DOT/FAA/TC-16/12

Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

Space Vehicle Operations Debris Threat Mitigation Study

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January 2016

Technical Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/TC-16/12		

4. Title and Subtitle
Space Vehicle Operations Debris Threat Mitigation Study

5. Report Date
January 2016

6. Performing Organization Code
ANG-E25

7. Author(s)

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8. Performing Organization Report No.
DOT/FAA/TC-16/12

9. Performing Organization Name and Address
Federal Aviation Administration
Human Factors Branch
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Federal Aviation Administration
Advanced Concepts Branch
800 Independence Avenue, S.W.
Washington, DC 20591

13. Type of Report and Period Covered
Technical Report

14. Sponsoring Agency Code
ANG-C54

15. Supplementary Notes

16. Abstract

Objective: The purpose of this study was to investigate three Next Generation Air Transportation System (NextGen) Space Vehicle Operations (SVO) concepts in a human-in-the-loop simulation. **Background:** The first concept was Space Transition Corridors (STCs) that are much smaller than current restricted areas for space vehicle operations. The second concept was the Just-in-Time Notification of active STCs based on high-certainty launch and reentry times. The third concept was the reactive separation of aircraft from Debris Hazard Volumes (DHVs) during off-nominal events. These SVO concepts were intended to allow for more efficient use of airspace during space vehicle operations and ensure safety in the National Airspace System (NAS). In addition to the concepts, the researchers developed a set of SVO tools for participants to use at their workstations. The tools included visual aids and graphics to identify the pre-active STC, active STC, and DHV as well as decision-support tools to help participants use the airspace effectively. **Method:** Eight Certified Professional Controllers and two Traffic Management Coordinators from Air Route Traffic Control Centers nationwide participated in the study. The participants controlled traffic in five scenarios simulating space vehicle launch and reentry operations during nominal and off-nominal conditions. In three of the scenarios, the participants tested the SVO tools while controlling traffic. **Results:** The results indicated that the participants could control several aircraft within the STC and effectively use the available airspace using the Just-in-Time Notification concept. When off-nominal events occurred, the participants used effective reactive separation by quickly contacting aircraft to avoid the DHV and clearing aircraft already in the DHV. Although the objective simulation data did not show much benefit using the SVO tools, the participants' subjective ratings of tool effectiveness, helpfulness, and importance were very good. **Conclusion:** In conclusion, this study represents an important first step in preparing for increased space vehicle operations in the NAS.

17. Key Words
Debris Hazard Volume
Debris Threat Mitigation
Space Transition Corridor
Space Vehicle Operations

18. Distribution Statement
This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	118	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Acknowledgments

We would like to thank Mary Delemarre, John Mick, and the rest of the Concepts and Systems Integration team for developing the simulation software, supporting the simulation during data collection, and managing the data during and after data collection. We thank Elliot Porterfield and the team from ACTA, Inc. for providing the Hazard Risk Assessment and Management software and expertise in modeling space vehicles. We thank Nicholas Richardson and team from the U.S. Department of Transportation John A. Volpe National Transportation Systems Center for developing the NextGen Traffic Management System prototype. We thank James Hamilton (ATEC), Michael Ross, and Scott Doucette from the Federal Aviation Administration (FAA) Target Generation Facility for providing the space vehicle and aircraft dynamics simulation. Many thanks to our subject matter experts, especially Shannon O'Brien and Matt Kukorlo. We thank the FAA Simulation Team pilots and staff for their assistance and support during data collection. Finally, we would like to thank all of the FAA controllers who volunteered to participate in this study.

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Executive Summary

The Federal Aviation Administration (FAA) will face challenges in the coming years as increased demand for space vehicle operations pushes the ability to integrate these operations with the aircraft operations of our National Airspace System (NAS). As part of the Next Generation Air Transportation System (NextGen) Space Vehicle Operations (SVO) research, there is a need to understand the implications of introducing and managing space vehicles into current and future trajectory environments. Commercial space vehicle operations are expected to grow substantially in the coming decade. Space vehicle operational profiles and launch and recovery locations are evolving and will present challenges to NAS integration. There is a need to reduce the NAS impact of launch and recovery operations to support increased future space vehicle and aircraft demand.

Current space vehicle operations involve the definition of relatively large hazard protection areas that span large time windows. A Specialty Activity Area (SAA) is created and all flights are deviated around the protection area for the entire window of operation despite the uncertainty in actual launch time. The SVO Concept of Operations (CONOPS) defines the concept of a Space Transition Corridor (STC) that encompasses the projected path of the space vehicle and the calculated near-term hazard areas, resulting in a smaller block of restricted airspace when compared to current operations with SAAs. In addition to the more efficient use of restricted airspace volume, the CONOPS also defines the notion of just-in-time activation of the STC based on a high certainty start time for the launch or reentry operation.

The NextGen Office of Advanced Concepts and Technology Development sponsored the SVO Debris Threat Mitigation (DTM) study as part of an FAA NextGen Air Traffic Control (ATC) Concept of Operations for the Management of SVOs in the NAS. The purpose of this study is to investigate three key SVO Concept components: STCs, just-in-time activation of STCs, and reactive separation from debris hazards.

Eight Certified Professional Controllers (CPCs) and two Traffic Management Coordinators (TMCs) from Air Route Traffic Control Centers nationwide participated in the study. The participants completed the study in two sessions, with a different group of four controllers and one TMC participating in each session. Each session consisted of three days of simulation and two days of travel. The simulation procedure consisted of two training scenarios and five testing scenarios. Within each session, the R-side and D-side controllers switched positions and repeated the simulation procedure.

We conducted the study in the NextGen Integration and Evaluation Capability (NIEC) laboratory at the FAA William J. Hughes Technical Center. The NIEC is a state-of-the-art facility with experiment rooms, ATC workstations, and human performance measurement equipment to support aviation human factors research. The simulation configuration consisted of the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (or DESIREE) ATC simulator, the Target Generation Facility (or TGF), the NextGen Traffic Management System (or NTMS), the SVO Hazard Risk Assessment and Management (or HRAM) software, and the Java En Route Development Initiative/User Request Evaluation Tool (or JEDI/URET) prototype. We configured all four systems to work together to provide a realistic ATC simulation for controllers. We selected Sector 18 and Sector 67—ultra-high sectors from Denver Center (ZDV) airspace—and created traffic scenarios from traffic samples obtained from the Aeronautical Data Exchange (ADX) portal.

We used two experimental conditions in a repeated measures design for the study. The first scenario was the Launch condition in which a winged vehicle operated within the airspace, transitioning from runway launch to a near-vertical climb to a suborbital trajectory. The second scenario was the ReEntry condition in which a de-orbiting space vehicle transitioned through the airspace following a ballistic trajectory. Within these conditions, we conducted some scenarios with the launch vehicle suffering a structural failure. We also introduced the use of a DTM tool and ran each condition with and without the tool.

The study results indicated that the participants could control several aircraft within the STC and make last moment usage of the STC before activation. This represents effective usage of the available airspace using the Just-in-Time Notification concept. In addition, when an off-nominal event occurred, participants were (a) quick to contact aircraft to avoid the Debris Hazard Volume (DHV) and (b) quick to clear aircraft already in the DHV. This represents effective reactive separation in the case of off-nominal events. The participants were the most effective using the SVO concepts during the ReEntry scenarios during nominal conditions. In the Launch scenarios during off-nominal conditions, participants used reactive separation to avoid the large DHV and rerouted aircraft. As expected, flight times increased and operating costs increased during off-nominal scenarios due to rerouting aircraft.

In addition to the SVO concepts, we developed a set of SVO tools for the En Route Automation Modernization (ERAM) and the Traffic Management Unit (TMU) to help participants effectively use the airspace. The tools included visual aids and graphics to identify a pre-active STC, active STC, and DHV. We also developed an ERAM decision-support tool on the aircraft datablock to help controllers make last moment usage of the airspace. Although the objective simulation data did not show much benefit using the tools, the participants' subjective ratings of tool effectiveness, helpfulness, and importance were very good. We must note that the controllers did not have much time to train with the tools, and the simulation results could have been better with more practice. Future research and development studies are needed to refine and improve the ERAM and TMU tools to support SVOs.

Finally, this study represents an important first step in preparing for increased SVOs in the NAS. The results of the study indicated that the controllers were able to effectively use the SVO concepts we developed in simulation. We also established an important integrated simulation environment where CPCs and TMCs can work together to evaluate future SVO concepts and identify operational issues.

1. INTRODUCTION

1.1. Background

The Federal Aviation Administration (FAA) will face challenges in the coming years as increased demand for space vehicle operations pushes the ability to integrate these operations with the aircraft operations of our National Airspace System (NAS). As part of the Next Generation Air Transportation System (NextGen) Space Vehicle Operations (SVO) research, there is a need to understand the implications of introducing and managing space vehicles into current and future trajectory environments. Commercial space vehicle operations are expected to grow substantially in the coming decade. Space vehicle operational profiles and launch and recovery locations are evolving, and will present challenges to NAS integration. There is a need to reduce the NAS impact of launch and recovery operations to support increased future space vehicle and aircraft demand.

The NextGen SVO program concept focuses on the introduction of space trajectories into existing NAS human and automation systems. Processing these launch requests and vehicle integration requires greater understanding of space vehicle trajectories and manipulation of Special Activity Areas (SAAs). SVO research requires analysis of space vehicles to include launch patterns, trajectory characteristics, safety data, locations, communication and surveillance requirements, expected launch frequencies, and impact to airborne and ground aircraft.

Development of the SVO concept requires validation through several human factors research activities such as cognitive walkthroughs, focus groups, and human-in-the-loop (HITL) simulations. A HITL at the FAA's NIEC lab at the William J. Hughes Technical Center (WJHTC) provides the SVO research team the ability to validate several core concepts of the SVO program.

1.2. Space Transition Corridors

Current SVOs involve the definition of larger than necessary hazard protection areas and spanning large time windows. An SAA is created and all flights are deviated around the protection area for the entire window of operation despite the uncertainty in actual launch time. The SVO Concept of Operations (CONOPS) defines the concept of a Space Transition Corridor (STC) that encompasses the projected path of the space vehicle and calculated near-term hazard areas resulting in a smaller block of restricted airspace when compared to current operations with SAAs (FAA, 2001).

In addition to the more efficient use of restricted airspace volume, the CONOPS also defines the notion of just-in-time activation of the STC. Rather than clearing airspace for the entire potential launch window—potentially hours in length—the space vehicle operator will be required to deliver a high certainty start time for the launch or reentry operation within a defined time window in advance (currently estimated to be 10 minutes). Prior to this high certainty time, the STC will remain open to aircraft that can transition the volume of airspace within the pre-activity notification time window.

The CONOPS for SVO STC involves

1. calculating transit times for all aircraft routed through the STC, prior to notification;
2. allowing aircraft to proceed, if their transit times are less than the notification time (plus a margin allowing time for the aircraft to be turned); and
3. re-routing aircraft whose transit times exceed the notification time windows (plus margin) to avoid the STC.

Following the activation of an STC, it is unnecessary for the controller to maneuver any aircraft that remain in the STC. The use of the high certainty time of operation and the measurement of aircraft transition times relative to the notification window ensures that all aircraft in the STC will exit safely before the SVO begins. Any aircraft still routed through, but not yet within the STC, must be re-routed around it, until the space vehicle is clear of it.

1.3. Debris Hazard Volumes

To safely limit the size of the STC in space vehicle operations, the CONOPS has also introduced the concept of reactive separation from Debris Hazard Volumes (DHVs). Rather than blocking off airspace that may be impacted should a vehicle experience an off-nominal event and break up as a result, all airspace around the STC will continue to be used until such an event occurs. Automation detects the event and calculates DHVs based on the last known state vector of the vehicle in near real-time. These DHVs will be presented on the En Route Automation Modernization (ERAM) and the Traffic Situation Display (TSD) workstations so that the controllers know where debris are projected to fall and can identify which aircraft will be affected. Only those aircraft that are in—or would enter—a DHV have to be maneuvered to safety. Depending on the space vehicle's position and velocity at the time of breakup, controllers would have several minutes to move the affected aircraft before the falling debris actually reach NAS aircraft altitudes.

1.4. Purpose

The *Space Vehicle Operations Debris Threat Mitigation Study* is part of an FAA NextGen Air Traffic Control (ATC) Concept of Operations for the Management of Space Vehicle Operations in the NAS. The purpose of this study is to investigate three key SVO Concept components: STCs, just-in-time activation, and reactive separation from debris hazards. Specifically, the objectives of this study are to conduct a series of HITL simulations with Certified Professional Controllers (CPCs) and Traffic Management Coordinators (TMC):

1. to evaluate the operational viability of just-in-time activation of STCs, and
2. to demonstrate that controllers can safely and efficiently reactively separate from off-nominal hazards.

2. METHOD

2.1. Participants

We recruited eight CPCs and two TMCs from Air Route Traffic Control Centers (ARTCCs) and ARTCC Traffic Management Units (TMUs) nationwide to serve as voluntary participants in the study. Nine of the participants were males and one was female. The participants ranged in age from 28-55 years of age and had from 6-32 years of experience as air traffic controllers. We also had volunteers from the Air Traffic Control System Command Center (ATCSCC) as well as from the Office of Commercial Space Transportation (AST) to play the role of Mission Control. The principal investigator informed the controllers of their rights as participants in a research study, and each participant read and signed an Informed Consent Statement. The FAA WJHTC Local Institutional Review Board (IRB) reviewed the routine ethical considerations and approved this study.

2.2. Research Personnel

An Engineering Research Psychologist (ERP) served as the principal investigator and conducted the simulation. The ERP briefed the participants, collected the data, and led the group discussions with controllers. The ERP supervised the operation of the simulation equipment and coordinated the work of the research personnel. Hardware and Software Engineers prepared the simulator and ensured that the equipment was operating properly.

Two Subject Matter Experts (SMEs) served as over-the-shoulder observers during this study. Each SME provided performance ratings as well as written comments after each traffic scenario. In preparation for the simulation, the SMEs assisted in the development of the practice and test scenarios.

Six simulation pilots operated pilot workstations with one additional pilot operating a *ghost* ATC position. The simulation pilots communicated with controllers using proper ATC phraseology and maneuvered the simulation aircraft based on controller instructions.

2.3. Simulation Environment

2.3.1. Research Facility

We conducted the study in the FAA WJHTC NIEC. The NIEC is a state-of-the-art facility with experiment rooms, ATC workstations, and human performance measurement equipment to support aviation human factors research. The simulation configuration consisted of the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) ATC simulator, the Target Generation Facility (TGF), the NextGen Traffic Management System (NTMS), the Hazard Risk Assessment and Management (HRAM) software, and the Java En Route Development Initiative/User Request Evaluation Tool (JEDI/URET) prototype. All four systems worked together to provide a realistic ATC simulation for controllers.

2.3.2. Software

Software engineers at the FAA WJHTC developed the DESIREE ATC simulator and the TGF to support air traffic research, development, and testing and evaluation activities. The DESIREE ATC simulator emulates both en route and terminal controller functions. DESIREE provides a flexible platform for researchers to modify the displayed information and functionality of controller workstations to evaluate new ATC concepts and procedures. In this study, DESIREE emulated the ERAM and received input from the TGF to display aircraft targets and flight information on the controller displays. DESIREE also implemented the role of the ghost controller to automate the aircraft handoff functions for the adjacent sectors in the simulation.

The Massachusetts Institute of Technology Research and Engineering (MITRE) Corporation developed the JEDI/URET prototype as a conflict probe and trial planning tool. The JEDI/URET prototype is similar to the URET system that controllers currently use in the field but can be implemented without the ERAM using DESIREE. JEDI/URET presents the Aircraft List, Plans Display, and the Graphic Plan Display windows on the Data-side (D-side) controller display. JEDI/URET and DESIREE shared data through a Host Automation Gateway (HAG)—so that JEDI/URET operated as if connected to ERAM, and DESIREE displayed the information on the controller display.

The TGF is a dynamic, real-time air traffic simulation capability designed to generate realistic aircraft targets for HITL simulations. The TGF models aircraft performance characteristics and maneuvers aircraft based upon scripted flight plan data and simulation pilot commands. TGF also consists of multiple simulation pilot workstations operated by trained personnel who communicate with controllers and enter flight plan changes based on controller instructions.

The HRAM prototype is developed by ACTA, Inc. as a tool to compute hazard area volumes for nominal and off-nominal SVOs in the NAS. ACTA's HRAM modeling is physics-based and statistically rigorous, and includes debris propagation and consequence analysis. The HRAM calculations used in this study follow industry standard, rigorously validated risk analysis procedures that have been used to support the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD) space operations for decades. HRAM receives and processes pre-mission planned trajectories, vehicle debris catalogs, real-time vehicle position reports, state vectors, and vehicle state change notifications. HRAM calculates the initial STC and Planning Volume, as well as off-nominal DHVs. Upon notification of vehicle failure, DHVs are calculated based on the vehicle debris catalog, the last known position, the last known state vector, and the winds aloft information. The calculated DHVs are sent over a network interface for display on ERAM and TSD. In this study, the calculation, distribution, and display of DHVs on ERAM and TSD took less than one second from the time of notification of a space vehicle breakup.

The Traffic Flow Management System (TFMS) is developed by Computer Sciences Corporation (CSC) and supports the monitoring and management of national and regional air traffic flow. TFMS is used at the FAA ATCSCC as well as at the TMUs at all ARTCCs, major Air Traffic Control Towers (ATCTs), and Terminal Radar Approach Control Facilities (TRACONs). A research and development version of TFMS was developed and installed at the NIEC by engineers from the Volpe National Transportation Systems Center.

The NTMS prototype is the research and development TFMS. NTMS is a Traffic Management System (TMS) prototyping platform derived from the Enhanced Traffic Management System (ETMS). NTMS was modified for the SVO HITL activity to include custom data exchange interfaces for receiving aircraft flight data and for sending and receiving space vehicle flight and operational data. In addition, a highly customized TSD was developed for displaying aircraft and space vehicle flight information. The TSD is a graphical user interface (GUI) for viewing and interacting with the aircraft and space vehicle flight data. The TSD includes a prototype interface that allows a traffic manager to input space vehicle operations event times that are distributed to external systems.

The systems used in this study were installed and configured within the NIEC laboratory. The systems were then integrated using common messaging protocols with Apache ActiveMQ™ providing the transport medium. Figure 1 illustrates the resulting system architecture.

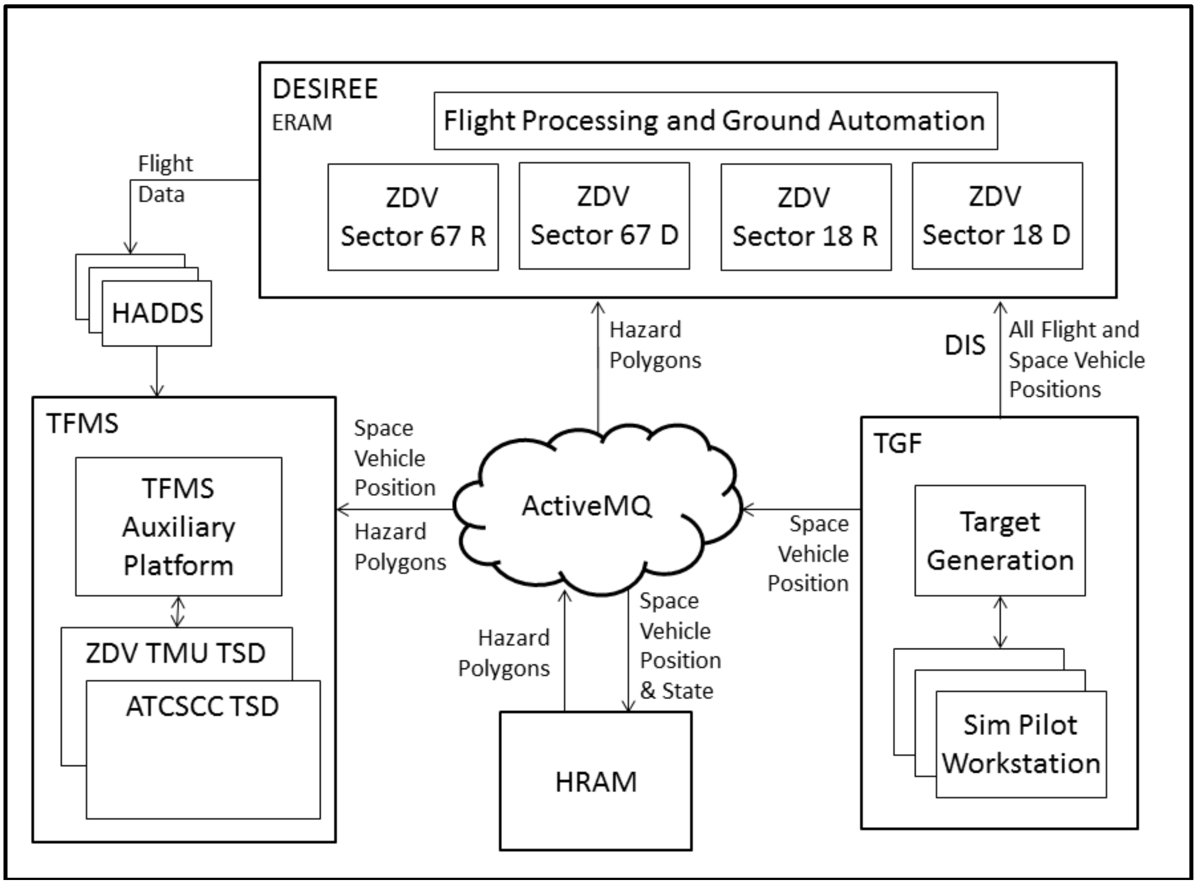

Figure 1. SVO Debris Threat Mitigation (DTM) HITL System Architecture.

