan Screen: Tails Status	Notify: Below 18,000' (**NASA01**)		

Appendix F. Task Decomposition Spreadsheet (SPO Specialist Off-Nominal)

	Check pressurization.				Scan Screen: Tails Management		Offline		
		Turn on exterior lights Notify			Speak w/ OBP () Discuss: Gate Connection Problem				
					Speak w/ OBP () Discuss: Gate Connection Solution				
	Listen to ATC		Say "All aircraft, Microburst alert at Denver, approaches are temporally discontinued, expect holding for all runways"		Comm: Reservation coordinator Discuss Gate Connections ()				
	Review weather				Notified of wx at DEN, possible hold and divert (NASA01)	Notify: Wx @ DEN			
	Review options				Review Fuel levels (**NASA01**)				
	Decide DA is needed				Review Weather (**NASA01**)				
	Say: "DA Request"				Scan Screen: Tails Status				
					Listen DA request (NASA01)		Notified of DA request (**NASA01**)		
					Review Altitude (**NASA01**)		Review Altitude (**NASA01**)	Connect Audio	
	Listen				Review Heading (**NASA01**)		Review Heading (**NASA01**)		
					Speak w/ OBP: Confirm DA request (NASA01)		Review Weather (**NASA01**)	Illuminate DA	
					Select DA	Request Confirmation	Select DA	Request Confirmation	
	Listen	"Dedicated Assistance"			Confirm handoff	Handoff all other AC	Confirm handoff	Handoff all other AC	
							Receives **NASA01** from GO2		
	Listen						Introduce		
	Introduce						Listen		
	Listen						Query		
	Problem (Multiple Cycles)						Listen (Multiple Cycles)		
	Listen						Speak w/ OBP (**NASA01**): "How can I help?"		
	Speak w/ GO: "Locate relevant alternate approach plates and check weather"						Listen		
	Listen						"Roger, locating."		
							Identify alternate airports		
							Locate approach plates (CYS/EGE/COS/GJT/PUB)		
		Load plates					Send plates to NASA01	Send plates to **NASA01** auto	
	Review plates						Locate weather (CYS/EGE/COS/GJT/PUB)		
		Load weather					Send weather to **NASA01**	Send weather to **NASA01** auto	
	Review weather						Review plates		
							Review weather		
	Discuss current state						Discuss current state		
	Agree on preliminary best alternate (CYS)						Agree on preliminary best alternate (CYS)		
	Assign duties: Chart set up, weather review, ATC communication, decision support						Listen.		
	Listen						Confirm duties		
		Notify OBP					Load primary alternate Airport (CYS)	Notify **NASA01** auto	
	Crosscheck GO								
	Discuss probable hold locations & pattern. Discuss fuel state and calculate endurance for a hold. (Find burn to DEN. Desired DEN landing fuel. Current burn rate. Time/fuel remaining. Crosscheck.)						Discuss probable hold locations & pattern. Discuss fuel state and calculate endurance for a hold. (Find burn to DEN. Desired DEN landing fuel. Current burn rate. Time/fuel remaining. Crosscheck.)		
		Notify OBP					Pre-load probable hold into CDU	Notify **NASA01** auto	
	Crosscheck GO								
	Discuss Alternate 1 (CYS) (distance/time/fuel/CAT/ATIS) (x2)						Discuss Alternate 1 (CYS) (distance/time/fuel/CAT/ATIS) (x2)		
							Action		
	Action								
	Discuss Alternate 2 (EGE) (distance/time/fuel/CAT/ATIS) (x2)						Discuss Alternate 2 (EGE) (distance/time/fuel/CAT/ATIS) (x2)		
							Action		
	Action								
	Discuss Alternate 3 (COS) (distance/time/fuel/CAT/ATIS) (x2)						Discuss Alternate 3 (COS) (distance/time/fuel/CAT/ATIS) (x2)		
							Action		
	Action								
	Listen to ATC	Pre-load ATC info	Say "NASA01, hold North of LAND8 on 216 radial, left-hand turns. Maintain one seven thousand, expect further clearance in one zero (10) minutes"				Listen to ATC	Pre-load ATC info	