2.3.3. Airspace

We selected two Denver ARTCC sectors to evaluate the SVO concept: the adjacent ultra-high Sectors 18 and 67 (see Figure 2). Sector 18 adjoins Minneapolis and Kansas City ARTCCs; the flow of traffic is mainly east/west en route aircraft. Sector 67 adjoins Minneapolis ARTCC; the main flow of traffic is overflying east/west aircraft, and eastbound Denver area departures. The western boundaries of both sectors extend to about 60 nm east of the spaceport. Sector 67 measures approximately 200 nm east/west and approximately 50 nm north/south. Sector 18 is irregular and also measures approximately 200 nm east/west and approximately 100 nm north/south at the widest point.

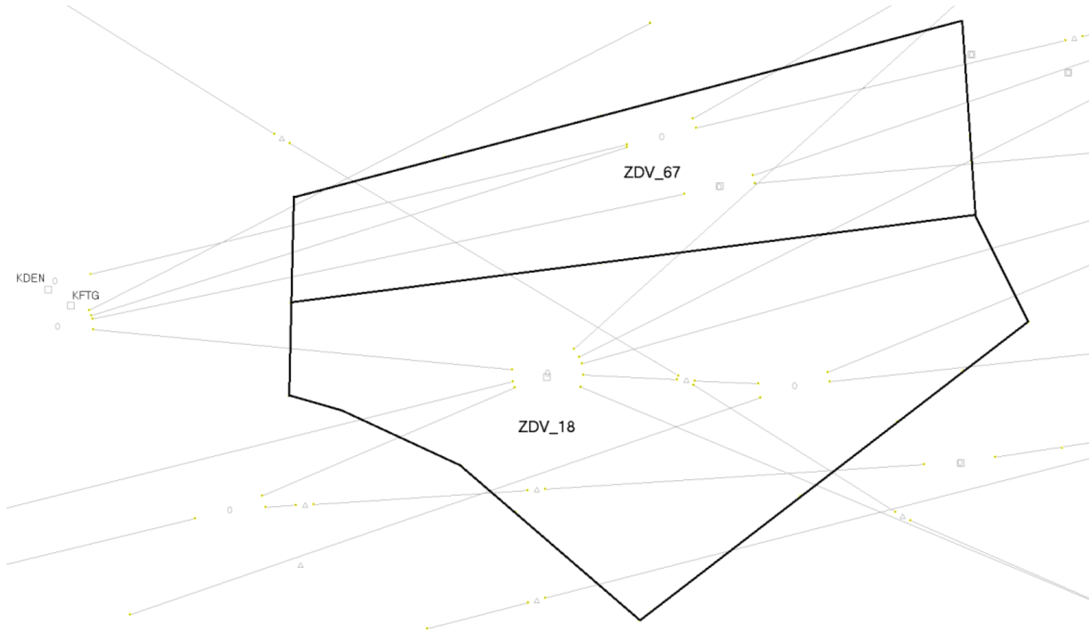

Figure 2. Denver Center, Sectors 18 and 67.

The Denver International Airport (DEN) traffic flow is configured (see Figure 3) with arriving aircraft approaching the airport from the northeast, southeast, northwest, and southwest. The departing aircraft exit the terminal airspace heading north, south, east, and west. As a result, the majority of the flights in Sector 67 and Sector 18 are either overflights or departing DEN. There are also arrival aircraft that pass through the lower portion of ZDV18.

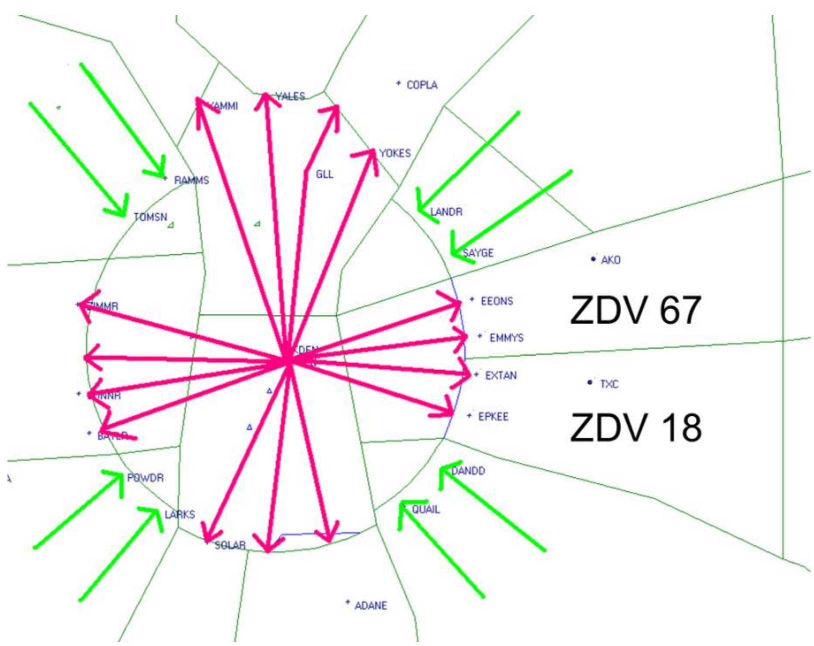

Figure 3. DEN Arrival and Departure Flows.

2.3.4. Traffic Scenarios

All experimental scenarios were 50 minutes in duration. For the duration of each scenario, the traffic levels were maintained at the forecast levels anticipated for the year 2025, or 128% of current traffic levels (a 2.5% year-over-year increase). Initial traffic samples were taken from current Denver ARTCC operations, and flights were added until the target level was reached.

The traffic scenarios were designed to support the responsibilities placed on the participants in the study. Each scenario included ZDV Sector 18 and Sector 67 en route controllers, a ZDV TMU TMC, an ATCSCC TMC, and a space vehicle Mission Controller. The positions in the NIEC facility were configured as illustrated in Figure 4. The en route controllers were given the task to manage the STC, reactively separate from debris hazards, and manage air traffic as they would when following FAA Order 7110.65. The TMU TMC was asked to coordinate with the space vehicle operator and ATCSCC, obtain and enter the high certainty time of vehicle entry into the STC, and manage air traffic following standard operating procedures. The ATCSCC TMC monitored traffic flows and sector loads in coordination with the ZDV TMU. The Mission Control operator was responsible for notifying the ZDV TMU of high certainty launch time and confirmation of vehicle status in off-nominal situations.

Figure 4. Position Configuration.

2.3.4.1 Spaceport

The horizontal space vehicle launch scenarios use a simulated spaceport , "Denver Spaceport," located 47.1 miles southeast of DEN. Launches occurred from Runway 08 at the simulated spaceport (see Figure 5 and Figure 6).

Figure 5. Spaceport relative to the Denver International Airport (DEN).

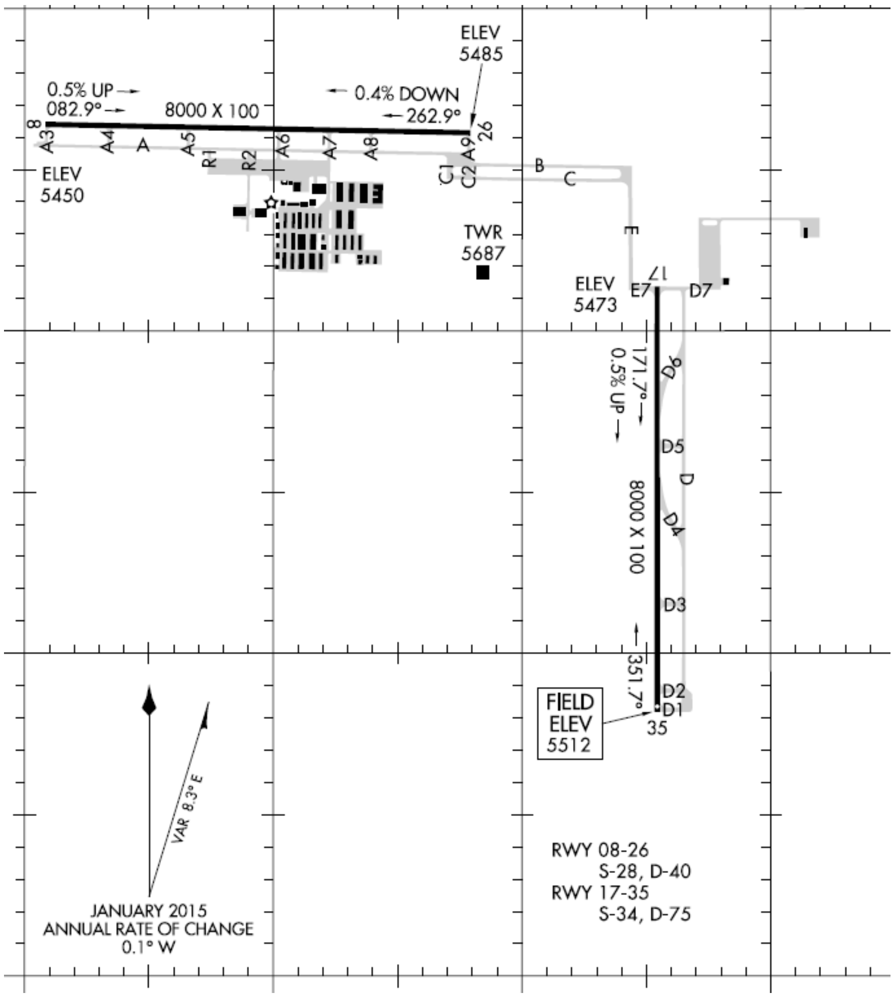

Figure 6. Denver Spaceport Runway Configuration.

2.3.4.2 Space Vehicles

Horizontal launch scenarios included a simulated XCOR Lynx Horizontal Takeoff Horizontal Landing (HTHL) rocket-powered winged vehicle. The Lynx is a two-passenger suborbital vehicle expected to operate in the NAS by 2025. The Lynx trajectory used in the study scenarios included takeoff from runway 08 at Denver Spaceport, followed by climb at a 70 degree angle-of-attack at a velocity in excess of Mach 2.

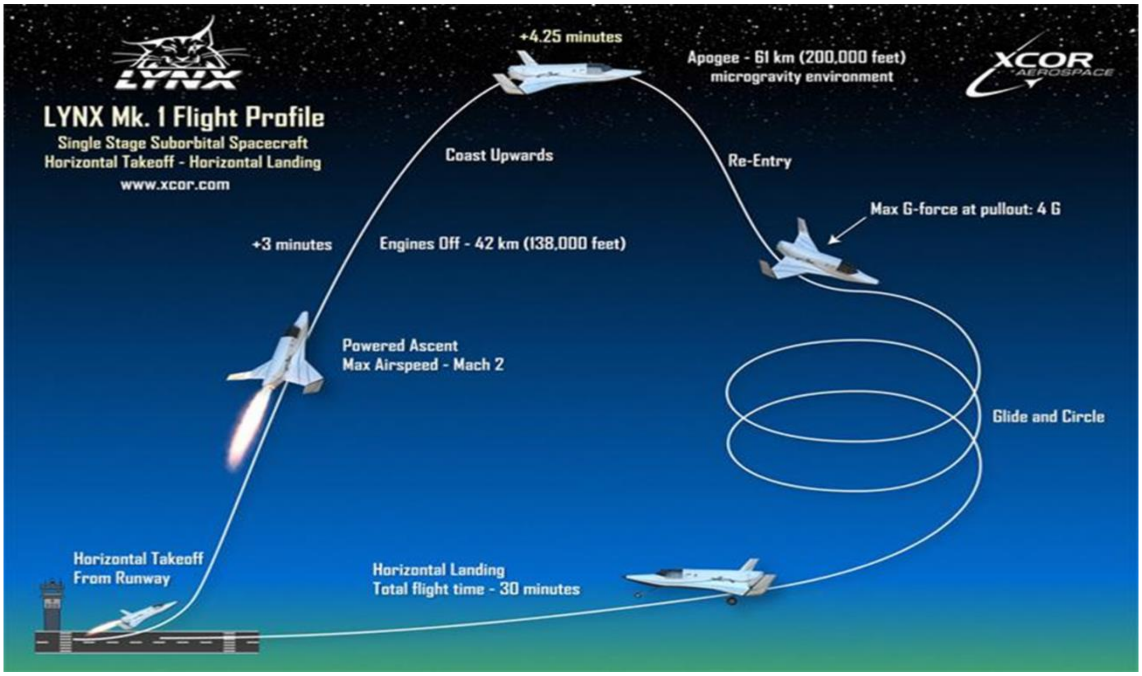

Figure 7. XCOR Lynx Trajectory.

Reentry scenarios included a simulated SpaceX Dragon V2 capsule. The Dragon V2 is a seven-passenger orbital vehicle capable of making a terrestrial soft landing, using side-mounted thruster pods, and expected to carry NASA astronauts by 2020.

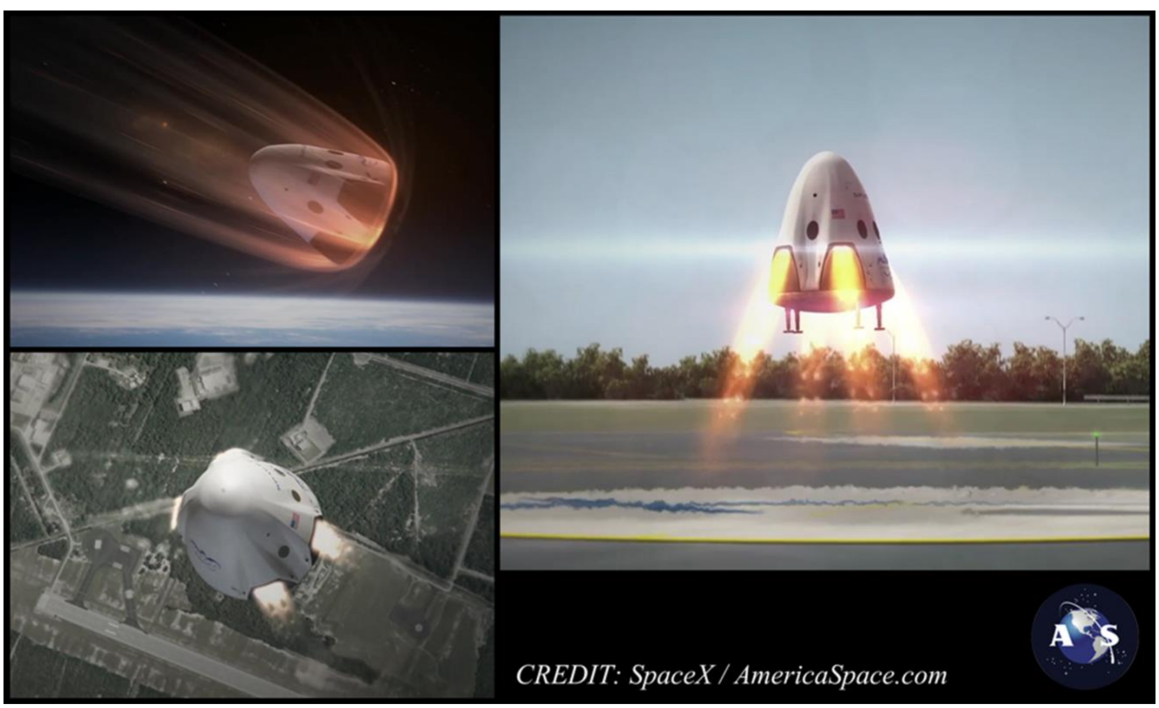

Figure 8. SpaceX Dragon V2 Capsule.

2.3.4.3 Space Vehicle Tracking

The Lynx and Dragon V2 vehicles were tracked and displayed on both ERAM and TSD displays with a 1-second update rate (air traffic update rates were not changed from operational update rates.) The Dragon V2 was displayed on the TSD beginning at orbital altitudes (over 200 miles) and speeds (over 14,000 knots) from the vicinity of Malaysia until touchdown. The Lynx was tracked from departure until vehicle failure (for off-nominal flights) or scenario end (for nominal flights).

2.3.4.4 Space Transition Corridors

The HRAM software created a custom STC for each scenario based on the characteristics of the space vehicle mission in that scenario. The STC size was determined based on the minimum amount of area required to contain the nominal operation of the vehicle as well as the off-nominal scenarios that could occur while the vehicle was still within the NAS. In addition, the STC included the off-nominal scenarios that would not leave the controller with adequate time to respond should one occur. The chosen response time for this study was five minutes. Any predicted off-nominal scenario that would give the controller more than five minutes to respond—meaning the space vehicle was well above the limits of the NAS—was not included in the bounds of the STC.

The STC first appeared to the controllers in a scheduled state as a white dashed boundary line on ERAM (see Figure 9) and a white solid line on the TSD (see Figure 10). In this state, the space vehicle window of operation has been identified, while the exact time of operation is not yet known. When the space vehicle operator communicated the exact time of operation to the TMC, and the TMC entered that time into the system, then the STC appearance changed to indicate that the operation was pending and would occur within the next 10 minutes. This was indicated as an orange dashed boundary line on ERAM (see Figure 9) and an orange solid line on the TSD (see Figure 10). In addition, a countdown timer was displayed on the ERAM display to assist the controllers in anticipating the operation while continuing to make the most efficient use of their airspace. Finally, at the time of the SVO, the STC transitioned to an active state. For this state, the most alerting presentation was chosen to be clear that a vehicle would be maneuvering within the STC. This was implemented as a red solid boundary line on ERAM (see Figure 11) and as a red stipple-filled boundary area on the TSD (see Figure 12).

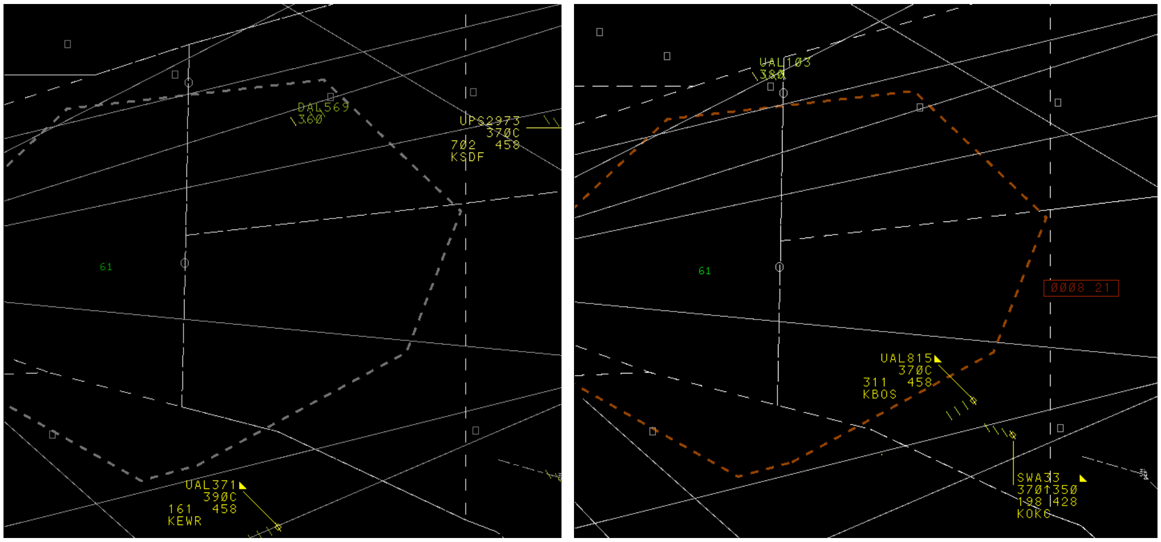

Figure 9. STC Scheduled (white dash) and Pending (orange dash) on ERAM.

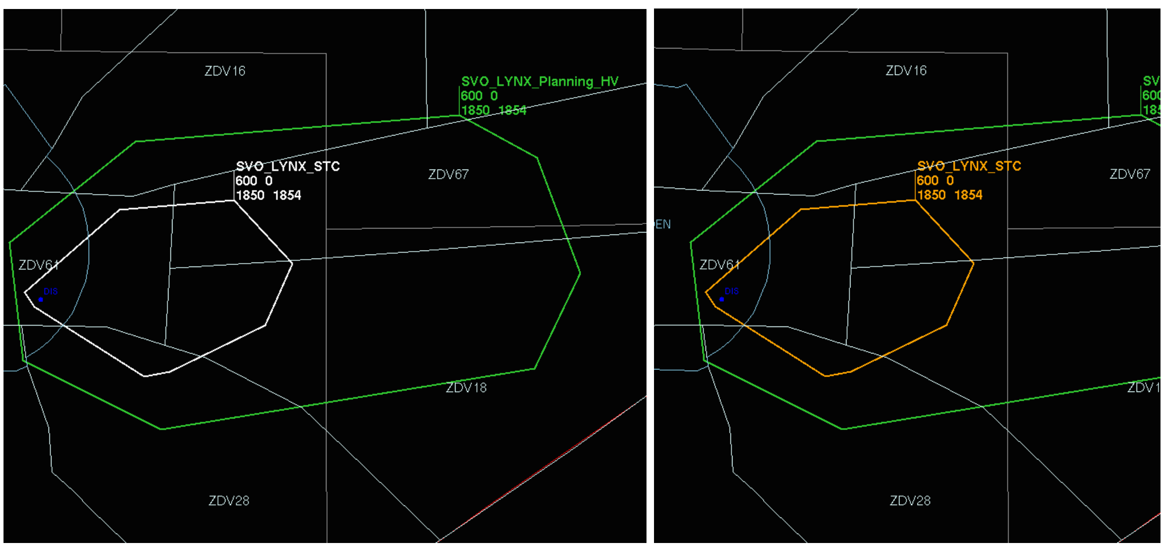

Figure 10. STC scheduled (solid white), pending (solid orange), and planning volume (solid green) on TSD.

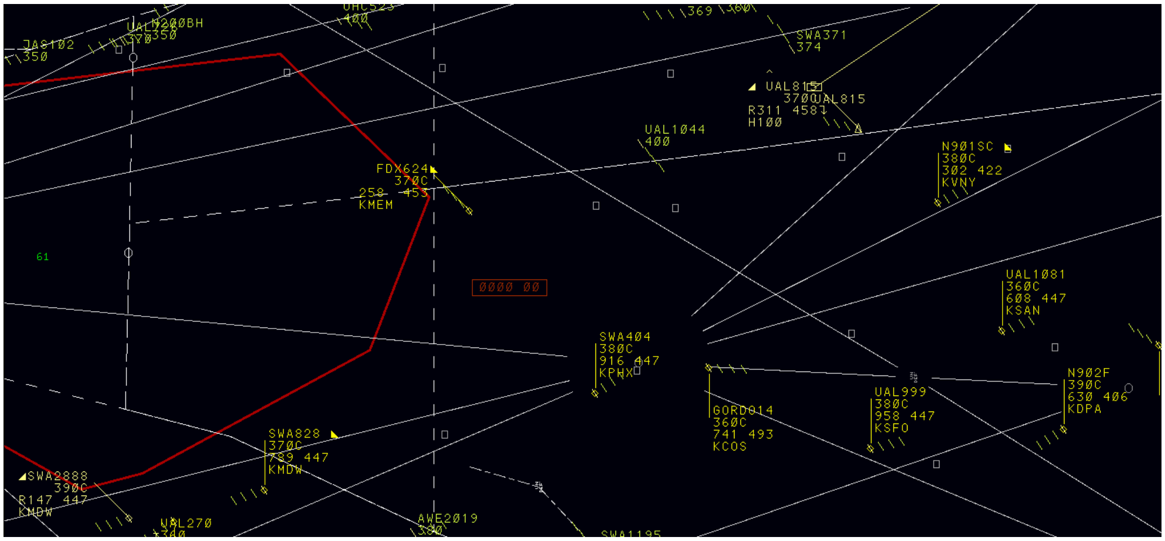

Figure 11. STC Active (solid red) on ERAM.

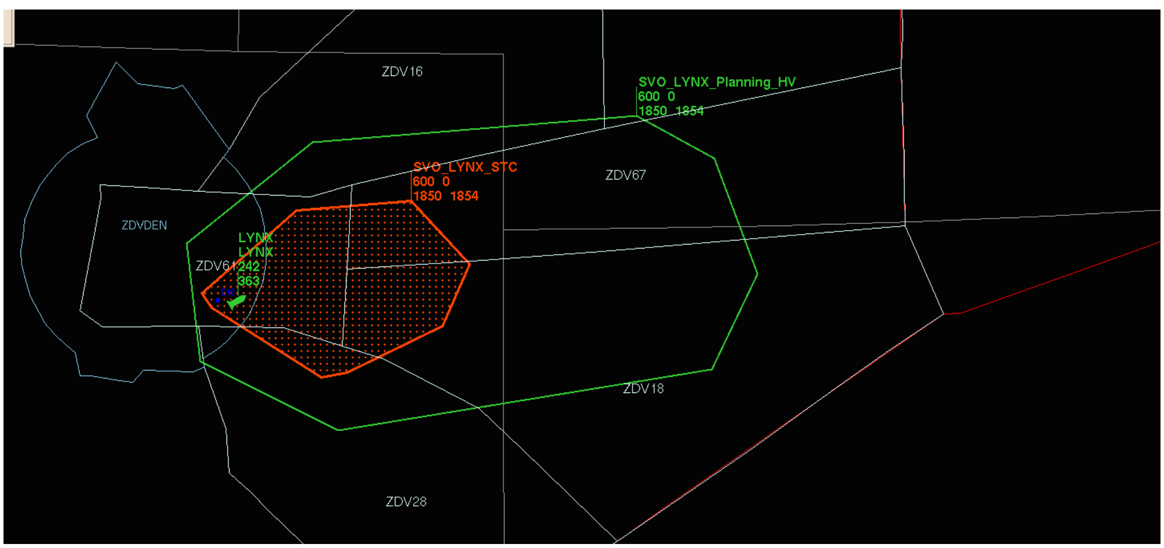

Figure 12. STC active (red stipple pattern) and planning volume (solid green) with space vehicle icon on TSD.

2.3.4.5 Planning Volumes

The TMC participants were provided with an additional defined airspace known as a Planning Volume. This volume was calculated by HRAM software to encompass the vehicle operating area and potential hazard areas much like the STC. However, unlike the STC that contained only the potential off-nominal hazards existing within the first five minutes after a space vehicle failure, this volume was designed to describe an area containing all predicted hazard areas based on a multitude of potential vehicle state vectors and encompassing all time periods. This provided the TMC with the situational awareness needed to perform advanced planning and be prepared for possible impacts to sectors and adjacent facilities. The Planning Volume was displayed as a solid green boundary line with a data tag indicating the scheduled window of operation (shown in Figure 10).

2.3.4.6 Debris Hazard Volumes

In some scenarios, the space vehicle experienced a structural failure during ascent at approximately 130,000 feet resulting in an off-nominal condition for our participants. The HRAM tool received notification of the failure and calculated DHVs based on the last known vehicle state vectors. The software was configured to generate three hazard volumes at three different altitude stratifications based on the space vehicle debris catalog, ballistic coefficients of fragments, 4-D aircraft impact probability, and wind models. The three altitude blocks were ground to 27,000 feet, 27,000 to 36,000 feet, and 36,000 to 60,000 feet. Given that our sectors of operation were both responsible for airspace above 36,000 feet, only the one applicable DHV was provided on the ERAM displays as a solid red boundary line (see Figure 13). On the TSD, all three DHVs were displayed in different shades of red with data tags to differentiate between them (see Figure 14). The TSD data tags also contained the predicted times at which debris would be in the volume. In contrast, the ERAM display showed the DHV as long as the hazard was present and removed the DHV when the threat was over.

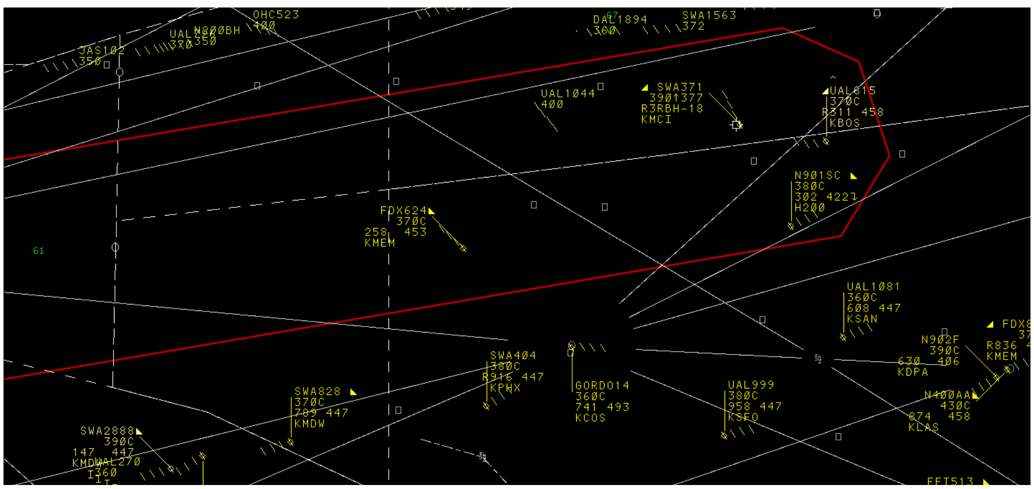

Figure 13. Debris Hazard Volume on ERAM.

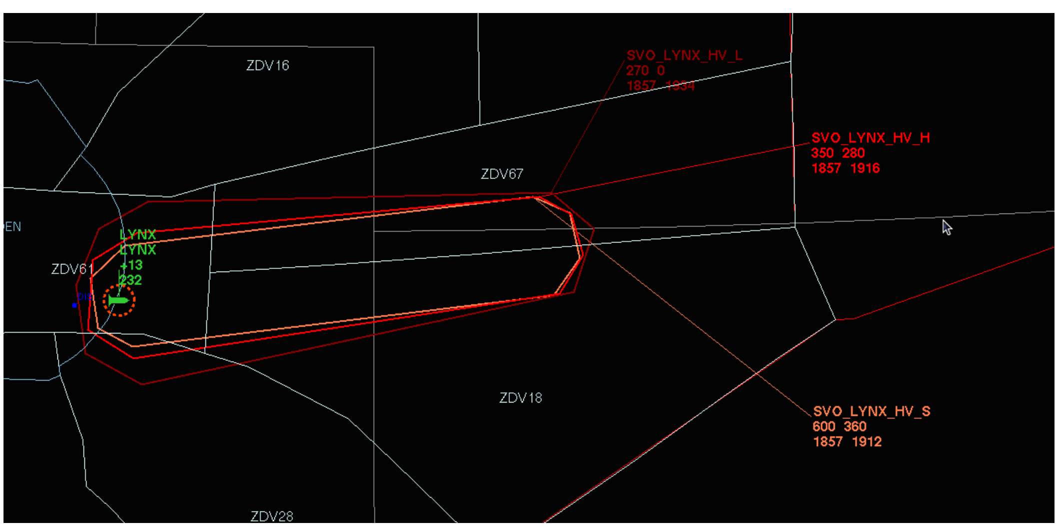

Figure 14. Debris Hazard Volumes on TSD.

2.3.4.7 Virtual Baselines

We developed a virtual baseline scenario to provide a basis of comparison for the impact to traffic flows around the STC and DHVs. The scenario simulated the Denver en route sectors with the traffic levels anticipated for the year 2025, and demonstrated aircraft following typical traffic patterns without space vehicle operations. This scenario represented the best possible flight path for the aircraft without the presence of an STC or a DHV.

2.4. Equipment

2.4.1. Controller Workstations

We configured the controller workstations for R-side/D-side team operations. The R-side controller workstation consisted of a high-resolution (2,048 x 2,048) 29" radar display, keyboard, trackball, and Keypad Selection Device (KSD). The D-side controller workstation consisted of a high-resolution (1,600 x 1,200) 21" display, keyboard, and mouse. The JEDI/URET prototype was deployed on the D-side controller display. The controllers used a simulated Voice Switching and Control System (VSCS) panel to communicate with the simulation pilots, other controllers, and the TMU specialist. In addition, controllers used a Workload Assessment Keypad (WAK) to record their workload ratings during the simulation.

The TMU and ATCSCC workstations were each built using an NTMS remote workstation with two monitors. Each monitor was a 24" LCD display. The TMC was able to take advantage of multiple displays and launch multiple instances of the TSD. The NTMS is a prototyping tool and did not have all TFMS capabilities. The TMC used a VSCS panel to communicate with the controllers, the Command Center Specialist, and the Space Vehicle Mission Control position. The primary tools available to the TMC were the TSD and sector monitor tools.

2.4.2. Communications System

2.4.2.1 Voice Communications

Controllers used the NIEC communications system that emulates the user interface of the VSCS currently used in the field. The communications system consists of a Push-to-Talk (PTT) capability with individual relay switchboxes, headsets with microphones, and PTT handsets or foot pedals. The communications system records the time, position, and switch status for every PTT transmission during a simulation.

2.4.2.2 Data Communications

During Data Communications (Data Comm) training sessions all aircraft were Data Comm equipped to maximize the controllers' opportunity to interact with this capability. During STC and DHV sessions, Data Comm equipage rates were set at 50% to approximate the level anticipated in the 2025 environment. For these sessions, the aircraft were equipped with Data Comm Segment I Services, including vertical clearances, speed changes, route modifications, and contact/monitor/surveillance services (see Figure 15). Because of the limited time available for training, and limited application in ultra-high sectors, crossing restrictions were disabled and were not trained.

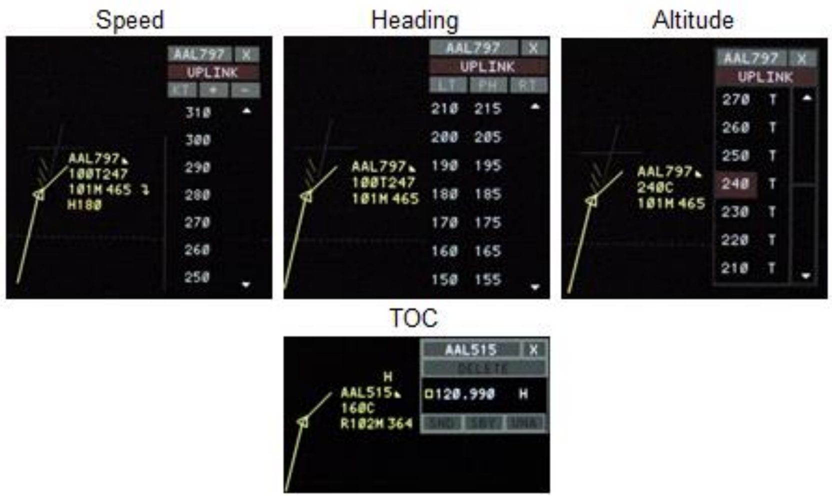

Figure 15. Data Communications services.

2.4.3. Debris Threat Mitigation Tool

The participants performed each of the STC and DHV scenarios under two conditions. In one condition, the participants used standard ERAM tools. In the other condition, the participants used additional automation to probe aircraft against the STC and DHV—the Debris Threat Mitigation (DTM) tool. In the case of the STC, the automation provided the controllers with an indication of whether or not each aircraft can safely enter and clear the STC within the defined high-certainty launch or reentry notification timeframe. For those aircraft that should not enter the STC, the ERAM R-side aircraft datablock presented an orange *S* character in line 0 (see Figure 16) and the D-side aircraft list also displayed an orange *S* (see Figure 17). When an off-nominal event occurred and debris hazards were presented to the controllers, the automation notified the participants of each aircraft that was projected to enter the DHV. On ERAM an orange *H* character was shown in line 0 of the aircraft datablock on the R-side (see Figure 16) as well as in the aircraft list on the D-side (see Figure 17). In addition to the indicator, the R-side controller was also provided with a suggested route for each aircraft around the DHV (see Figure 18). If the aircraft was Data Comm equipped, the controller had the option of clicking a "Send DL" button to uplink the recommended route directly to the aircraft. For aircraft not appropriately equipped, the controller clicked a "VOICE" button to indicate that the route had been acknowledged and voiced to the pilot.

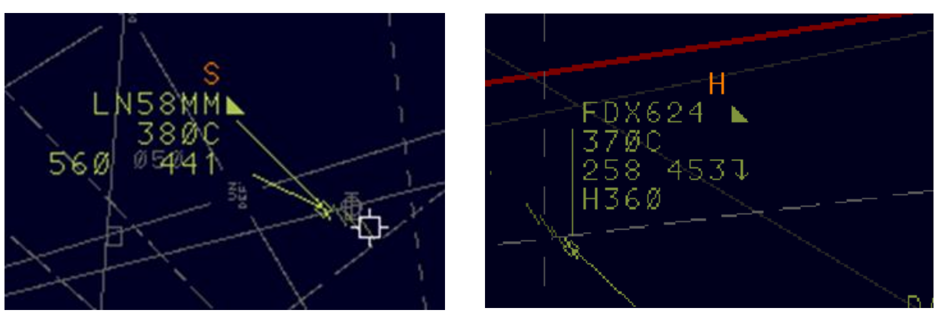

Figure 16. Debris Threat Mitigation Tool datablock indicators on ERAM R-side.

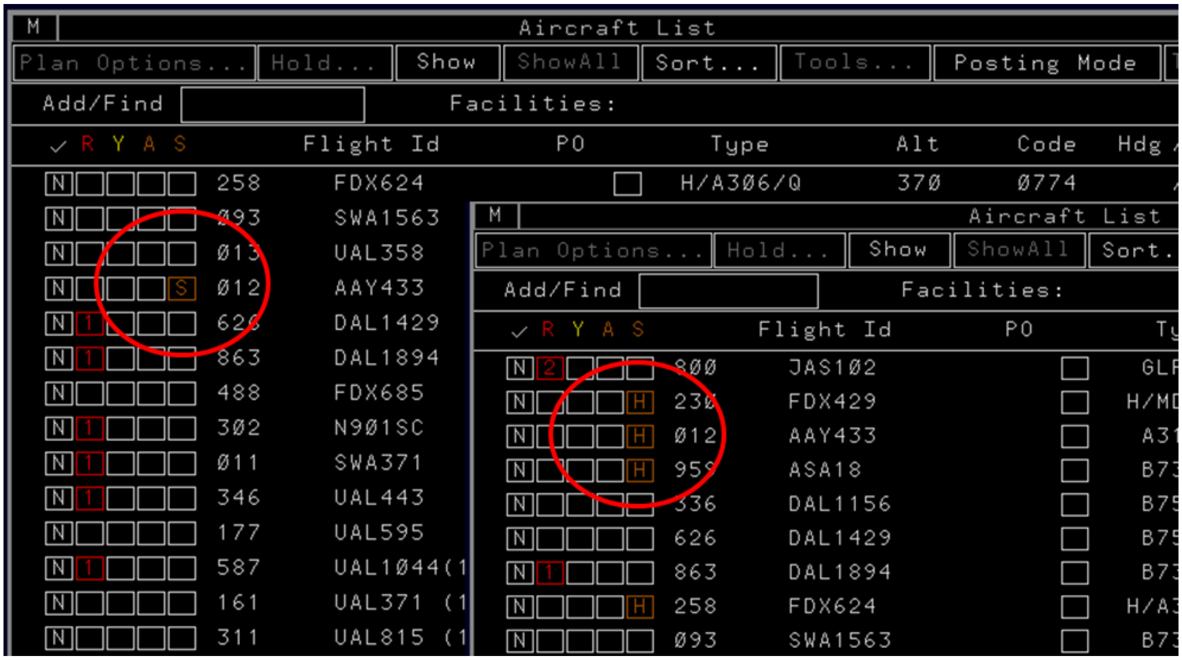

Figure 17. Debris Threat Mitigation Tool on ERAM D-side Aircraft List.

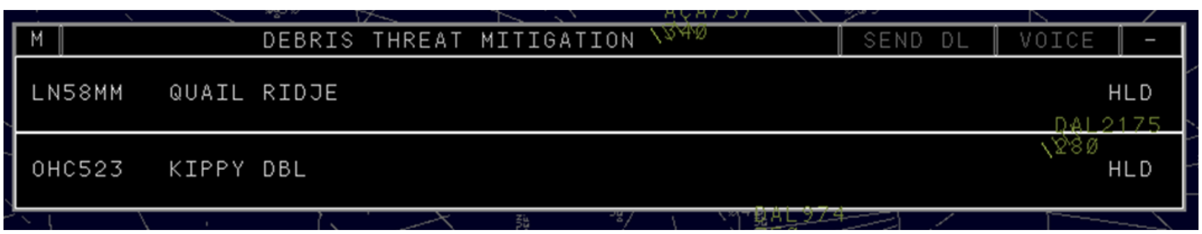

Figure 18. Debris Threat Mitigation Tool on ERAM R-side.

2.4.4. Workload Assessment Keypad

Controllers used the NIEC WAK devices to provide workload ratings using the Air Traffic Workload Input Technique (ATWIT). ATWIT is an unobtrusive and reliable technique for collecting controller workload ratings as controllers work traffic in a simulation (Stein, 1985; Stein, 1991). The WAK consists of a touch-panel display with 10 buttons labeled from 1 to 10. The WAK is connected to a computer that controls the device and records workload ratings. The system is programmable allowing researchers to select the timing parameters for the study. The system prompts controllers for workload ratings at a selected time interval by emitting a tone and illuminating the keypad buttons. Controllers provide their workload ratings by pressing one of the 10 buttons, where 1 indicates *very low* workload and 10 indicates *very high* workload. If controllers do not respond before the timeout period, the system records a code indicating there was no response. In this simulation, we selected 2 minutes as the rating time interval and 20 seconds as the timeout period.