GO tasks (Other AC)

GO tasks (Other AC)

Appendix F. Task Decomposition Spreadsheet (SPO Specialist Off-Nominal)

10,879' AGL	61 nm	Decide on Cheyenne (CYS) as the alternate. Discuss fuel state and calculate endurance for a hold with CYS as new destination. (Find burn to CYS. Desired CYS landing fuel. Current burn rate. Time/fuel remaining. Crosscheck.)			GO tasks (Other AC)	GO tasks (Other AC)	Decide on Cheyenne (CYS) as the alternate. Discuss fuel state and calculate endurance for a hold with CYS as new destination. (Find burn to CYS. Desired CYS landing fuel. Current burn rate. Time/fuel remaining. Crosscheck.)	
		Listen					Say "NASA01 maintaining 17,000', will hold at LANDR"	
		Crosscheck GO					Say "Denver Center, NASA01 at LANDR, time 15, 17,000"	
		Crosscheck ATC info						
		Execute hold	Send to ground auto					Update Info (NASA01) / Notify GO
							Crosscheck hold	
		Listen to ATC		Say "All aircraft, Tower evacuated due to funnel cloud sighting, divert to other airports."			Listen to ATC	
		Listen to ATC. Decide to divert to CYS (the Decide piece requires that alternates are removed from consideration by a process of elimination - weather, distance to land, and fuel - OTHERS?). Execute Alternate 1 Plan.					Listen to ATC command. Decide to divert to CYS (the Decide piece requires that alternates are removed from consideration by a process of elimination - weather, distance to land, and fuel - OTHERS?). Execute Alternate 1 Plan.	
		CA: Validates / in agreement with mental map						
		Action						
							Action	
		Listen. Crosscheck GO					"Denver Center, NASA01 request IFR clearance to Cheyenne via direct"	
		Listen to ATC	Pre-load ATC info	"NASA01 standby" "NASA01 cleared to Cheyenne via direct GILL, direct Cheyennne"			Listen to ATC	Pre-load ATC info
			Load CYS as new destination in CDU. Get ATIS. Build a route, Load expected Approach/Arrival Information: Airport, Runway, Altimeter, Speed changes, landing flaps, DH, frequencies. Load LNAV/VNAV. Notify OBP.					Load CYS as new destination in CDU. Get ATIS. Build a route, Load expected Approach/Arrival Information: Airport, Runway, Altimeter, Speed changes, landing flaps, DH, frequencies. Load LNAV/VNAV. Notify GO.
		Crosscheck AUTO info					Crosscheck AUTO info	
		Execute route	Send to ground auto					Update Info (NASA01) / Notify GO
		CA: Validates / in agreement with mental map					Crosscheck route	
		Pre-Arrival briefing. (Taxi Chart, taxi route, gate, flaps, target landing speed, descent speed, brake settings.					Monitor PF Pre-Arrival Briefing. Crosscheck	
		Listen to ATC	Pre-load ATC info	Say "NASA01 Fly heading 281 GILL, maintain one seven thousand"			Listen to ATC	Pre-load ATC info
		Listen. Crosscheck GO					Say "Roger, NASA01, 281 to GILL, maintaining 17,000."	
		Crosscheck AUTO info						
		Execute Heading	Send to ground auto					Update Info (NASA01) / Notify GO
							Crosscheck Heading	
		Listen to ATC	Pre-load ATC info	Say "NASA01, Fly heading 350, Cleared direct HAMER, direct CYS, descend and maintain 10,000, expect runway 27 approach to CYS; Cheyenne altimeter 28.15"			Listen to ATC	Pre-load ATC info
		Listen. Crosscheck GO					Say "Roger, NASA01, 350, direct to HAMER, direct CYS, descend and maintain 10,000, expect runway 27 approach; altimeter 28.15"	
		C4 crosscheck. If Schema not correct, get ATIS & amend Approach briefing.						
		Execute route	Send to ground auto					Update Info (NASA01) / Notify GO
							Crosscheck OBP	
		Exit hold	Send to ground auto					Update Info (NASA01) / Notify GO
							Crosscheck OBP	
			Set 2 cockpit Altimeters Notify NASA01 & GO					Set 1 ground Altimeter Notify GO & NASA01
		Crosscheck AUTO info					Crosscheck AUTO info	
		Execute Altimeters					Execute Altimeter	
3,879' AGL	49 nm	Listen to ATC	Pre-load ATC info	Say "NASA01 contact Cheyenne Approach on 124.55"			Listen to ATC	Pre-load ATC info
		Listen. Crosscheck GO					Say "Roger, NASA01, 124.55"	
		Crosscheck AUTO info					Crosscheck AUTO info	
							Execute radio frequency	
		Listen. Crosscheck GO					Say "Cheyenne Approach, NASA01, one zero thousand with Alpha."	