2.4.5. Audio-Visual Recording System

We used the NIEC audio-video recording system to record controller voice communications and actions during the simulation. We positioned an overhead video camera above each team to record controllers' upper body and arm actions. The audio-video recording serves as a record of the simulation that the researchers can review if needed.

2.4.6. Simulation Pilot Workstations

The present study required six simulation pilot workstations linked together in a network with the controller workstations. Each simulation pilot workstation consisted of a computer monitor, keyboard, and mouse. A section of the computer monitor depicted a situation display of the airspace and aircraft in the simulation similar to the controller display. The remaining display area contained a list of aircraft assigned to the simulation pilot, flight information, and a user interface to enter flight plan changes into the system. Each simulation pilot was responsible for several aircraft during the simulation. The simulation pilots used the NIEC communications system to talk to controllers.

2.5. Materials

2.5.1. Informed Consent Statement

Each participant read and signed the Informed Consent Statement before beginning the study. The Informed Consent Statement described the purpose of the study and the rights and responsibilities of the participants, and assured participants that their data would be confidential and anonymous (see Appendix A).

2.5.2. Biographical Questionnaire

Each participant completed the Biographical Questionnaire before beginning the experiment. The purpose of the Biographical Questionnaire was to collect general descriptive information about the participants including gender, age, and level of ATC experience (see Appendix B).

2.5.3. Post-Scenario Questionnaire

The participants completed the Post-Scenario Questionnaire (PSQ) after each test scenario. The purpose of the PSQ was to collect data regarding the controller's experience in the traffic scenario just completed. The controllers provided ratings about their performance, workload, and situation awareness. Controllers also provided ratings about the experimental conditions tested in the scenario, such as the generic procedures and support tools (if any). The PSQ included ratings and open-ended questions about the support tools and their effects on safety, capacity, and efficiency. The controllers were able to comment about anything they experienced during the scenario that they considered relevant to the study (see Appendix C).

2.5.4. Exit Questionnaire

The participants completed the Exit Questionnaire after completing all traffic scenarios. The purpose of the Exit Questionnaire was to collect data regarding the controller's experience in the entire study. The controllers provided ratings about the realism of the simulation including the airspace, traffic scenarios, and ATC equipment. Controllers also provided ratings that compared the experimental conditions tested in each experiment. The Exit Questionnaire included ratings and open-ended questions. The controllers were able to comment about anything they experienced that they considered relevant to the study (see Appendix D).

2.5.5. Observer Rating Form

After each test scenario, the SMEs used the Observer Rating Form to provide performance ratings for each of the R-side/D-side controller teams or for individual controllers when they operated in the R-side only configuration. ERPs and SMEs in the Research Development and Human Factors Laboratory (RDHFL) developed the Observer Rating Form to evaluate new ATC concepts and procedures by observing controller performance in HITL simulations (Sollenberger, Stein, & Gromelski, 1997; Vardaman & Stein, 1998). The Observer Rating Form consists of several rating scales designed to assess different aspects of ATC performance, such as resolving aircraft conflicts, sequencing aircraft, prioritizing tasks, communicating effectively, and maintaining situation awareness (see Appendix E). SMEs filled out a PSQ after each scenario and filled out the Exit Questionnaire at the completion of the study.

2.6. Experimental Design

2.6.1. Independent Variables

We designed three traffic scenarios to evaluate the SVO concepts of Just-in-Time STC activation and reactive separation from a DHV during off-nominal events. The first scenario was a space vehicle ReEntry scenario under nominal conditions. The second scenario was a space vehicle Launch scenario with an off-nominal event. In both scenarios, the participants controlled traffic with and without the SVO Tools in separate runs to evaluate the benefits of the tools. The ReEntry and Launch scenarios run with or without the SVO Tools represent four different experimental conditions in the study (ReEntry-No Tools, ReEntry-Tools, Launch-No Tools, Launch-Tools). We designed the last scenario as a Special Launch scenario under nominal conditions and always using the SVO Tools. This Special Launch scenario represents the fifth experimental condition in the study (Special-Tools).

We designed a timeline of events for each scenario. For the ReEntry scenarios, the participants saw the STC on either the ERAM or the TSD, followed by a High Certainty Notification of the space vehicle reentry, then reentry, and the STC deactivation after reentry was completed. For the Launch scenarios, the participants saw the STC on either the ERAM or the TSD, followed by a High Certainty Notification of the space vehicle launch, then launch, followed by the off-nominal event and the DHV, and the STC deactivation after the debris was clear. The timeline for the Special Launch scenario was similar to the ReEntry scenarios without the off-nominal event.

In addition to the five main experimental conditions, there were two additional factors in the study. We assigned two controllers to each of the Sectors (Sector 18, Sector 67) and to either Position (R-side, D-side). All of the controllers participated in each of the five experimental conditions as both the R-side and the D-side controller in separate runs; however, the participants did not control traffic in both sectors. Although there were no research questions concerning the SVO concepts associated with the Sector and Position, these factors are part of the overall experimental design for data analysis.

2.6.2. Simulation Measures

2.6.2.1 Space Transition Corridor and Debris Hazard Volume Measures

The NIEC simulation software has an extensive data collection system that records aircraft track and status information during the simulation. We processed the raw simulation data for all the aircraft in each scenario run to evaluate the SVO concepts. There were several measures of interest to determine how effectively the controllers were using the STC prior to activation and the DHV during off-nominal events.

- Number of aircraft operating in the STC during pre-activation.
- Elapsed time between the last aircraft to exit the pre-active STC until the STC activation.
- Number of aircraft operating in the DHV.
- Minimum, Maximum, and Mean time that aircraft were inside the DHV.
- Elapsed time between the DHV appearance and the first transmission to reroute an aircraft.
- Elapsed time between the DHV appearance and the time to clear all aircraft from the DHV.
- Number of aircraft changing course from virtual baseline flight plan.
- Additional flight time for aircraft changing course from virtual baseline flight plan.
- Cost of changing course from virtual baseline flight plan in terms of aircraft operating costs.

2.6.2.2 System Effectiveness Measures

We processed the raw simulation data to produce several objective measures of system effectiveness in the critical areas of safety, efficiency, capacity, and communications (Buckley, DeBaryshe, Hitchner, & Kohn, 1983; Stein & Buckley, 1992).

- Number of aircraft flying through the sectors.
- Aircraft flight times through the sectors.
- Aircraft flight distances through the sectors.
- Frequency and duration of controller transmissions.

2.6.2.3 Controller Workload and Questionnaires

We collected controller ratings of workload during each scenario using the ATWIT method and the WAK touchscreens. We also collected controller ratings of performance, workload, situation awareness, and their evaluation of the SVO concepts in the Post-Scenario and Exit Questionnaires. Finally, SMEs observed the controllers and provided ratings of their effectiveness using the SVO concepts in the Observer Rating Form.

2.7. Procedure

2.7.1. Daily Schedule

Table 1 shows the daily schedule of activities for the participants in the current study (also see Table 2 for a description of each scenario listed in the schedule). Each group of participants consisted of four controllers and one TMC who were released from their facility for one week to participate in the SVO DTM Study. The controllers traveled to the FAA WJHTC on Monday and departed on Friday.

Table 1. Daily Schedule of Activities

Tuesday		Wednesday		Thursday	
Time	Activity	Time	Activity	Time	Activity
8:00-8:30	Welcome	8:00-8:50	ReEntry (Tools)	8:00-8:50	ReEntry (Tools)
8:30-9:30	Project Briefing	8:50-9:10	Break	8:50-9:10	Break
9:30-10:30	Sector Briefing	9:10-10:00	ReEntry (Tools)	9:10-10:00	Special Launch
10:30-10:45	Break	10:00-10:20	Break	10:00-10:20	Break
10:45-11:45	Hands On Training	10:20-11:10	Launch (Tools)	10:20-11:10	Launch (Tools)
11:45-1:00	Lunch	11:10-12:50	Lunch	11:10-12:50	Lunch
1:00-1:30	Practice #1	12:50-1:40	Launch (Tools)	12:50-1:40	Launch (Tools)
1:30-1:50	Break	1:40-2:00	Break	1:40-2:00	Break
1:50-2:20	Practice #2	2:00-2:50	Special Launch	2:00-2:50	(Makeup Run or Debrief)
2:20-2:40	Break	2:50-3:10	Break	2:50-3:10	(Break or Debrief)
2:40-3:10	Practice #3	3:10-4:00	ReEntry (Tools)	3:10-4:00	(Makeup Run or Debrief)
3:10-3:30	Break	4:00-4:30	Discussion	4:00-4:30	Debrief
3:30-4:00	Practice #4				
4:00-4:30	Discussion				

On Tuesday, Wednesday, and Thursday, the controllers participated in the experiment and performed training and experimental scenarios. The daily schedule was the same across participants with the exception that the order of exposure to "Tools" conditions within each of the three experiments was counterbalanced across participants. At the end of each day, we held a group meeting to answer the participants' questions and discuss their experiences in the simulation.

On the first day of the study, we briefed the participants about the project goals and sectors they were operating in the simulation. The participants completed the Informed Consent Statement and the Biographical Questionnaire. On the last day of the study, we conducted an exit briefing, and the participants completed the Exit Questionnaire.

To ensure anonymity, we did not attach the participants' names to any of the questionnaires. We assigned sequential numbers to the controllers in the order that they participated in the study. For example, the first R-side/D-side controller team was assigned as Participants 1 and 2.

2.7.2. Training and Experimental Sessions

Table 2 shows a summary of the training and experimental sessions. Tuesday was a training session; Wednesday and Thursday were testing sessions. The participants performed four practice scenarios to become familiar with the simulation equipment and procedures. The controllers switched R-side and D-side positions so that all CPCs completed five test scenarios as both the R-side and D-side controller.

Table 2. Summary of Training and Experimental Sessions

Scenario	Mission	Experimental Conditions	SVO Tools
Practice #1	Launch	Off Nominal Launch	None
Practice #2	ReEntry	Nominal ReEntry	All SVO Tools
Practice #3	Launch	Off Nominal Launch	None
Practice #4	ReEntry	Nominal ReEntry	All SVO Tools
Launch	Launch	Off Nominal Launch	None
Launch Tools	Launch	Off Nominal Launch	All SVO Tools
ReEntry	ReEntry	Nominal ReEntry	None
ReEntry Tools	ReEntry	Nominal ReEntry	All SVO Tools
Special Launch	Launch	Nominal Launch	All SVO Tools

For all experiments, participants used WAKs during all training and experimental scenarios. We used the audio-video recording system during the experimental sessions. After each experimental scenario, controllers completed the PSQ and SMEs completed the PSQ as well as the Observer Rating Form.

3. RESULTS AND DISCUSSION

3.1. Space Transition Corridor and Debris Hazard Volume

We were interested in determining how effectively the controllers were using the pre-active STC prior to the active restriction of airspace. In addition, we were interested in determining how effectively the controllers were using reactive separation from the DHV during off-nominal events. We processed the raw simulation data for all aircraft radar track updates in each scenario run to evaluate these SVO concepts. Although our simulator records aircraft time and position data very precisely, there is a degree of error in these measures because track data are updated every radar sweep and aircraft are shown on a computer monitor with limited resolution.

Table 3 shows the results for two measures regarding the pre-active STC. The first is the number of aircraft that were operating in the STC during pre-activation. As Table 3 indicates, there were 12-15 aircraft using the pre-active STC in the ReEntry scenarios. This represents effective usage of the available airspace using the Just-in-Time Notification concept. In today's operating procedures, these aircraft would be restricted from using the airspace and controllers would have to reroute the aircraft. There were fewer aircraft using the pre-active STC in the Launch scenarios. One reason for this may be because the STC covered the primary departure gates and there was a traffic management initiative in place requiring Denver Tower to reroute departures with transit times greater than 10 minutes. Note that the Special-Tools scenario is a Launch scenario, but without the off-nominal event in the other Launch scenarios.

The second measure shows the elapsed time between the last aircraft to exit the pre-active STC and STC activation (see Table 3). Short time intervals represent effective *last moment* usage of the available airspace using the Just-in-Time Notification concept. As shown, the elapsed time for the ReEntry scenarios was approximately 1 minute (1:18 recorded) and between a few seconds to approximately 4.5 minutes in the Launch scenarios (see Table 3). The time intervals for the Launch scenarios were slightly longer but still showed effective usage of the available airspace. There does not appear to be any differences between the scenarios without the tools and the scenarios with the tools. Note that in the scenarios without the SVO tools, the controllers could still use standard ERAM capabilities to manage the airspace.

Table 3. Controller Usage of the Pre-active Space Transition Corridor

Run	Scenario	Aircraft operating in pre-active STC	Last aircraft to exit from pre-active STC until active
1	ReEntry-No Tools	15	1:18
6	ReEntry-No Tools	14	1:18
12	ReEntry-No Tools	12	1:18
17	ReEntry-No Tools	14	1:18
2	ReEntry-Tools	14	1:18
7	ReEntry-Tools	14	1:18
11	ReEntry-Tools	13	1:18
16	ReEntry-Tools	14	1:18
3	Launch-No Tools	0	-
9	Launch-No Tools	1	1:22
14	Launch-No Tools	0	-
20	Launch-No Tools	0	-
4	Launch-Tools	0	-
10	Launch-Tools	1	1:13
13	Launch-Tools	0	-
19	Launch-Tools	0	-
5	Special-Tools	5	0:05
8	Special-Tools	3	4:30
15	Special-Tools	1	4:30
18	Special-Tools	1	4:30

Note. Time durations in minutes:seconds.

Table 4, Table 5, and Table 6 show the results for several measures regarding the DHV after the off-nominal event. Only two of the Launch scenarios had off-nominal events. The ReEntry scenarios and the Special-Tools scenario had nominal situations. Table 4 shows that from 1-5 aircraft were operating in the DHV depending on the scenario run. Most of the aircraft (4 out of 5) were in the DHV when the event occurred; however, in some runs from 1-3 aircraft entered the DHV after the event occurred. It is important to note that controllers cannot anticipate rare off-nominal events and ensure that all aircraft will avoid a potential DHV. However, quickly getting aircraft out of the DHV when it occurs represents effective reactive separation.

Table 4. Number of Aircraft Operating in the Debris Hazard Volume

Run	Scenario	Aircraft in DHV start of active	Aircraft enter DHV after active	Total aircraft in DHV during active
3	Launch-No Tools	1	1	2
9	Launch-No Tools	1	1	2
14	Launch-No Tools	1	1	2
20	Launch-No Tools	1	0	1
4	Launch-Tools	4	1	5
10	Launch-Tools	4	1	5
13	Launch-Tools	0	3	3
19	Launch-Tools	1	0	1

Note. Time durations in minutes:seconds.

Table 5 shows the minimum, maximum, and mean times that aircraft were inside the DHV. Any time less than 4 minutes is effective reactive separation to the off-nominal event. However, there were two runs where three aircraft were inside the DHV for longer than 4 minutes. We reviewed the video replays for both runs. In Run 10, one aircraft was in the DHV for approximately 4.5 minutes (4:48 recorded) due to pilot error turning the aircraft in the wrong direction. The other aircraft was in the DHV for approximately 5 minutes, but the controller did not take immediate action. In Run 13, the aircraft was in the DHV for approximately 6 minutes due to a Data Comm command that the sending controller did not uplink and may have confused the receiving controller. Note that the controllers received only minimal Data Comm training, which was less than would be provided for simulation studies focused on Data Comm usage.

Table 5. Minimum, Maximum, and Mean Time in the Debris Hazard Volume

Run	Scenario	Minimum in DHV during active	Maximum in DHV during active	Mean in DHV during active
3	Launch-No Tools	1:12	2:59	2:05
9	Launch-No Tools	0:12	3:39	1:56
14	Launch-No Tools	1:23	1:25	1:24
20	Launch-No Tools	3:24	3:24	3:24
4	Launch-Tools	0:24	2:36	1:46
10	Launch-Tools	0:12	5:00	3:02
13	Launch-Tools	0:12	6:01	2:10
19	Launch-Tools	2:00	2:00	2:00

Note. Time durations in minutes:seconds.

Table 6 shows the elapsed time between the DHV appearance and the first transmission to reroute an aircraft as well as the time to clear all aircraft from the DHV. The first measure represents how quickly the controllers started reactive separation when the off-nominal event occurred. The second measure represents how long it took the controllers to finish reactive separation. As Table 6 shows, the controllers took less than approximately 36 seconds to contact the first pilot and reroute the aircraft. The results indicate that it took controllers from as little as approximately 1.5 minutes (1:42 recorded) to as much as approximately 6 minutes (6:14 recorded) to clear all aircraft from the DHV. In the two runs where it took over 4 minutes to clear the DHV, one delay was due to pilot error and the other because of confusion in Data Comm usage.

Table 6. Reactive Separation Time to Aircraft in the Debris Hazard Volume

Run	Scenario	DHV start until first reroute	DHV start until all aircraft clear
3	Launch-No Tools	0:36	3:05
9	Launch-No Tools	0:21	3:50
14	Launch-No Tools	0:01	1:42
20	Launch-No Tools	0:25	3:30
4	Launch-Tools	0:19	2:42
10	Launch-Tools	0:11	5:30
13	Launch-Tools	0:29	6:14
19	Launch-Tools	0:12	2:06

Note. Time durations in minutes:seconds.

In addition to the 20 runs with participants, we ran each of the five scenarios without participants to collect basic data for comparison to the HITL runs. We called these virtual baseline runs. We collected data for aircraft flight times and distances as aircraft flew their intended flight plans without rerouting around the STC or DHV as if these restricted zones did not exist. In addition, we did not reroute aircraft for traffic and disregarded loss of aircraft separation for these runs. The virtual baseline runs represent an efficient ideal standard. We used the virtual baseline runs to estimate the cost of rerouting aircraft around the STC and DHV in terms of added flight time and aircraft operating costs.

Table 7 shows the number of aircraft that changed course from the virtual baseline flight plans during the participant runs. Most of the course changes were due to rerouting around the STC and DHV; however, some changes may also have occurred for traffic or other reasons. We were not able to determine the actual reasons for rerouting from the simulation data. That would require a SME to replay and review each participant run. As shown, the participants rerouted fewer aircraft for the ReEntry scenarios (8-15 aircraft) compared to the Launch scenarios (23-39 aircraft). This occurred because the STC was smaller for the ReEntry scenarios and there was no off-nominal event and DHV to reroute around like there was for the Launch scenarios. There were slightly fewer aircraft rerouted in the Special-Tools scenarios (20-37 aircraft), which was also a Launch scenario, but under nominal conditions without the DHV.

Table 7 also shows the total flight time difference between the participant runs and the virtual baseline runs. We computed this measure by using the simulator's estimated time of arrival at its destination airport for each aircraft. This time will increase as participants reroute aircraft farther off its flight plan. As Table 7 indicates, the total time differences were smaller for the ReEntry scenarios, ranging from as little as 48 seconds to approximately 24 minutes (24:15 recorded). Also, note that Run 6 and Run 11 showed a few minutes of negative differences, indicating that participants were able to give some aircraft more direct routings than their flight plans. The total time differences for the Launch scenarios were much larger, ranging from as little as 11 minutes (11:14 recorded) to as much as approximately 3 hours (2:53:46 recorded). For the Special-Tools scenarios, the flight time differences ranged from approximately 5 minutes (4:44 recorded) to approximately 1 hour and 18 minutes (1:18:31 recorded).

The last two measures in Table 7 show the increased operating costs for the aircraft due to increased flight times from their flight plans. These costs are based on the FAA estimate of $4,456 per 1 hour of airborne flight time for a passenger aircraft. As Table 7 shows, the increased operating costs for all aircraft that changed course in the ReEntry scenarios were between $59 and $1,800 per hour and a few hundred dollars in savings for the two runs with negative differences. The total operating costs for the Launch scenarios were much greater: between $834 and $12,905. The Special-Tools scenarios, representing launches under nominal conditions, ranged between $351 and $5,831.

Table 7. Number of Aircraft Changing Course from Virtual Baseline Flight Plan, Flight Time Differences, and Aircraft Operating Costs

Run	Scenario	Number of aircraft	Total flight time difference	Cost per aircraft	Total cost
1	ReEntry-No Tools	8	0:00:48	$7.43	$59.41
6	ReEntry-No Tools	8	-0:01:57	-$18.10	-$144.82
12	ReEntry-No Tools	15	0:10:15	$50.75	$761.23
17	ReEntry-No Tools	10	0:24:15	$180.10	$1,800.97
2	ReEntry-Tools	9	0:17:31	$144.54	$1,300.90
7	ReEntry-Tools	10	0:13:42	$101.75	$1,017.45
11	ReEntry-Tools	13	-0:04:21	-$24.85	-$323.06
16	ReEntry-Tools	11	0:01:52	$12.60	$138.63
3	Launch-No Tools	23	2:53:46	$561.09	$12,905.07
9	Launch-No Tools	29	2:34:26	$395.49	$11,469.25
14	Launch-No Tools	29	0:21:25	$54.85	$1,590.54
20	Launch-No Tools	24	0:11:14	$34.76	$834.26
4	Launch-Tools	28	0:20:03	$53.18	$1,489.05
10	Launch-Tools	34	0:56:48	$124.07	$4,218.35
13	Launch-Tools	39	0:51:14	$97.56	$3,804.93
19	Launch-Tools	30	1:52:07	$277.55	$8,326.53
5	Special-Tools	23	0:47:02	$151.87	$3,493.01
8	Special-Tools	20	1:18:31	$291.56	$5,831.17
15	Special-Tools	32	0:15:50	$36.75	$1,175.89
18	Special-Tools	37	0:04:44	$9.50	$351.53

Note. Time durations in hours:minutes:seconds. Cost is in dollars per hour.

3.2. Number of Aircraft Flying through Sectors

We processed the raw simulation data to determine the number of aircraft flying through the sectors during each 50-minute scenario run. These data indicate how busy the controllers were working traffic and represent a measure of sector capacity and throughput using the SVO concepts. Figure 19 shows the scenario means computed across the participants for each sector. The error bars for each scenario represent one standard deviation above and below the mean as a measure of variability. The participants controlled between 42 aircraft and 66 aircraft, depending on the scenario. The controllers in Sector 18 worked more aircraft than the controllers in Sector 67, and the Launch scenarios were slightly busier than the ReEntry scenarios. The busiest scenario appears to be the Special-Tools scenario—a Launch scenario under nominal conditions. However, there does not seem to be much difference between the scenarios without the tools and the scenarios with the tools.

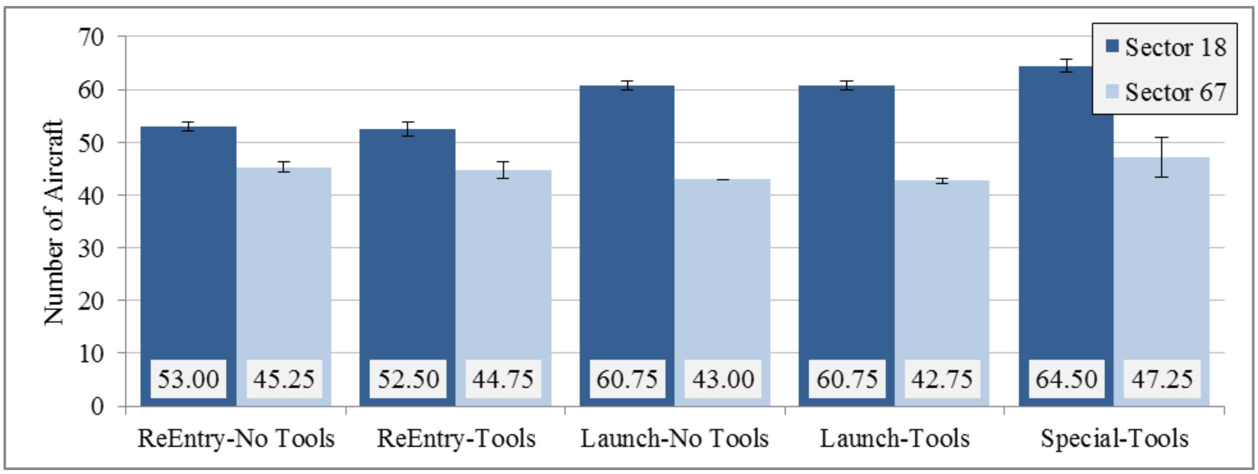

Figure 19. Number of aircraft flying through the sectors.

3.3. Aircraft Flight Time and Distance through Sectors

We processed the raw simulation data to determine the aircraft flight times and distances through the sectors. These data represent measures of traffic flow efficiency and relate to aircraft fuel burn. Controllers can reduce flight times and distances by using direct routings when possible or increase flight times and distances to avoid restricted airspace when necessary. Figure 20 shows the scenario means for the total flight time of all aircraft through the sectors and the mean flight time per aircraft. The total flight times ranged between 415-867 minutes (6.92-14.45 hours) and the mean flight times ranged between 9.87-14.12 minutes, depending on the scenario. The total flight times for Sector 18 were longer than the total flight times for Sector 67 because there were more aircraft in Sector 18, especially for the Launch scenarios. There does not seem to be any differences in the total flight times or the mean flight times between the scenarios without the tools and the scenarios with the tools.

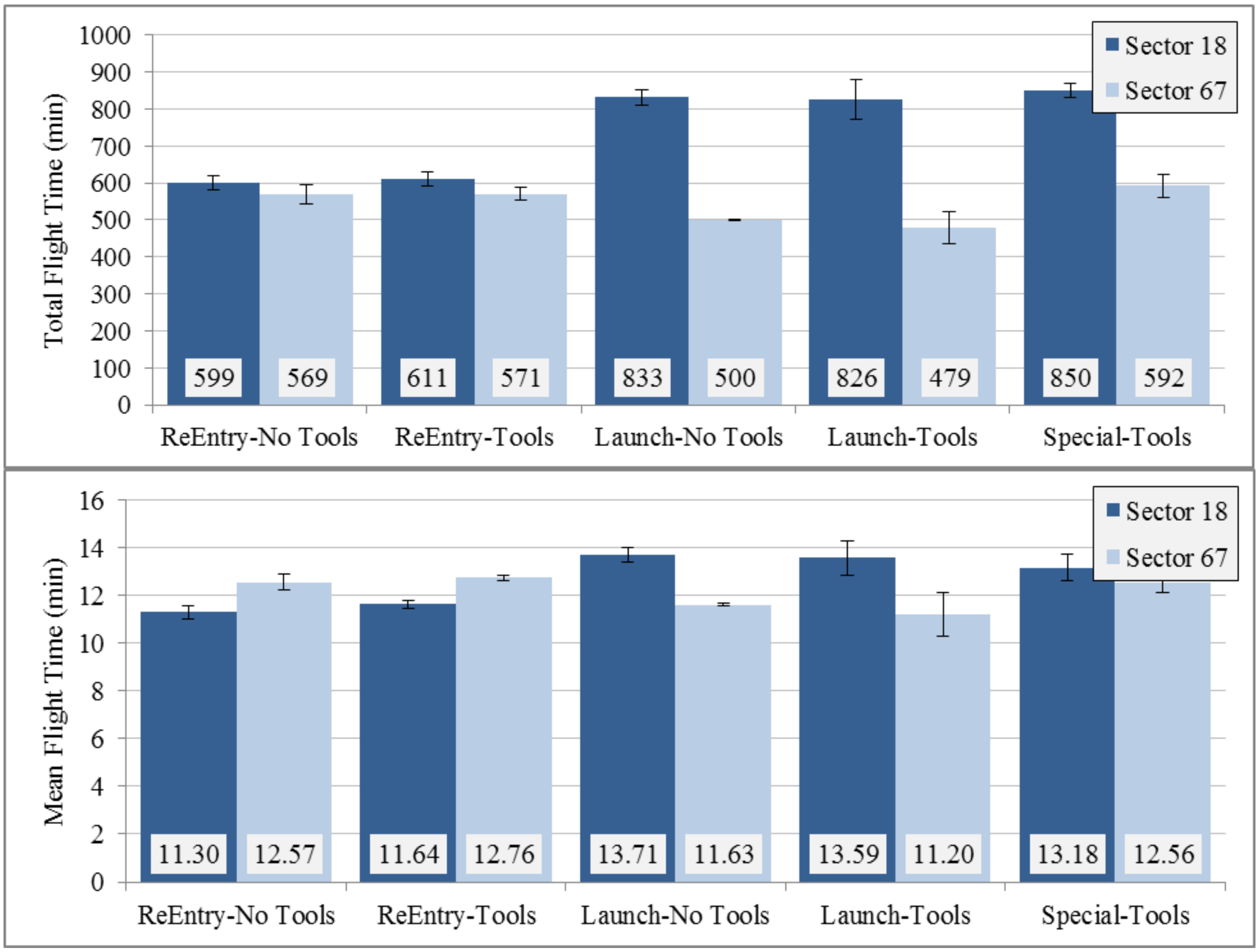

Figure 20. Aircraft flight times through the sectors.

Figure 21 shows the scenario means for the total flight distance of all aircraft through the sectors and the mean flight distance per aircraft. The total flight distances ranged between 3,202-6,700 nm and the mean flight distances ranged between 76.25-109.83 nm, depending on the scenario. The total flight distances for Sector 18 were longer than the total flight distances for Sector 67 because there were more aircraft in Sector 18, especially for the Launch scenarios. There do not seem to be any differences in the total flight distances or the mean flight distances between the scenarios without the tools and the scenarios with the tools.

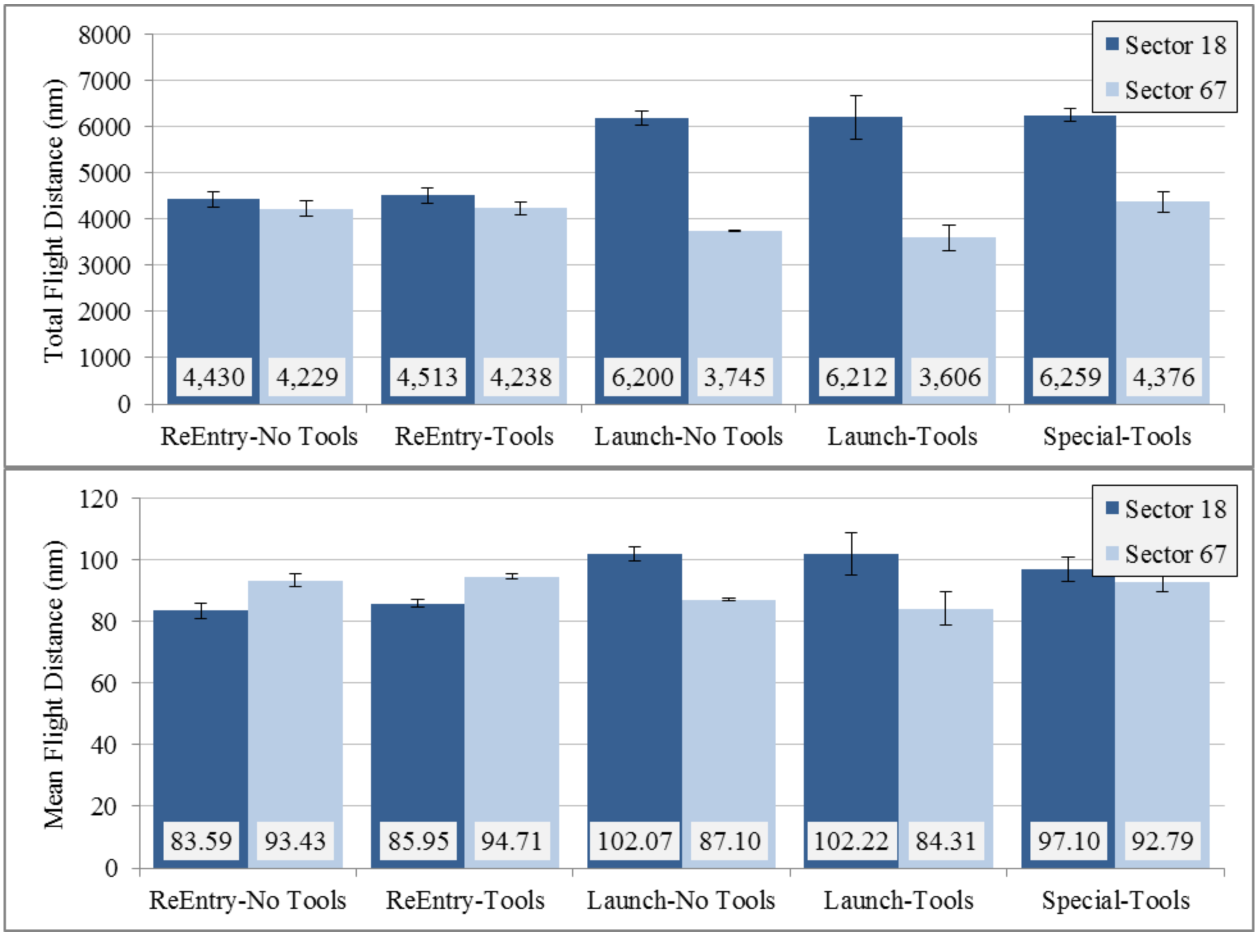

Figure 21. Aircraft flight distances through the sectors.

3.4. Air Traffic Workload Input Technique

We used the ATWIT and the WAK touchscreens to collect workload ratings from the participants as they controlled traffic in each scenario. The controllers provided workload ratings every 4 minutes during the 50-minute scenarios. We processed the data for each of the 12 workload ratings and computed a scenario mean for each participant. A major factor for controller workload is the traffic volume in scenarios; however, the SVO tools and concepts could also affect workload. Figure 22 shows the scenario means computed across the participants for each controller position and each sector. The results indicate that workload was higher for the R-side position compared to the D-side position and higher for Sector 18 compared to Sector 67. The workload was higher for the Launch scenarios relative to the ReEntry scenarios, but there were no significant differences between the scenarios without the tools and the scenarios with the tools.

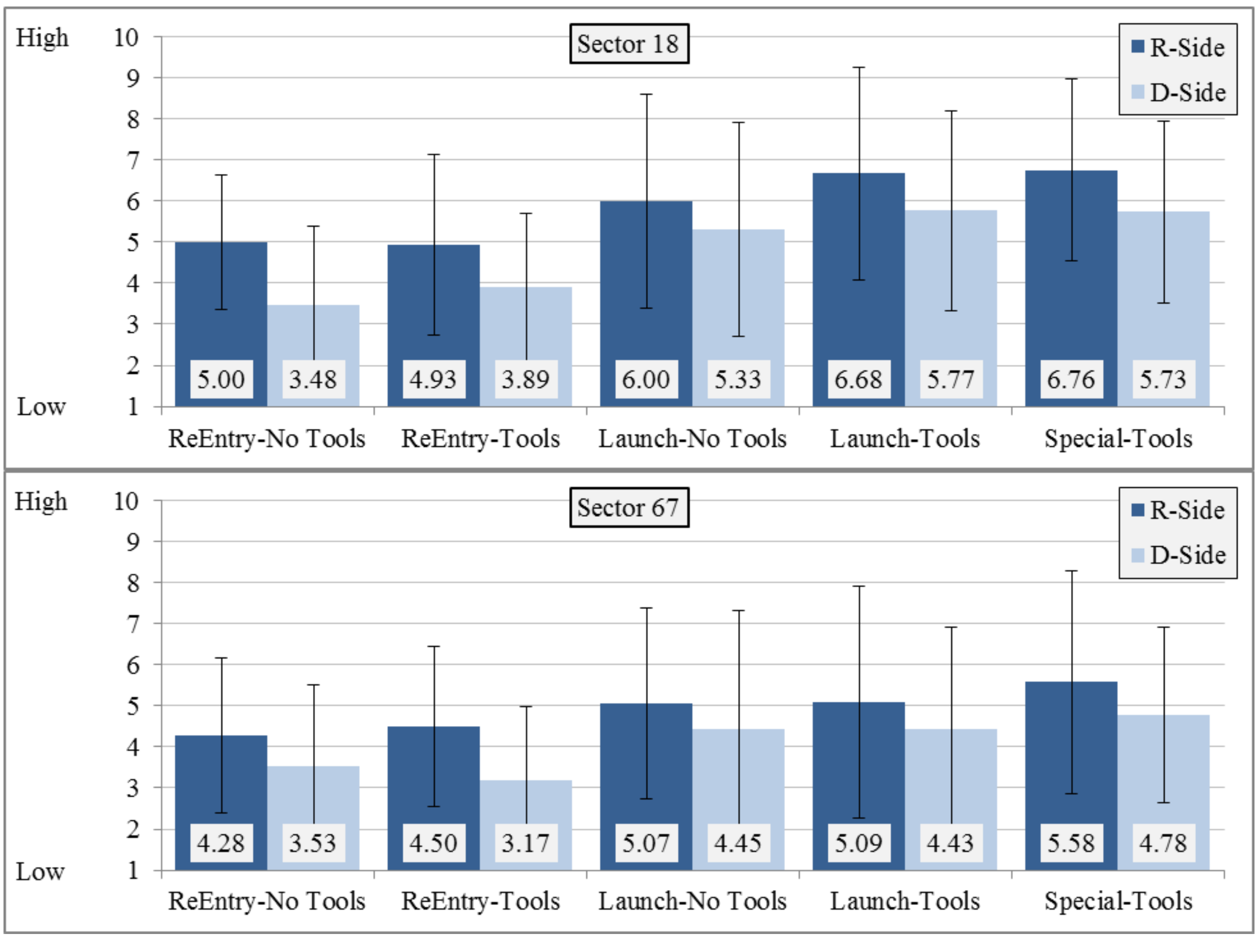

Figure 22. ATWIT workload ratings.

3.5. Post-Scenario Questionnaire Ratings

After each simulation run, the controllers completed the Post-Scenario Questionnaire and provided ratings of performance, workload, situation awareness and tool effectiveness. Appendix F shows a summary of the controller responses to all of the Post-Scenario Questionnaire ratings. Figure 23 shows the mean scenario ratings of tool effectiveness for supporting the just-in-time STC activation. In scenarios that did not include the SVO tools, the controllers rated the effectiveness of the standard ERAM tools. In general, the tool effectiveness ratings were very high across the scenarios. Over 31% of the ratings were either a 9 or 10; only 9% of the ratings were less than 6. The ratings were equally high for both the R-side and the D-side controllers and for both sectors. There was a trend for the scenario ratings to be higher for Tools vs. No Tools when comparing the R-side ratings to each other and the D-side ratings to each other for each sector (Note exception Sector 18, R-side: ReEntry-Tools vs. ReEntry-No Tools).

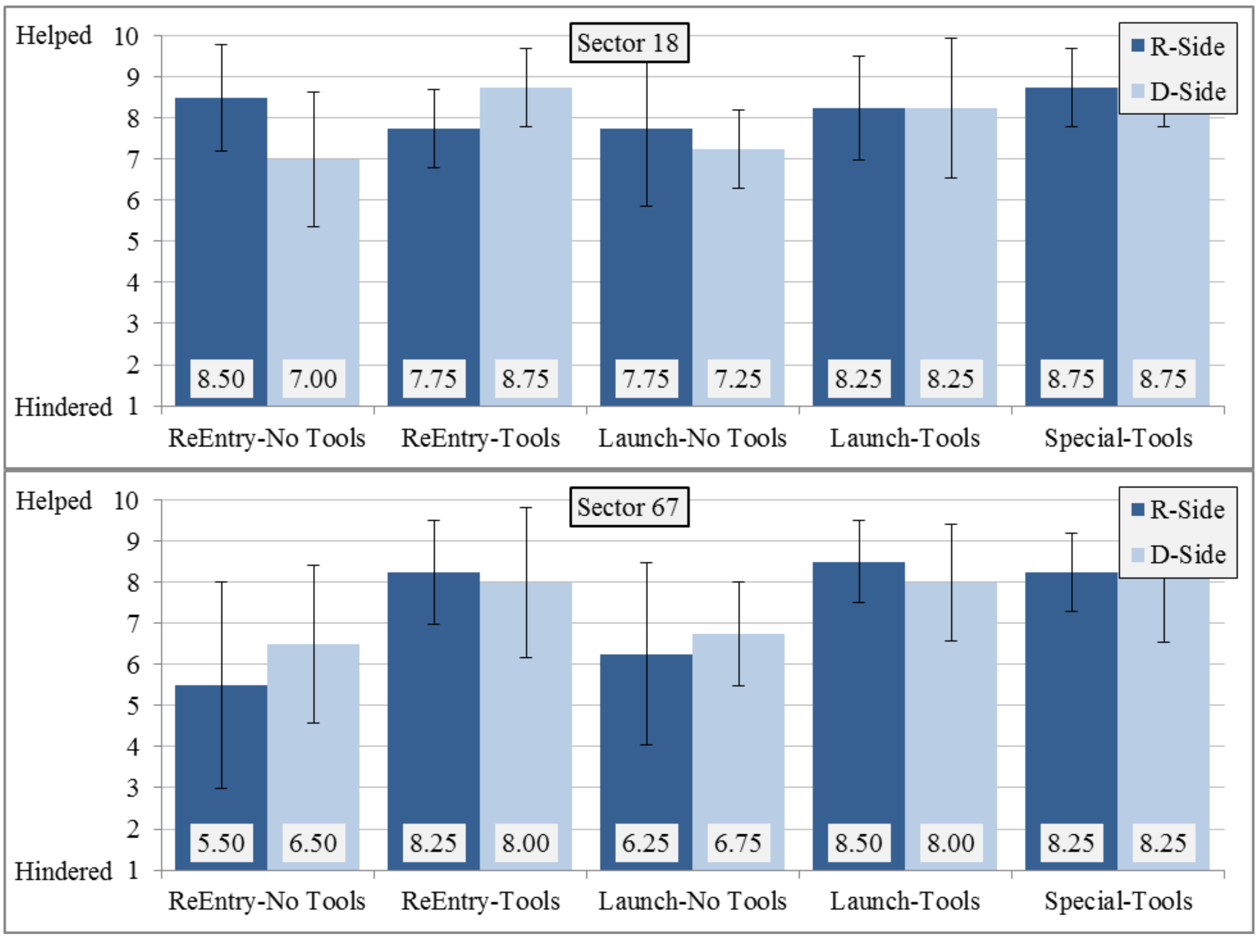

Figure 23. Supporting the just-in-time STC activation ratings.