Appendix F. Task Decomposition Spreadsheet (SPO Specialist Off-Nominal)

		Listen to ATC	Pre-load ATC info	Say "Roger, NASA01. descend and maintain flight level 9000"	GO tasks (Other AC)		Listen to ATC	Pre-load ATC info	
		Listen. Crosscheck GO					Say "Roger, 9000 for NASA01"		
		Crosscheck AUTO info							
		Execute Altitude	Send to ground auto						Update Info (NASA01) / Notify GO
							Crosscheck Altitude		
		Speak w/ GO: "I am ready to release Dedicated Assistance""					Listen		
		Listen					Speak w/OBP: "Confirming Dedicated Assistance release, you'll be returning to GO2"		
		Speak w/ GO:: "Thanks for the assistance"					Listen		
		Listen					Interact NASA01: "No problem, goodnight."		
		Execute DA release	Send to ground auto			Receive NASA01 from GO3			Notify DA Released
		Listen				Speak w/ OBP: DA Inquiry (NASA01)			Update Info (NASA01) / Notify GO
		Speak w/ GO: DA resolved				Listen			
2,879' AGL	15 nm	Listen to ATC	Pre-load ATC info	Say "NASA01, turn left heading 350, base leg."		Review Altitude & Heading (NASA01)			
		Say "Roger, heading 350, base leg, NASA01"				Review Fuel levels (NASA01)			
		Crosscheck AUTO info				Review Weather (NASA01)			
		Execute Heading	Send to ground auto			Review new route (NASA01)	Update Info **(NASA01)**		
		Listen	Remind: Flaps 1			Speak w/ Customer care team Discuss: Delays (NASA01)			
		Reach and set flaps to 1				Scan Screen: Tails Status			
		Set speed (210)				Scan Screen: Tails Management			
		Listen	Remind: Flaps 5			Review Fuel levels ()			
		Reach and set flaps to 5.				Review Weather ()			
		Listen to ATC	Pre-load ATC info	Say "NASA01, turn left heading 280, maintain 7,800 until established. Maintain 180 kts to ZUNUG, contact tower on 118.7"		Review Altitude & Heading ()			
		Say "Roger, left 280, 7,800 until established and 180 until ZUNUG, contacting Tower at 118.7, NASA01"				Scan Screen: Tails Status	Remind GO: Attend to AC ()		
		Crosscheck auto info: Altitude				Scan Screen: Tails Management			
		Execute Altitude	Send to ground auto			Review Fuel levels ()	Update Info **(NASA01)**		
		Crosscheck auto info: Heading				Review Weather ()			
		Execute Heading	Send to ground auto			Scan Screen: Tails Status	Update Info **(NASA01)**		
		Listen	Remind: Arm approach mode			Scan Screen: Tails Management			
		Arm Approach Mode	Send to ground auto			Review Fuel levels ()	Update Info **(NASA01)**		
		Confirm FMA reads as expected				Review Weather ()			
		Crosscheck auto info: Radio frequency				Listen			
		Execute radio frequency	Send to ground auto			Speak w/ OBP () Discuss: Fuel temp test	Update Info **(NASA01)**		
1,679' AGL	15 nm		Remind: Flaps 15			Calculate fuel temp			
		Reach and set flaps to 15.				Send test results/min fuel temp ()			
		Set speed (180)				Scan Screen: Tails Status			
		Say "Cheyenne Tower, NASA01 turning Final for the ILS 27L approach."				Scan Screen: Tails Management			
		Listen to ATC		Say "NASA01, cleared for the ILS 27L approach."		Review Fuel levels ()			
		Say "Roger, cleared for ILS 27L, NASA01"				Review Weather ()			
		Disconnect autopilot	Aural alert. Send to ground auto			Receive and Understand message (ATC) "……."	Update Info **(NASA01)**		
		Listen	Remind: Landing gear			Identify relevant AC			
		Set landing gear				Scan Screen: Tails Status			
		Set speed (146)				Scan Screen: Tails Management			
		C4 Arm speed brake				Speak w/ OBP () Discuss: Security information			
		Set TDZE				Scan Screen: Tails Status			
						Scan Screen: Tails Management			
		Listen	Remind: Flaps 20			Review Fuel levels ()			
		Reach and set flaps to 20.				Review Weather ()			
1,670' AGL	5.1 nm	Glideslope capture	Send to ground auto			Scan Screen: Tails Status	Notify: New Outbound () Update Info (NASA01)		
		Confirm FMA display reads: LOC & G/S				Scan Screen: Tails Management			
		Listen	Remind: Flaps 25			Prepare Outbound for release Check weather ()			
		Reach and set flaps to 25.				Prepare Outbound for release Check flight plan ()			