Figure 24 shows the mean scenario ratings of tool effectiveness for supporting reactive separation from the DHV. In general, the tool effectiveness ratings were very high across the scenarios. Over 34% of the ratings were either a 9 or 10; only 11% of the ratings were less than 6. The ratings were equally high for both the R-side and the D-side controllers and for both sectors. There was a trend for the scenario ratings to be higher for Tools vs. No Tools when comparing the R-side ratings to each other and the D-side ratings to each other for each sector (Note exception Sector 18, R-side: Launch-Tools vs. Launch-No Tools).

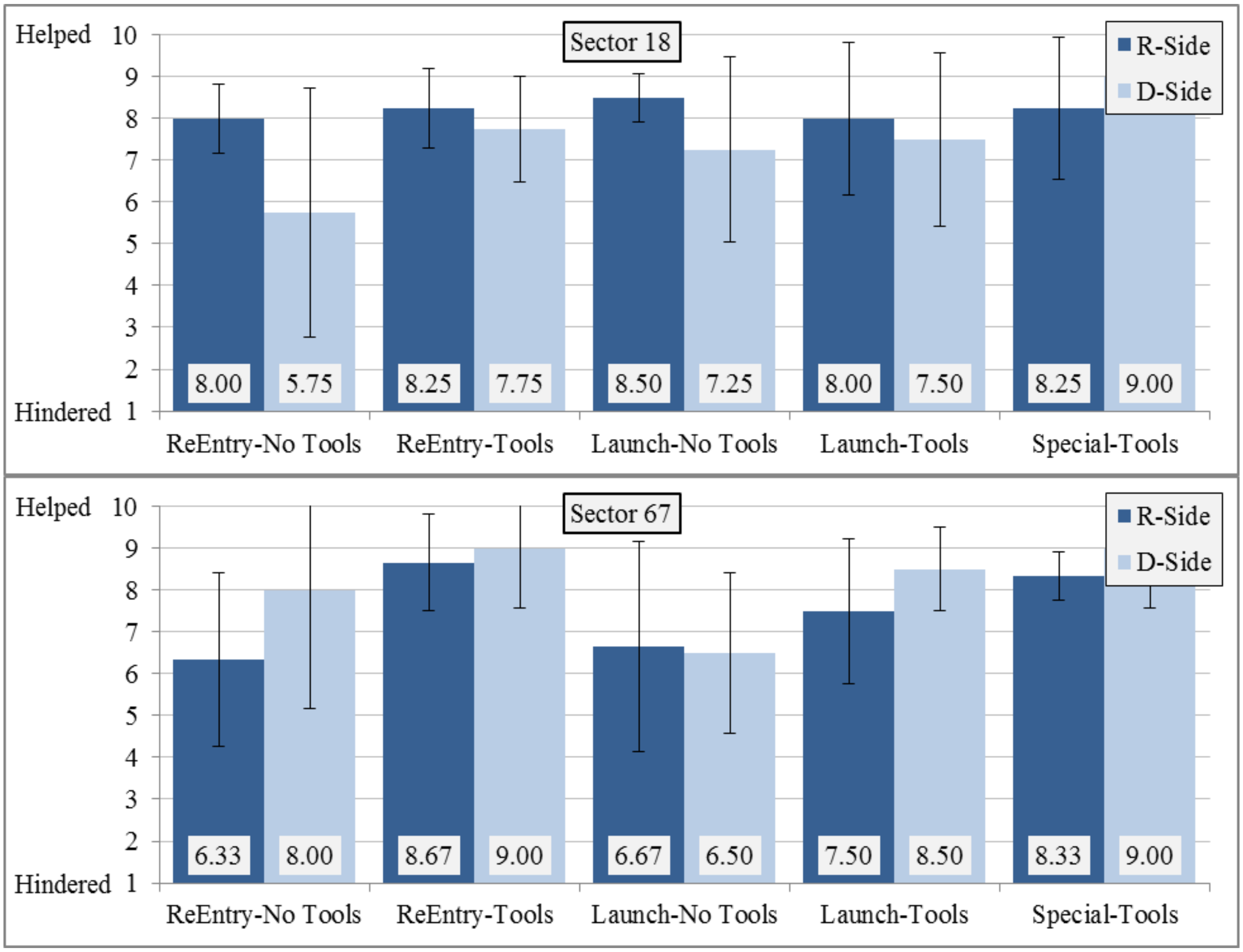

Figure 24. Supporting reactive separation from the DHV ratings.

3.6. Subject Matter Expert Observer Ratings

During each simulation run, SMEs observed the participants controlling traffic and provided several ratings of their effectiveness using the SVO concepts. Appendix G shows a summary of the SME responses to all of the Observer Rating Form scales.

Figure 25 shows the mean scenario ratings for maintaining separation and resolving potential conflicts. The ratings for Sector 67 were much higher than the ratings for Sector 18. The reason for this result is that there were two SMEs observing the different sectors, and they had different rating standards. This is not unusual for experts using subjective rating scales. In addition, one of the

SMEs was from Denver ARTCC and had significantly more knowledge and experience with the airspace. There was a trend for the observer on Sector 67 to provide higher ratings for the Tools scenarios relative to the No Tools scenarios. However, for the observer on Sector 18, there were no consistent differences in the ratings.

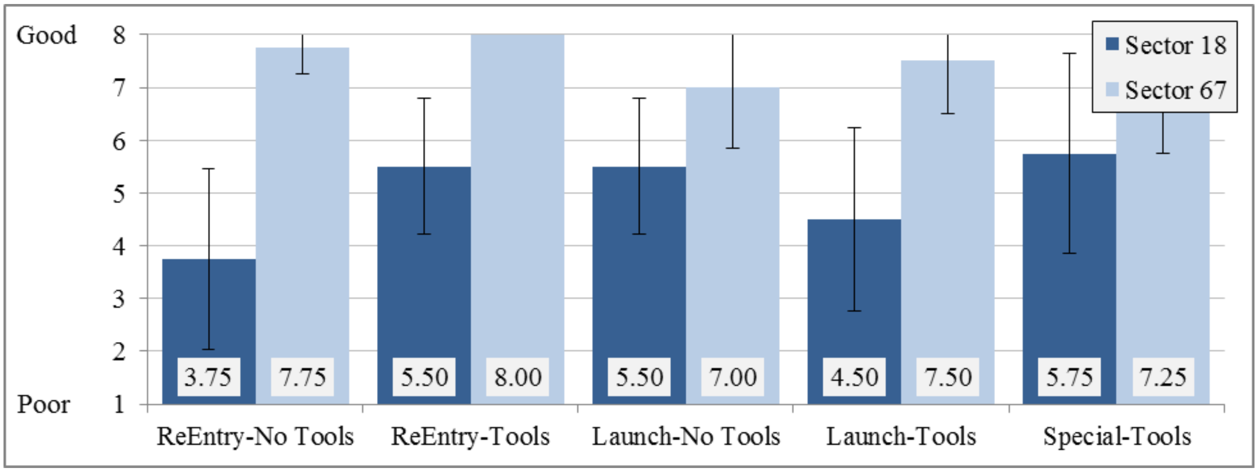

Figure 25. Maintaining separation and resolving potential conflicts ratings.

3.7. Exit Questionnaire Responses

After all the simulation runs were finished, the controllers completed the Exit Questionnaire and provided ratings of the simulation realism, the STC and DHV airspace tools, and the SVO information presented in the study. Table 8 shows the means and standard deviations for the participant ratings of the simulation realism for the eight CPCs and two TMCs. In general, the simulation realism ratings were very high. Over 36% of the ratings were either a 9 or 10; only 13% of the ratings were less than 6.

Table 8. Simulation Realism and Research Apparatus Ratings

Question	Low Anchor 1	CPCs Mean (*SD*)	TMCs Mean (*SD*)	High Anchor 10
1. Rate the overall realism of the simulation experience compared to actual ATC operations.	Extremely Unrealistic	8.13 (1.25)	6.00 (2.83)	Extremely Realistic
2. Rate the realism of the simulation hardware compared to actual equipment.	Extremely Unrealistic	7.88 (1.46)	9.50 (0.71)	Extremely Realistic
3. Rate the realism of the simulation software compared to actual functionality.	Extremely Unrealistic	6.75 (1.91)	9.00 (1.41)	Extremely Realistic
4. To what extent did the WAK online workload rating technique interfere with your ATC performance?	None at All	4.00 (2.83)	5.00 (0.00)	A Great Deal

Table 9 shows the means and standard deviations for the participant ratings of the STC and DHV airspace tools for both the CPCs and TMCs. Overall, the participants responded very favorably to the airspace tools in the study. All of the mean ratings for tool impact, helpfulness, and importance were above 7.5. Most of the ratings for information timeliness and saliency were in the mid-range indicating appropriate levels. However, the TMCs mean rating for the timeliness of the airspace status information was 9.0, which indicates a little sooner than optimal.

Table 9. STC and DHV Airspace Tools Ratings

Question	Low Anchor 1	CPCs Mean (*SD*)	TMCs Mean (*SD*)	High Anchor 10
6. How much impact did the SVO have on sector operations?	None at All	7.50 (1.60)	8.00 (2.83)	A Great Deal
7. How much impact did the DHV have on sector operations?	None at All	8.38 (1.30)	9.00 (1.41)	A Great Deal
8. How helpful overall were the new SVO tools on the TSD?	Not Helpful	9.00 (1.31)	8.50 (2.12)	Very Helpful
9. How important is it to use special coding of the STC boundary to indicate the notification time?	Not Important	9.75 (0.46)	8.50 (2.12)	Very Important
10. How important is it to use special coding of the STC boundary to indicate the launch time?	Not Important	9.75 (0.46)	8.50 (2.12)	Very Important
11. How important is it to use special coding to identify aircraft with STC conflicts?	Not Important	9.38 (1.19)	9.00 (1.41)	Very Important
12. How important is it to have aircraft-specific information on the D-side?	Not Important	9.50 (0.76)	8.00 (0.00)	Very Important
13. How important is it to have aircraft-specific information on the R-side?	Not Important	9.88 (0.35)	8.00 (0.00)	Very Important
14. Rate the overall timeliness of the airspace status information (boundary coding).	Too Late	5.88 (1.13)	9.00 (1.41)	Too Soon
15. Rate the overall timeliness of the airspace-conflict information (datablock indicators).	Too Late	4.50 (2.00)	6.50 (2.12	Too Soon
16. Rate the overall salience of the airspace status information (boundary coding).	Too Easily Overlooked	5.43 (0.53)	6.50 (2.12)	Too Distracting
17. Rate the overall salience of the airspace-conflict information (datablock indicators).	Too Easily Overlooked	5.88 (1.13)	6.50 (2.12)	Too Distracting

Table 10 shows the means and standard deviations for the participant ratings of the SVO information for both the CPCs and TMCs. Overall, the participants responded very favorably to the SVO information presented in the study. Most of the mean ratings were over 8.0, indicating that participants agreed that the information was adequate. However, the TMCs mean ratings for information required for safe and efficient operations were 6.0 or 7.0, which are a little lower, but still very good.

Table 10. Space Vehicle Operations Information Ratings

Question	Low Anchor 1	CPCs Mean (*SD*)	TMCs Mean (*SD*)	High Anchor 10
18. The launch related information provided on ERAM/TSD was useful.	Disagree	8.75 (1.39)	9.00 (1.41)	Agree
19. The status of the space vehicle was easy to determine at all times.	Disagree	8.50 (1.69)	9.00 (1.41)	Agree
20. The status of the STC was easy to determine at all times.	Disagree	8.88 (1.36)	8.50 (2.12)	Agree
21. The status of the DHV was easy to determine at all times.	Disagree	8.50 (3.07)	8.50 (2.12)	Agree
22. Overall, the space vehicle operation proceeded smoothly.	Disagree	9.14 (0.69)	9.00 (1.41)	Agree
23. I had all of the information required for maintaining safe and efficient operations prior to the space vehicle operation.	Disagree	8.63 (1.60)	6.00 (1.41)	Agree
24. I had all of the information required for maintaining safe and efficient operations during the space vehicle operation.	Disagree	8.63 (1.77)	7.00 (1.41)	Agree
25. I had all of the information required for maintaining safe and efficient operations during the off-nominal event.	Disagree	8.63 (1.60)	6.00 (0.00)	Agree
26. Overall, the space vehicle operation scenario seemed realistic.	Disagree	8.38 (0.52)	9.00 (1.41)	Agree
27. I expect that space vehicle operations will proceed in reality as they did in this simulation.	Disagree	6.38 (1.85)	8.50 (2.12)	Agree

4. CONCLUSIONS

The purpose of this study was to investigate three key SVO concept components: STCs, Just-in-Time Activation of STCs, and Reactive Separation from Debris Hazards. The study represents a preliminary research effort recruiting experienced CPCs and TMCs to participate in a HITL simulation. The simulation environment included CPCs working at their ERAM workstations and TMCs using their TFMS. The integrated simulation environment at the FAA WJHTC represents a high-fidelity research facility to investigate future ATC concepts, such as SVO.

In the five Launch and ReEntry scenarios that we developed for this study, the participants demonstrated that they could control several aircraft within the STC and make last moment usage of the STC before activation. This represents effective usage of the available airspace using the Just-in-Time Notification concept. In addition, when an off-nominal event occurred, participants were quick to contact aircraft to avoid the DHV and quick to clear aircraft already in the DHV. This represents effective reactive separation in the case of off-nominal events. The participants were the most effective using the SVO concepts during the ReEntry scenarios during nominal conditions. In the Launch scenarios during off-nominal conditions, participants used reactive separation to avoid the large DHV and rerouted aircraft. As expected, flight times increased and operating costs increased during off-nominal scenarios due to rerouting aircraft.

In addition to the SVO concepts, we developed a set of SVO tools for ERAM and the TMU to help participants effectively use the airspace. The tools included visual aids and graphics to identify pre-active STC, active STC, and DHV. We also developed an ERAM decision-support tool on the aircraft datablock to help controllers make last moment usage of the airspace. Although the objective simulation data did not show much benefit using the tools, the participants' subjective ratings of tool effectiveness, helpfulness, and importance were very good. We must note that the controllers did not have much time to train with the tools, and the simulation results could have been better with more practice. Future research and development studies are needed to refine and improve the ERAM and TMU tools to support space vehicle operations.

In conclusion, this study represents an important first step in preparing for increased space vehicle operations in the NAS. The results of the study indicate that the controllers were able to effectively use the SVO concepts we developed in simulation. We also established an important integrated simulation environment where CPCs and TMCs can work together to evaluate future SVO concepts and identify operational issues.

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Acronyms

ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATM	Air Traffic Management
ATWIT	Air Traffic Workload Input Technique
CPC	Certified Professional Controller
Data Comm	Data Communications
DEN	Denver International Airport
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
DHV	Debris Hazard Volume
D-side	Data-side
DTM	Debris Threat Mitigation
ERAM	En Route Automation Modernization
ERP	Engineering Research Psychologist
FAA	Federal Aviation Administration
HITL	Human-In-The-Loop
HRAM	Hazard Risk Assessment and Management
JEDI	Java En Route Development Initiative
JPDO	Joint Planning and Development Office
MAP	Monitor Alert Parameter
MITRE	Massachusetts Institute of Technology Research and Engineering Corp.
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NIEC	NextGen Integration and Evaluation Capability
NTMS	NextGen Traffic Management System
PTT	Push-To-Talk
RDHFL	Research Development and Human Factors Laboratory
R-side	Radar-side
SAA	Specialty Activity Area
SME	Subject Matter Expert
STC	Space Transition Corridor

SVO	Space Vehicle Operations
TFMS	Traffic Flow Management System
TGF	Target Generation Facility
TMC	Traffic Management Coordinator
TMS	Traffic Management System
TMU	Traffic Management Unit
TSD	Traffic Situation Display
URET	User Request Evaluation Tool
VSCS	Voice Switching and Control System
WAK	Workload Assessment Keypad
WJHTC	William J. Hughes Technical Center

Appendix A: Informed Consent Statement

Informed Consent Statement

I, ______________________________, understand that this study, entitled "Space Vehicle Operations (SVO) Debris Threat Mitigation (DTM) Study" is sponsored by the Federal Aviation Administration (FAA) and is being directed by Mr. Daniel R Johnson.

Nature and Purpose:

I have been recruited to volunteer as a participant in this project. The purpose of the study is to investigate Next Generation Air Transportation System (NextGen) concepts for the introduction of space trajectories into existing NAS human and automation systems. The SVO Concept encompasses three key components: Space Transition Corridors, just-in-time activation, and reactive separation from debris hazards. The researchers will use the results of the study to evaluate the operational viability of the concepts and to identify human performance issues.

Experimental Procedures:

A different group of four certified professional controllers (CPC) and one traffic management coordinator (TMC) will be released from their facility for one week to participate in the SVO DTM study. The controllers will travel to the FAA William J. Hughes Technical Center (WJHTC) on Monday. On Tuesday, Wednesday, and Thursday the controllers will participate in the study and perform air traffic scenarios in our laboratory's ATC simulator. The participants will work from 8:00 AM to 4:30 PM each day with a rest break after each traffic scenario and a midday lunch break. At the end of each day, we will have a group meeting to answer the participants' questions and discuss their experiences in the simulation. On the first day of the study, we will brief the participants about the project goals and sectors they will be operating in the simulation. On the last day of the study, we will conduct an exit briefing to gather feedback from participants about the entire study.

The study will consist of three experimental conditions to test the STC just-in-time activation concept and two conditions to test the concept of reactive separation from debris hazard volumes in the two Denver ARTCC sectors that we selected. The participants will perform several practice scenarios in each sector before starting the experimental scenarios. Each participant will perform each of the five conditions as an R-side and D-side controller executing a total of ten scenarios.

After each test scenario, the controllers will complete a questionnaire to evaluate their performance, workload, and situation awareness. In addition, subject matter experts will make over-the-shoulder observations during the simulation to evaluate the effects of the experimental conditions on controller performance. Finally, the simulation software will record aircraft track and status data to produce measures of safety, capacity, efficiency, and communications. We will use the laboratory's audio-visual recording system during the study.

Discomfort and Risks:

I understand that I will not be exposed to any foreseeable risks. The work that I will perform in the study is safe and includes operating traffic scenarios, completing questionnaires, and providing feedback to the researchers about my simulation experience.

Anonymity and Confidentiality:

My participation is strictly confidential. All information that I provide will be anonymous to the experimenters. I understand that a participant code will be attached to my data for research purposes. My name and identity will not be released in any reports. All data collected in the study will be used for scientific purposes and must be kept confidential by law. Laboratory personnel will not disclose or release any Personally Identifiable Information (PII) to any FAA personnel or elsewhere, or publish it in any report, except as may be required by statute. I understand that situations when PII may be disclosed are discussed in detail in FAA Order 1280.18 "Protecting Personally Identifiable Information (PII)."

Benefits:

I understand that the only benefit to me is that I will be able to provide the researchers with valuable feedback and insight about my experiences in the simulation. My data will help the FAA to safely implement the NextGen concept examined in the study.

Participant Responsibilities:

I am aware that to participate in this study I must be a certified professional controller who is qualified at an air traffic control facility and holds a current medical certificate. I will control traffic and answer any questions asked during the study to the best of my abilities. I will not discuss the content of the experiment with anyone until the study is completed on November 20, 2014.

Participant's Assurances:

I understand that my participation in this study is completely voluntary, and I have the freedom to withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they feel this to be in my best interest. I have not given up any of my legal rights or released any individual or institution from liability for negligence.

Mr. Johnson has adequately answered all the questions I have asked about this study. I understand that Mr. Johnson or another member of the research team will be available to answer any other questions that I may have as the study proceeds. If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Mr. Johnson at (609) 485-7464.

Compensation and Injury:

I agree to immediately report any injury or suspected adverse effect to Mr. Daniel R. Johnson at (609) 485-7464. Local clinics and hospitals will provide any treatment, if necessary. I agree to provide, if requested, copies of all insurance and medical records arising from any such care for injuries/medical problems.

Signature Lines:

I have read this informed consent statement. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, if I want to, I may have a copy of this statement.

Research Participant:______________________________________ Date:__________

Investigator:____ Date:__________

Witness:____ Date:__________

Appendix B: Biographical Questionnaire

Biographical Questionnaire

Instructions:

This questionnaire is designed to obtain information about your background and experience as a Certified Professional Controller (CPC). Researchers will only use this information to describe the participants in this study as a group. Your identity will remain anonymous.