Appendix F. Task Decomposition Spreadsheet (SPO Specialist Off-Nominal)

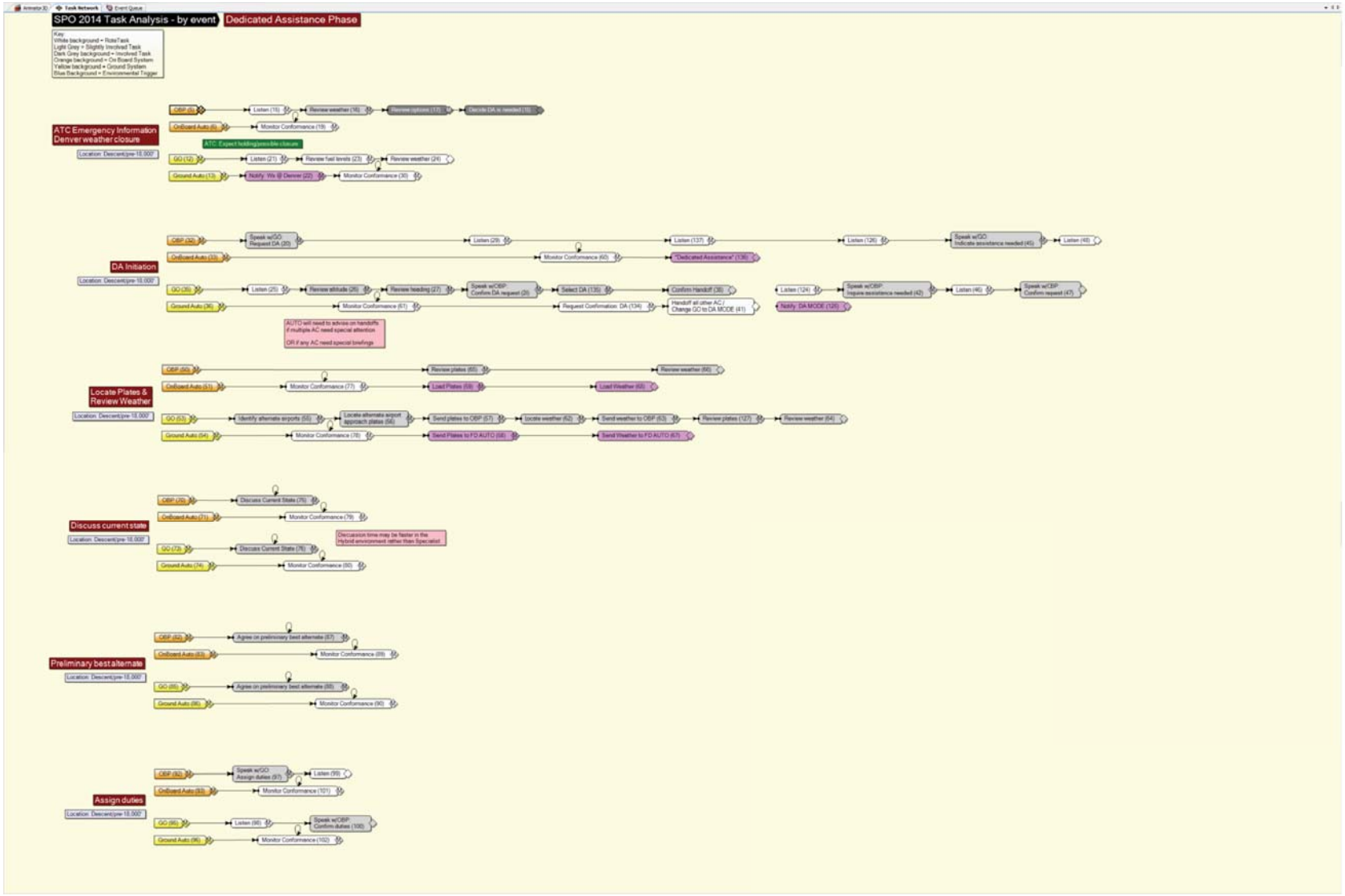
		Listen	Remind: Flaps 30		GO tasks (Other AC)	Scan Screen: Tails Status	Remind GO: Attend to AC ()	Offline
		Reach and set flaps to 30.				Scan Screen: Tails Management		
			Remind: Landing checklist			Scan Screen: Tails Status		
		Indicate landing checklist complete				Scan Screen: Tails Management		
		Say "Tower, NASA01 for RWY two seven left"				Speak w/ OBP () Discuss: Gate Connection Problem		
		Listen to ATC		Say "NASA01 cleared to land RWY two seven left"		Speak w/ OBP () Discuss: Gate Connection Solution		
		Say "Roger, cleared to land RWY two seven for NASA01"				Comm: Reservation coordinator Discuss Gate Connections ()		
1,000' AGL	**3.9 nm**	Listen	"1,000 feet"			Review Altitude & Heading	Notify: Below 1,000' (**NASA01**)	
		Acquire runway	Send to ground auto			Review Fuel levels (**NASA01**)	Update Info (NASA01)	
		Listen	"Approaching DH"			Review Weather (**NASA01**)		
500' AGL	**~1nm**	Listen	"500 feet"			Scan Screen: Tails Status		
		Recheck stabilized approach status				Scan Screen: Tails Management		
		Listen	"100"			Review Fuel levels ()		
		Listen	"50"			Review Weather ()		
		Listen	"30"			Speak w/ OBP () Discuss: Airport/inbound delays		
		Listen	"20"			Speak w/ Customer care team Discuss: Delays ()		
		Listen	"10"			Speak w/ Reservation coordinator Discuss: Delays ()		
Touchdown								

Appendix G. Micro Saint Sharp Task Groups (OBP-Centric Nominal Mode)

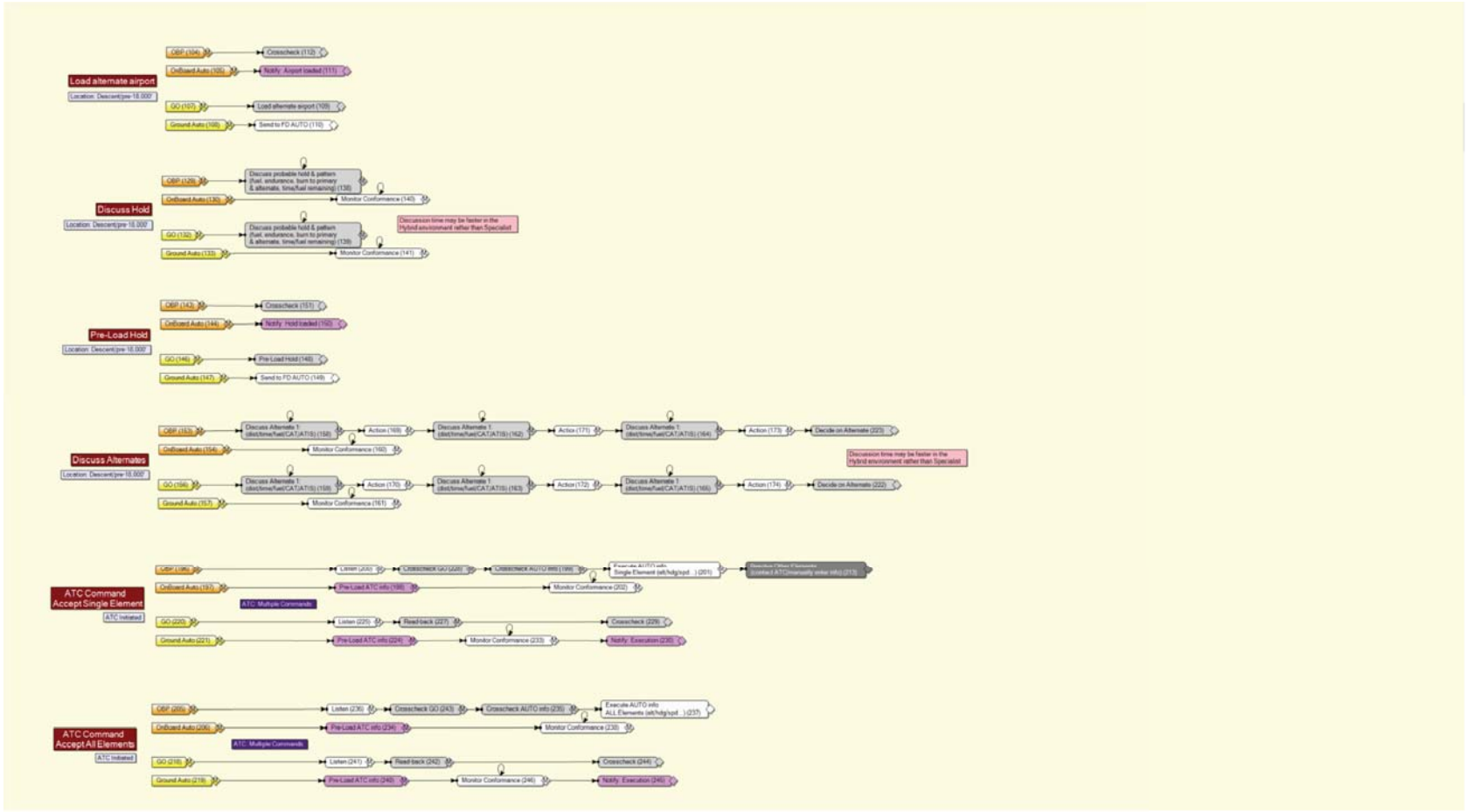
Appendix G. Micro Saint Sharp Task Groups (OBP-Centric Nominal Mode)

Appendix H. Micro Saint Sharp Task Groups (GO-Centric Nominal Mode)

Appendix I. Micro Saint Sharp Task Groups (Dedicated Assistance Mode)