1. What is your **gender**?	○ Male	○ Female

2. What is your **age**?	_____ years _____ months

3. How long have you worked as an **ATCS (include both FAA and military experience)**?	_____ years _____ months

4. How long have you worked as a **CPC for the FAA**?	_____ years _____ months

5. How long have you worked as a **TMC for the FAA**?	_____ years _____ months
5b. How long since you worked traffic full time?	_____ years _____ months
5c. How long since you maintained dual currency?	_____ years _____ months

6. How long have you **actively controlled traffic** in the en route environment?	_____ years _____ months

7. How long have you **actively controlled traffic** in the terminal environment?	_____ years _____ months

8. How many of the **past 12 months** have you actively controlled traffic?	_____ months

9. Rate your current **skill as a CPC/TMC**.	Not Skilled	①②③④⑤⑥⑦⑧⑨⑩	Extremely Skilled

10. Rate your **level of motivation** to participate in this study.	Not Motivated	①②③④⑤⑥⑦⑧⑨⑩	Extremely Motivated

11. Do you have previous ATC **experience with space vehicle operations** at your facility?	○ Yes	○ No

11a. On average, how may **space vehicle operations** do you handle per month?	_____ per month

11b. In your work experience, how did **space vehicle operations affect the ATC services** in your position?	Unfavorable Effect	①②③④⑤⑥⑦⑧⑨	Favorable Effect

Please list the **types of space vehicle operations** that you have worked:

____

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Comments:

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Appendix C: Post-Scenario Questionnaire

Post-Scenario Questionnaire

Instructions:

Please answer the following questions based upon your experience in the scenario just completed. Circle one number to indicate your response to each item. Your identity will remain anonymous.

Performance

1. Rate your **performance for separating aircraft safely** during this scenario.	Extremely Poor	1 2 3 4 5 6 7 8 9 10	Extremely Good
2. Rate your **performance for moving aircraft efficiently** during this scenario.	Extremely Poor	1 2 3 4 5 6 7 8 9 10	Extremely Good

Workload

3. Rate your **workload due to scanning for aircraft conflicts** during this scenario.	Extremely Low	1 2 3 4 5 6 7 8 9 10	Extremely High
4. Rate your **workload due to separating aircraft** effectively during this scenario.	Extremely Low	1 2 3 4 5 6 7 8 9 10	Extremely High
5. Rate your **workload due to separating aircraft from STC/DHV** effectively during this scenario.	Extremely Low	1 2 3 4 5 6 7 8 9 10	Extremely High
6. Rate your **workload due to ensuring smooth traffic flow** during this scenario.	Extremely Low	1 2 3 4 5 6 7 8 9 10	Extremely High
7. Rate your **workload due to communicating to pilots** during this scenario.	Extremely Low	1 2 3 4 5 6 7 8 9 10	Extremely High
8. Rate your **workload due to coordination with other sectors** during this scenario.	Extremely Low	1 2 3 4 5 6 7 8 9 10	Extremely High
9. Rate your **workload due to collaborating with your teammate.**	Extremely Low	1 2 3 4 5 6 7 8 9 10	Extremely High

Situation Awareness

10. Rate your **situation awareness for aircraft conflicts with STC/DHV**.	Extremely Poor	1 2 3 4 5 6 7 8 9 10	Extremely Good
11. Rate your **situation awareness for identifying opportunities for efficient aircraft routing** during this scenario.	Extremely Poor	1 2 3 4 5 6 7 8 9 10	Extremely Good

Scenario Difficulty

12. Rate the **difficulty** of this scenario.	Extremely Easy	1 2 3 4 5 6 7 8 9 10	Extremely Difficult

Effectiveness of Workstation Tools

13. What tools did you use to aid you in separating aircraft from the Space Transition Corridor or Debris Hazard Volumes?
    - ☐ Aircraft List
    - ☐ Continuous Flight Plan Readout
    - ☐ Graphic Plan Display
    - ☐ STC/DHV outline
    - ☐ Vector lines
    - ☐ QU command to display route
    - ☐ R-side line-zero indicators on datablocks
    - ☐ Other (please explain) – ____________________

Rate the **effectiveness of the tools you used in this scenario** for performing these ATC tasks:

14. Detecting aircraft-to-airspace conflicts	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly
15. Maintaining situation awareness for aircraft-to-airspace conflicts	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly
16. Resolving aircraft-to-airspace conflicts	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly
17. Routing or planning flights	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly
18. Managing sector/position resources	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly
19. Supporting just-in-time STC activation	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly
20. Managing STC before notification	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly
21. Managing STC after notification	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly
22. Managing STC during activation	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly
23. Supporting reactive separation from DHV	Hindered greatly	1 2 3 4 5 6 7 8 9 10	Helped greatly

General Comments

24. Provide any additional comments or clarifications about your experience in this scenario.

Appendix D: Exit Questionnaire

Exit Questionnaire

Instructions:

Please answer the following questions based upon your overall experience in the simulation. Your identity will remain anonymous.

Simulation Realism and Research Apparatus Ratings

1. Rate the overall realism of the simulation experience compared to actual ATC operations.	Extremely Unrealistic	1 2 3 4 5 6 7 8 9 10	Extremely Realistic
2. Rate the realism of the simulation hardware compared to actual equipment.	Extremely Unrealistic	1 2 3 4 5 6 7 8 9 10	Extremely Realistic
3. Rate the realism of the simulation software compared to actual functionality.	Extremely Unrealistic	1 2 3 4 5 6 7 8 9 10	Extremely Realistic
4. To what extent did the WAK online workload rating technique interfere with your ATC performance?	None At All	1 2 3 4 5 6 7 8 9 10	A Great Deal

5. Provide any comments or suggestions for improvement regarding our simulation capabilities.

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Airspace Conflict Information Location and Format

These questions pertain to the presentation of information concerning aircraft conflicts with closed airspace in the scenario just completed. Circle one digit to indicate your response to each item.

6. How much impact did SVO have on sector operations?	None at all	1 2 3 4 5 6 7 8 9 10	Very much
7. How much impact did DHV have on sector operations?	None at all	1 2 3 4 5 6 7 8 9 10	Very much
8. How helpful overall were the new SVO tools on the TSD?	Not helpful	1 2 3 4 5 6 7 8 9 10	Very helpful
9. How important is it to use special coding of the STC boundary to indicate the notification time?	Not important	1 2 3 4 5 6 7 8 9 10	Very important
10. How important is it to use special coding of the STC boundary to indicate the launch time?	Not important	1 2 3 4 5 6 7 8 9 10	Very important
11. How important is it to use special coding to identify aircraft with STC conflicts?	Not important	1 2 3 4 5 6 7 8 9 10	Very important
12. How important is it to have aircraft-specific information on the D-side?	Not important	1 2 3 4 5 6 7 8 9 10	Very important
13. How important is it to have aircraft-specific information on the R-side?	Not important	1 2 3 4 5 6 7 8 9 10	Very important
14. Rate the overall timeliness of the airspace status information. (boundary coding)	Too late	1 2 3 4 5 6 7 8 9 10	Too soon
15. Rate the overall timeliness of the airspace-conflict information. (datablock indicators)	Too late	1 2 3 4 5 6 7 8 9 10	Too soon
16. Rate the overall salience ('attention-getting-ness') of the airspace status information. (boundary coding)	Too easily overlooked	1 2 3 4 5 6 7 8 9 10	Too distracting
17. Rate the overall salience of the airspace-conflict information. (datablock indicators)	Too easily overlooked	1 2 3 4 5 6 7 8 9 10	Too distracting

Space Vehicle Operations Concepts

These statements pertain to the presentation of information related to SVO concepts. Circle one digit to indicate your agreement with each item.

18. The launch related information provided on ERAM/TSD was useful.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree
19. The status of the space vehicle was easy to determine at all times.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree
20. The status of the STC was easy to determine at all times.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree
21. The status of the DHV was easy to determine at all times.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree
22. Overall, the space vehicle operation proceeded smoothly.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree
23. I had all of the information required for maintaining safe and efficient operations **prior to** the space vehicle operation.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree
24. I had all of the information required for maintaining safe and efficient operations **during** the space vehicle operation.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree
25. I had all of the information required for maintaining safe and efficient operations during **the off-nomial event**.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree
26. Overall, the space vehicle operation scenario seemed realistic.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree
27. I expect that space vehicle operations will proceed in reality as they did in this simulation.	Disagree	1 2 3 4 5 6 7 8 9 10	Agree

28. In this simulation the STC resembles an SAA. Is this a good or bad idea? Why/why not?

29. In this simulation the DHVs resemble SAA. Is this a good or bad idea? Why/why not?

30. What additional information would you like to be displayed about the STC?

31. What additional information would you like to be displayed about the DHV?

32. What additional information would you like to be displayed about aircraft with STC conflicts?

33. What additional information would you like to be displayed about aircraft with DHV conflicts?

34. What information was displayed in this study that was not helpful? Could it have been presented in a more useful form, or was it not needed at all?

____

____

35. What information was displayed in this study that was most helpful?

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36. Was there any additional information needed to help you manage traffic flows before or during the operation?

____

____

37. Are there any additional tools that would have been helpful before or during the operation?

____

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38. If you could make any changes to the procedures followed in the scenario to make them more effective in the "real world" what would you change?

____

____

39. What additional support could TMC/TMU provide for SVO?

____

____

General Comments

40. Is there anything about the study that we should have asked or that you would like to comment about?

Appendix E: Observer Rating Form

Observer Rating Form

Instructions

This form is designed to be used by supervisory air traffic control specialists (SATCSs) to evaluate the effectiveness of controllers working in simulation environments. SATCSs will observe and rate the performance of controllers in several different performance dimensions using the scale below as a general purpose guide. Use the entire scale range as much as possible. Take extensive notes on what you see. Do not depend on your memory. Write down your observations. Space is provided after each scale for comments. You may make preliminary ratings during the course of the scenario. However, wait until the scenario is finished before making your final ratings and remain flexible until the end when you have had an opportunity to see all the available behavior. At all times please focus on what you actually see and hear. This includes what the controller does and what you might reasonably infer from the actions of the pilots. If you do not observe relevant behavior or the results of that behavior, then you may leave a specific rating blank. Also, please write down any comments that may help improve this evaluation form. Do not write your name on the form itself. You will not be identified by name. An observer code known only to yourself and the researchers conducting this study will be assigned to you. The observations you make do not need to be restricted to the performance areas covered in this form and may include other areas that you think are important.

Assumptions

ATC is a complex activity that contains both observable and unobservable behavior. There are so many complex behaviors involved that no observational rating form can cover everything. A sample of the behaviors is the best that can be achieved, and a good form focuses on those behaviors that controllers themselves have identified as the most relevant in terms of their overall performance. Most controller performance is at or above the minimum standards regarding safety and efficiency. The goal of the rating system is to differentiate performance above this minimum. The lowest rating should be assigned for meeting minimum standards and also for anything below the minimum since this should be a rare event. It is important for the observer/rater to feel comfortable using the entire scale and to understand that all ratings should be based on behavior that is actually observed.

I - MAINTAINING SAFE AND EFFICIENT TRAFFIC FLOW	
	Poor ----------- Excellent
1. Maintaining Separation and Resolving Potential Conflicts • using control instructions that maintain appropriate aircraft and airspace separation • detecting and resolving impending conflicts early • recognizing the need for speed restrictions and wake turbulence separation	**1 2 3 4 5 6 7 8**
2. Sequencing Aircraft Efficiently • using efficient and orderly spacing techniques for arrival, departure, and en route aircraft • maintaining safe arrival and departure intervals that minimize delays	**1 2 3 4 5 6 7 8**
3. Using Control Instructions Effectively/Efficiently • providing accurate navigational assistance to pilots • issuing economical clearances that result in need for few additional instructions to handle aircraft completely • ensuring clearances require minimum necessary flight path changes	**1 2 3 4 5 6 7 8**
4. Overall Safe and Efficient Traffic Flow Scale Rating	**1 2 3 4 5 6 7 8**

II - MAINTAINING ATTENTION AND SITUATION AWARENESS	
	Poor ----------- Excellent
5. Maintaining Awareness of Aircraft Positions • avoiding fixation on one area of the radar scope when other areas need attention • using scanning patterns that monitor all aircraft on the scope	**1 2 3 4 5 6 7 8**
6. Giving and Taking Handoffs in a Timely Manner • ensuring handoffs are initiated/accepted in a timely manner • ensuring that handoffs are made according to procedures	**1 2 3 4 5 6 7 8**
7. Ensuring Positive Control • tailoring control actions to situation • using effective procedures for handling heavy, emergency, and unusual traffic situations	**1 2 3 4 5 6 7 8**
8. Detecting Pilot Deviations from Control Instructions • ensuring that pilots follow assigned clearances correctly • correcting pilot deviations in a timely manner	**1 2 3 4 5 6 7 8**
9. Correcting Own Errors in a Timely Manner • acting quickly to correct errors • changing an issued clearance when necessary to expedite traffic flow	**1 2 3 4 5 6 7 8**
10. Overall Attention and Situation Awareness Scale Rating	**1 2 3 4 5 6 7 8**

III – PRIORITIZING								
	Poor			**-----------**				**Excellent**
11. Taking Actions in an Appropriate Order of Importance • resolving situations that need immediate attention before handling low priority tasks • issuing control instructions in a prioritized, structured, and timely manner	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
12. Preplanning Control Actions • scanning adjacent sectors to plan for future and conflicting traffic	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
13. Handling Control Tasks for Several Aircraft • shifting control tasks between several aircraft when necessary • communicating in timely fashion while sharing time with other actions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
14. Overall Prioritizing Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

IV – PROVIDING CONTROL INFORMATION								
	Poor			**-----------**				**Excellent**
15. Providing Essential Air Traffic Control Information • providing mandatory services and advisories to pilots in a timely manner • exchanging essential information	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
16. Providing Additional Air Traffic Control Information • providing additional services when workload permits • exchanging additional information	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
17. Providing Coordination • providing effective and timely coordination • using proper point-out procedures	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
18. Overall Providing Control Information Scale Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

V – TECHNICAL KNOWLEDGE	
	Poor ----------- Excellent
19. Showing Knowledge of LOAs and SOPs • controlling traffic as depicted in current LOAs and SOPs • performing handoff procedures correctly	**1 2 3 4 5 6 7 8**
20. Showing Knowledge of Aircraft Capabilities and Limitations • using appropriate speed, vectoring, and/or altitude assignments to separate aircraft with varied flight capabilities • issuing clearances that are within aircraft performance parameters	**1 2 3 4 5 6 7 8**
21. Showing Effective Use of Equipment • updating data blocks • using equipment capabilities	**1 2 3 4 5 6 7 8**
22. Overall Technical Knowledge Scale Rating	**1 2 3 4 5 6 7 8**

VI – COMMUNICATING	
	Poor ----------- Excellent
23. Using Proper Phraseology • using words and phrases specified in the 7110.65 • using phraseology that is appropriate for the situation • using minimum necessary verbiage	**1 2 3 4 5 6 7 8**
24. Communicating Clearly and Efficiently • speaking at the proper volume and rate for pilots to understand • speaking fluently while scanning or performing other tasks • ensuring clearance delivery is complete, correct and timely • speaking with confident, authoritative tone of voice	**1 2 3 4 5 6 7 8**
25. Listening to Pilot Readbacks and Requests • correcting pilot readback errors • acknowledging pilot or other controller requests promptly • processing requests correctly in a timely manner	**1 2 3 4 5 6 7 8**
26. Overall Communicating Scale Rating	**1 2 3 4 5 6 7 8**

I - Maintaining Safe and Efficient Traffic Flow
II - Maintaining Attention and Situation Awareness
III – Prioritizing
IV – Providing Control Information
V – Technical Knowledge
VI – Communicating

Appendix F: Post-Scenario Questionnaire Ratings

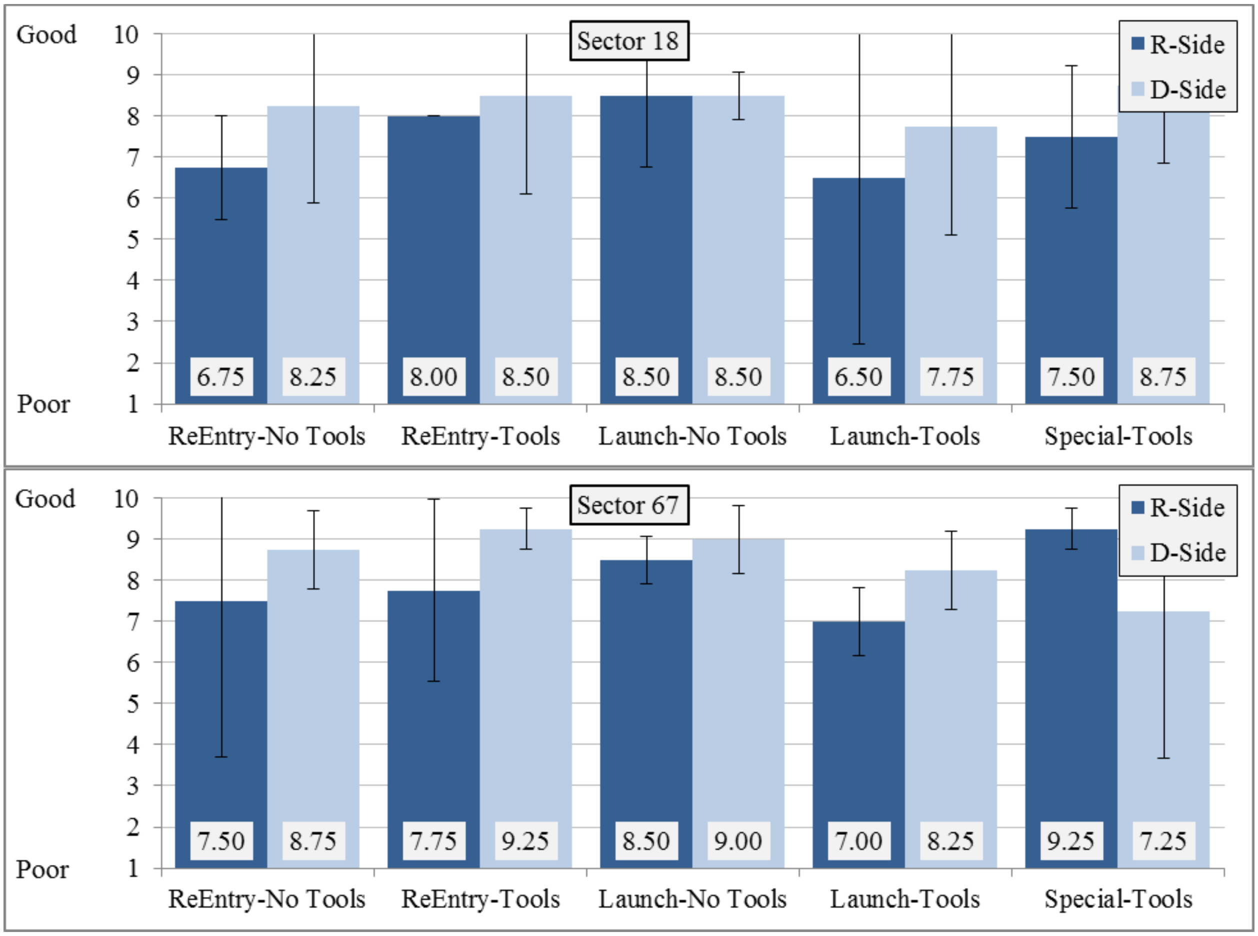

Figure F1. Rate your performance for separating aircraft safely during this scenario.