Appendix I. Micro Saint Sharp Task Groups (Dedicated Assistance Mode)



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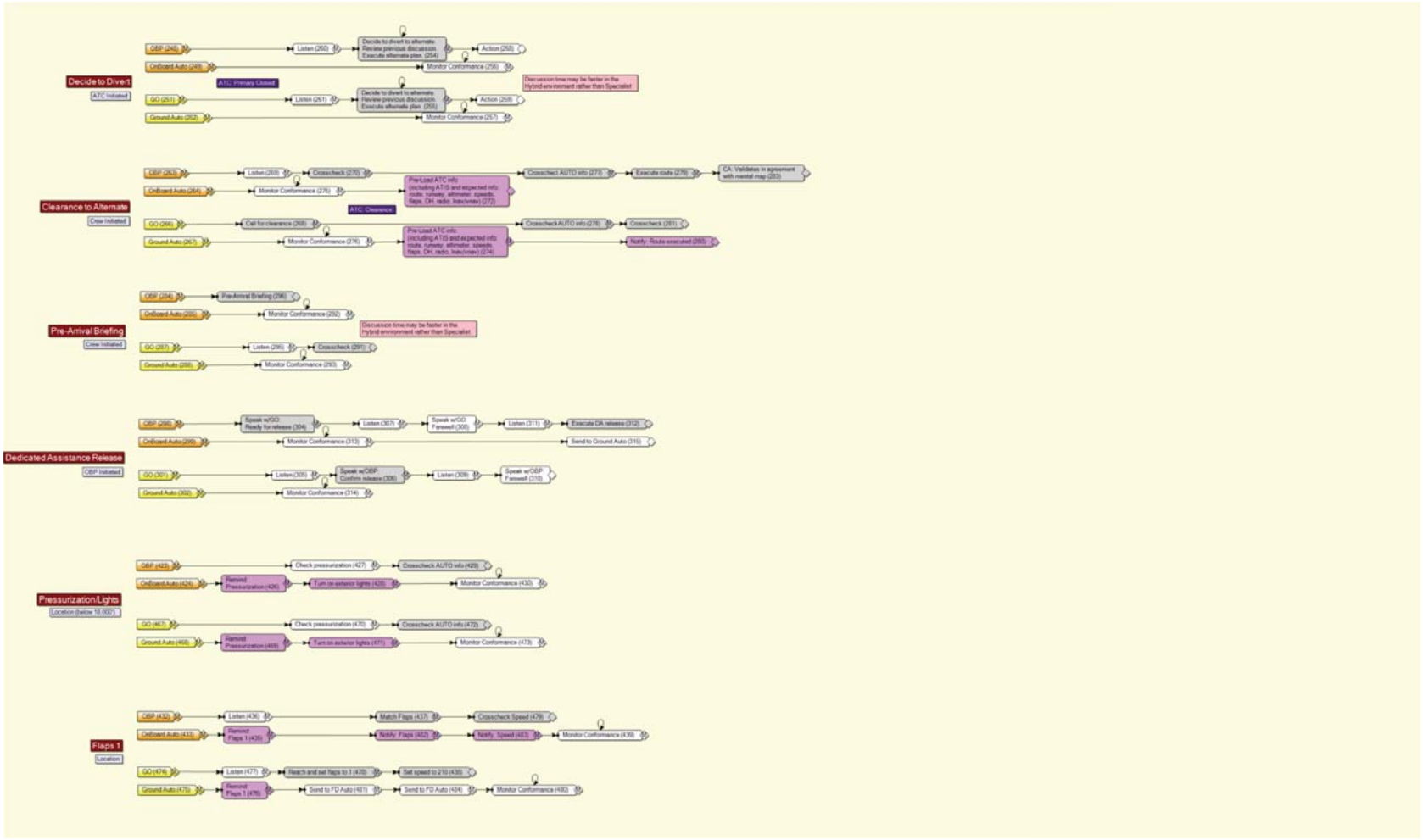

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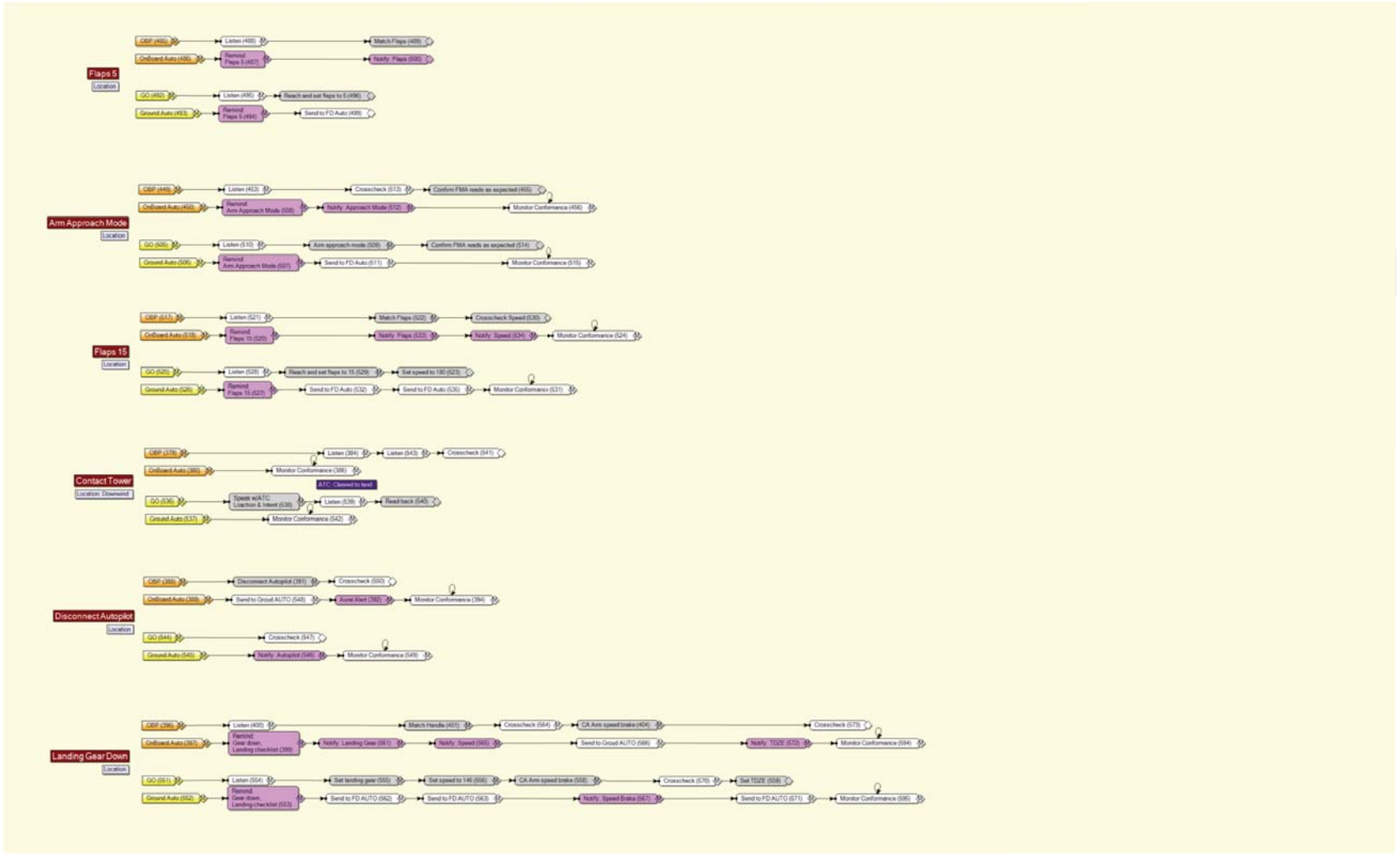

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