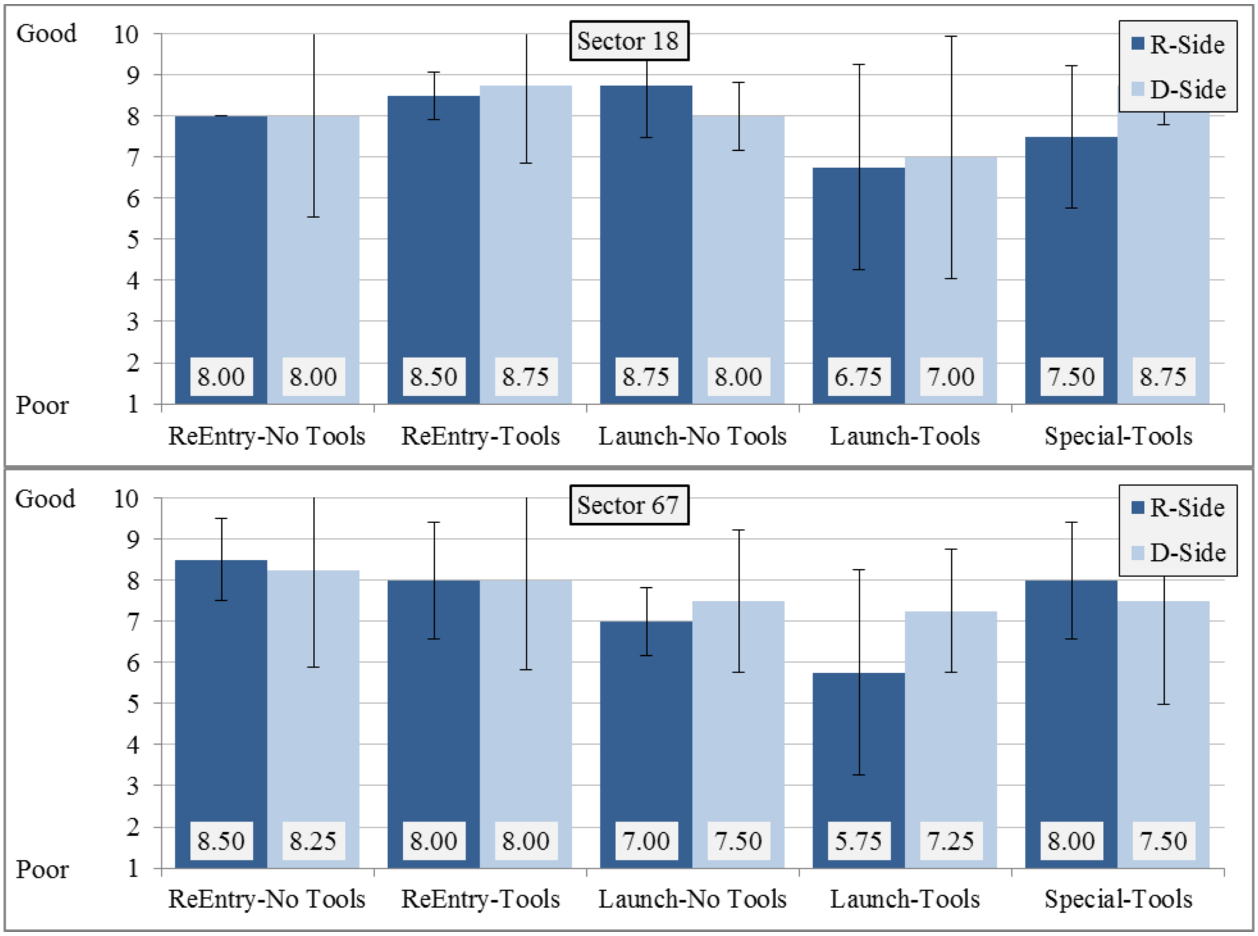

Figure F2. Rate your performance for moving aircraft efficiently during this scenario.

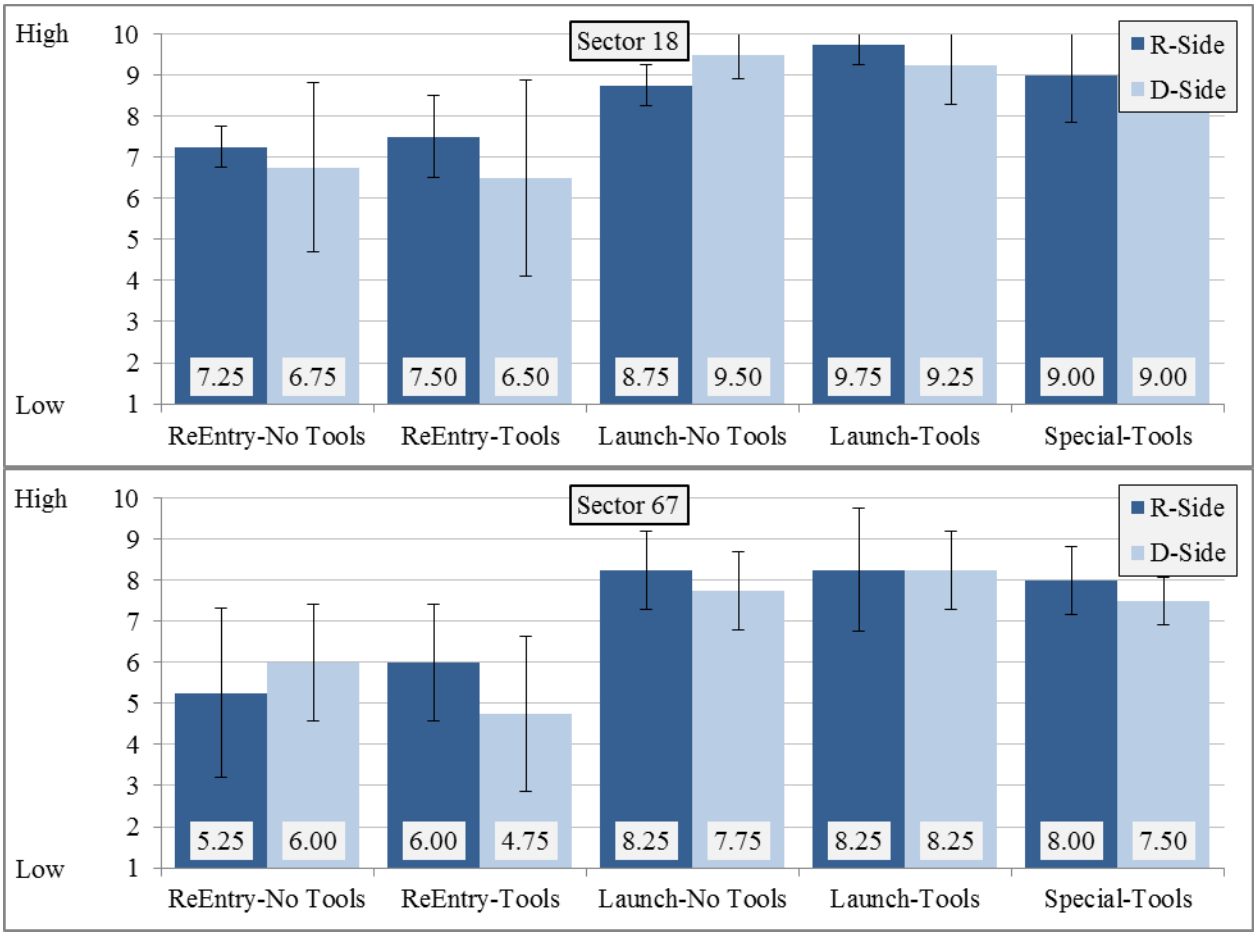

Figure F3. Rate your workload due to scanning for aircraft conflicts during this scenario.

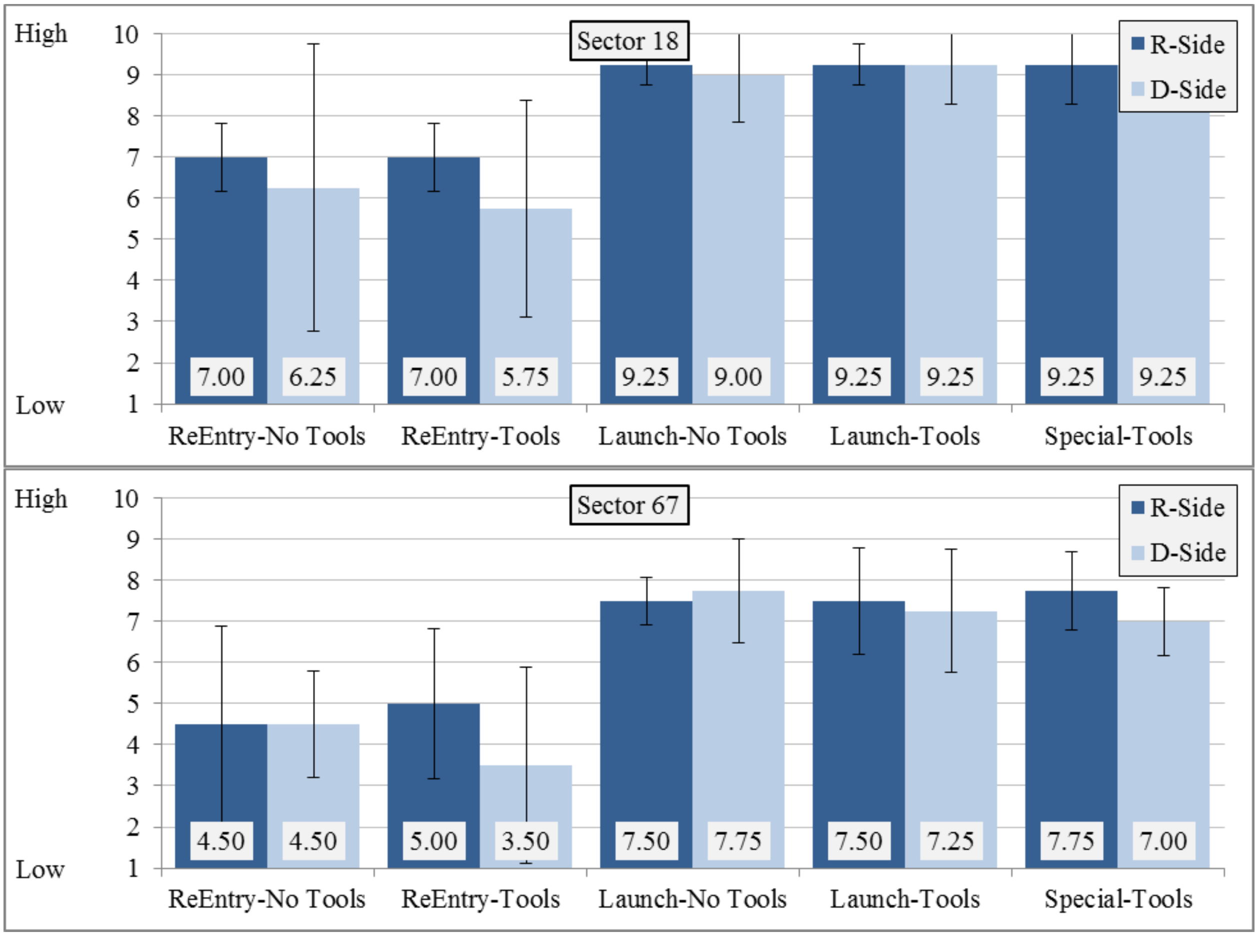

Figure F4. Rate your workload due to separating aircraft effectively during this scenario.

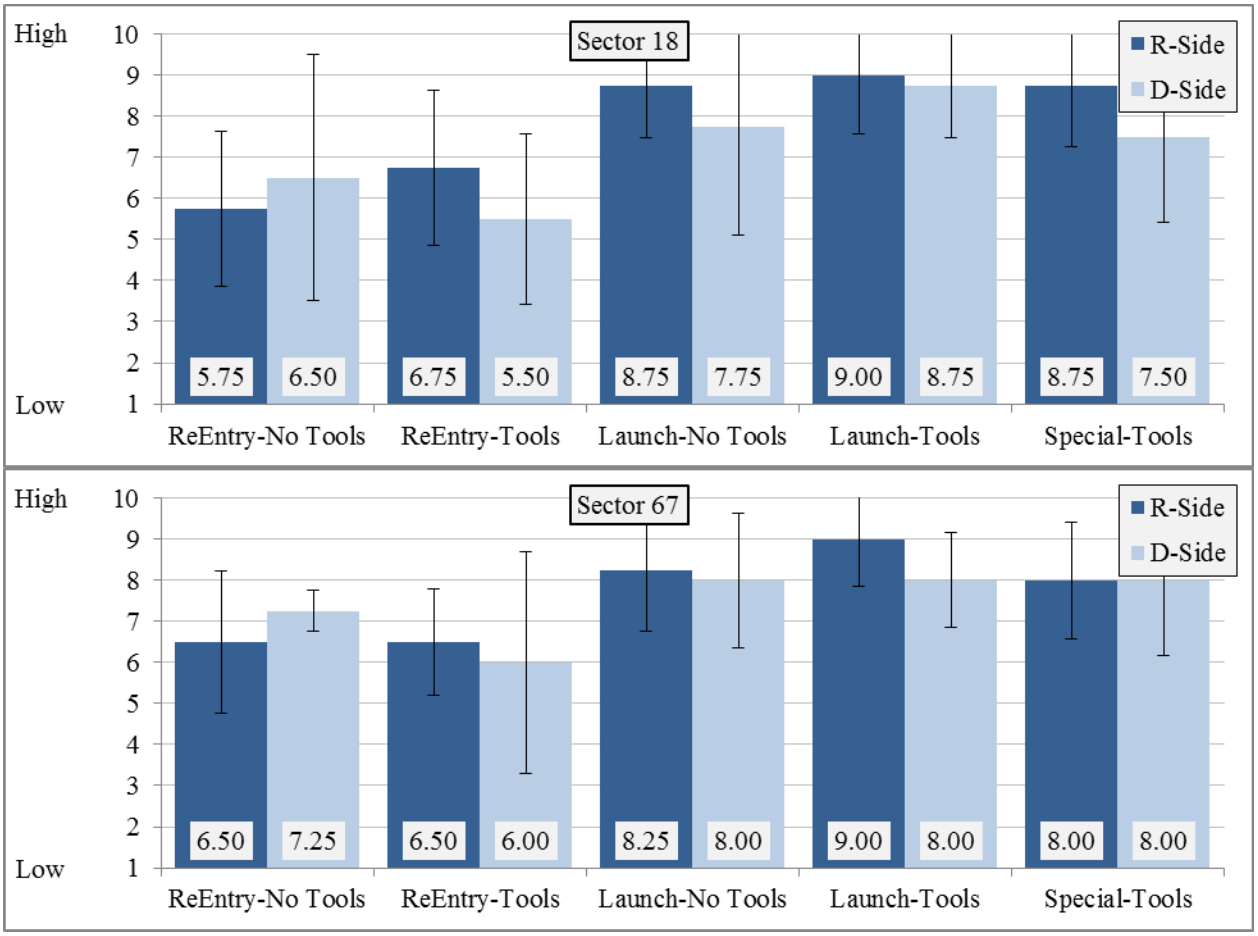

Figure F5. Rate your workload due to separating aircraft effectively from the STC/DHV during this scenario.

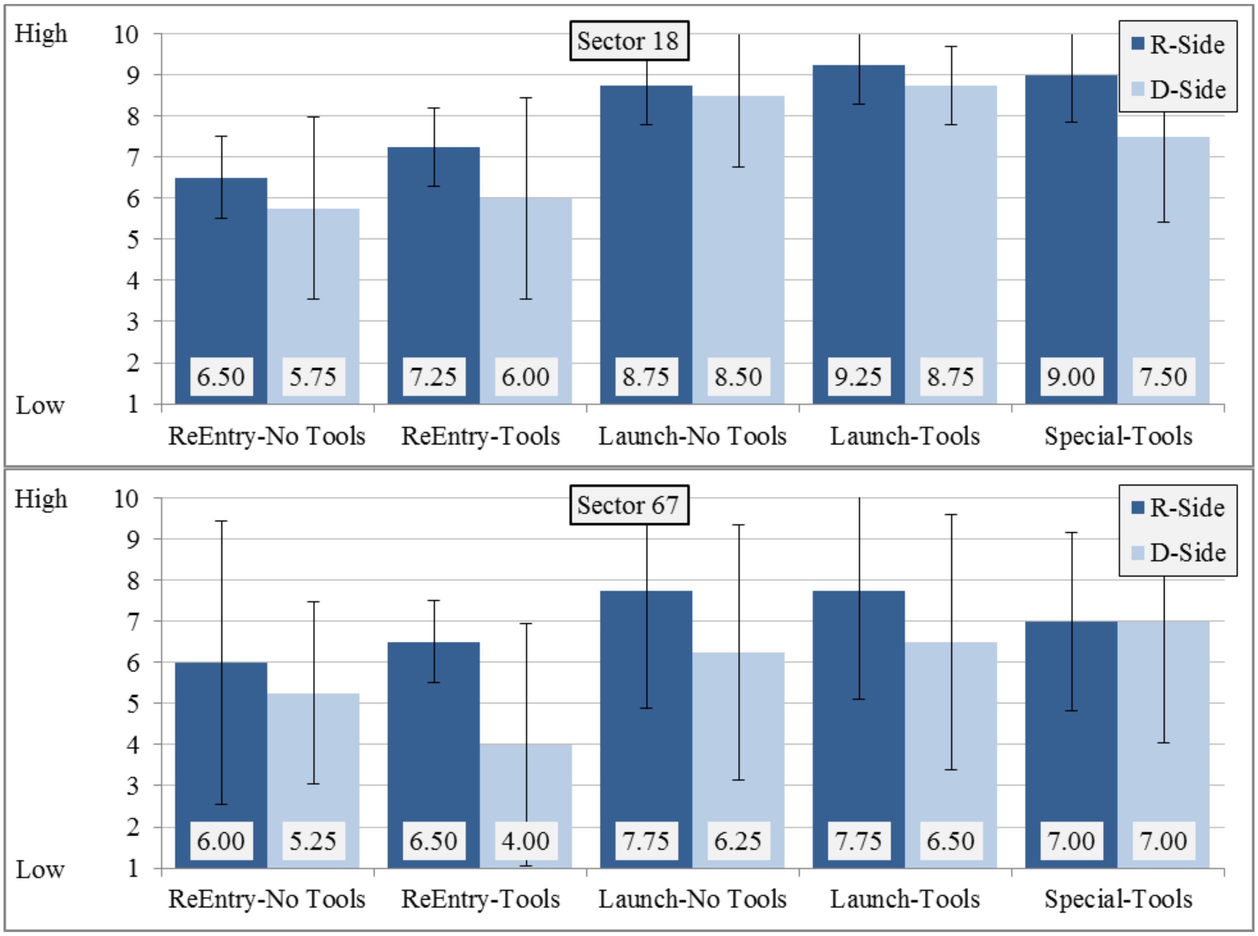

Figure F6. Rate your workload due to ensuring smooth traffic flow during this scenario.

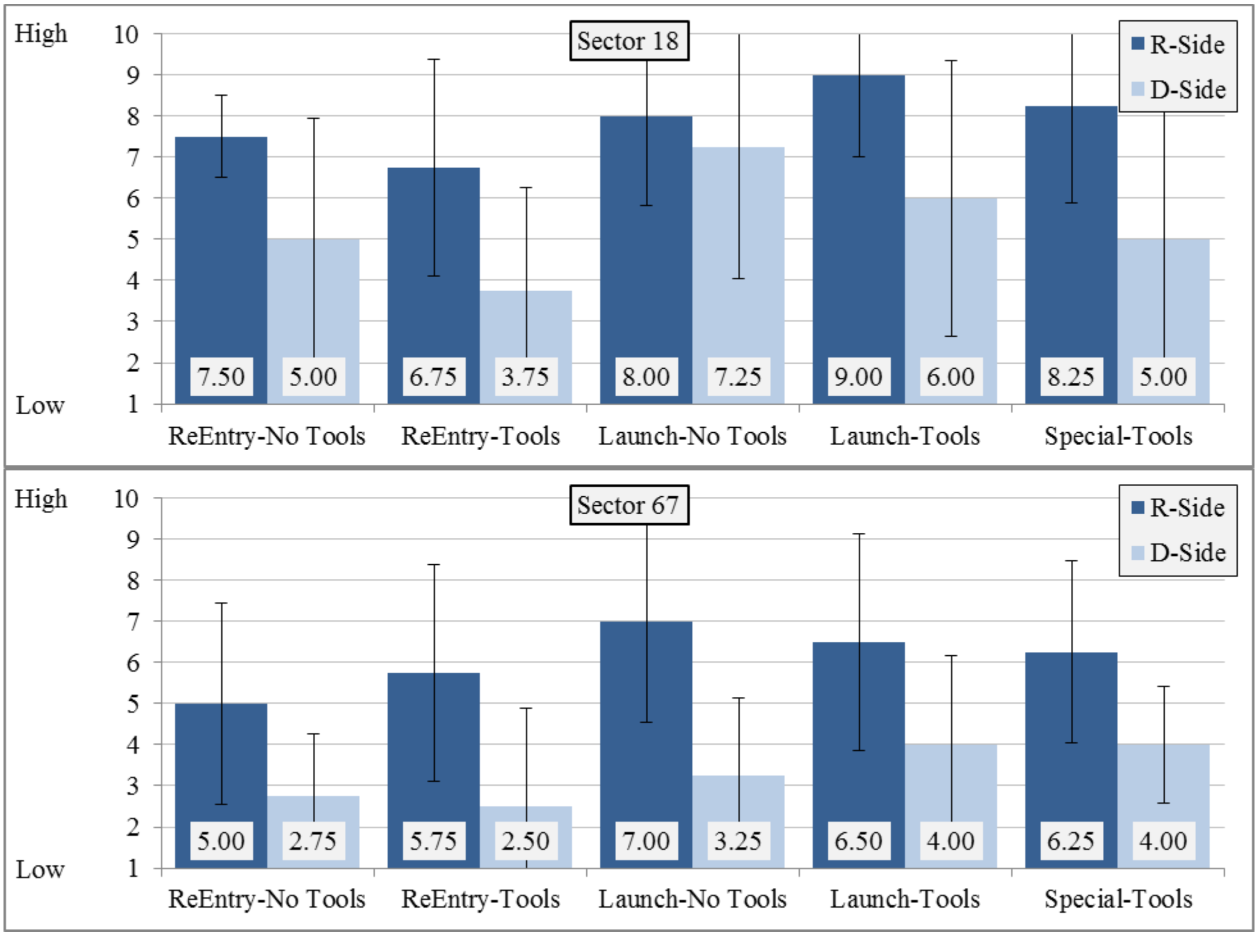

Figure F7. Rate your workload due to communicating to pilots during this scenario.

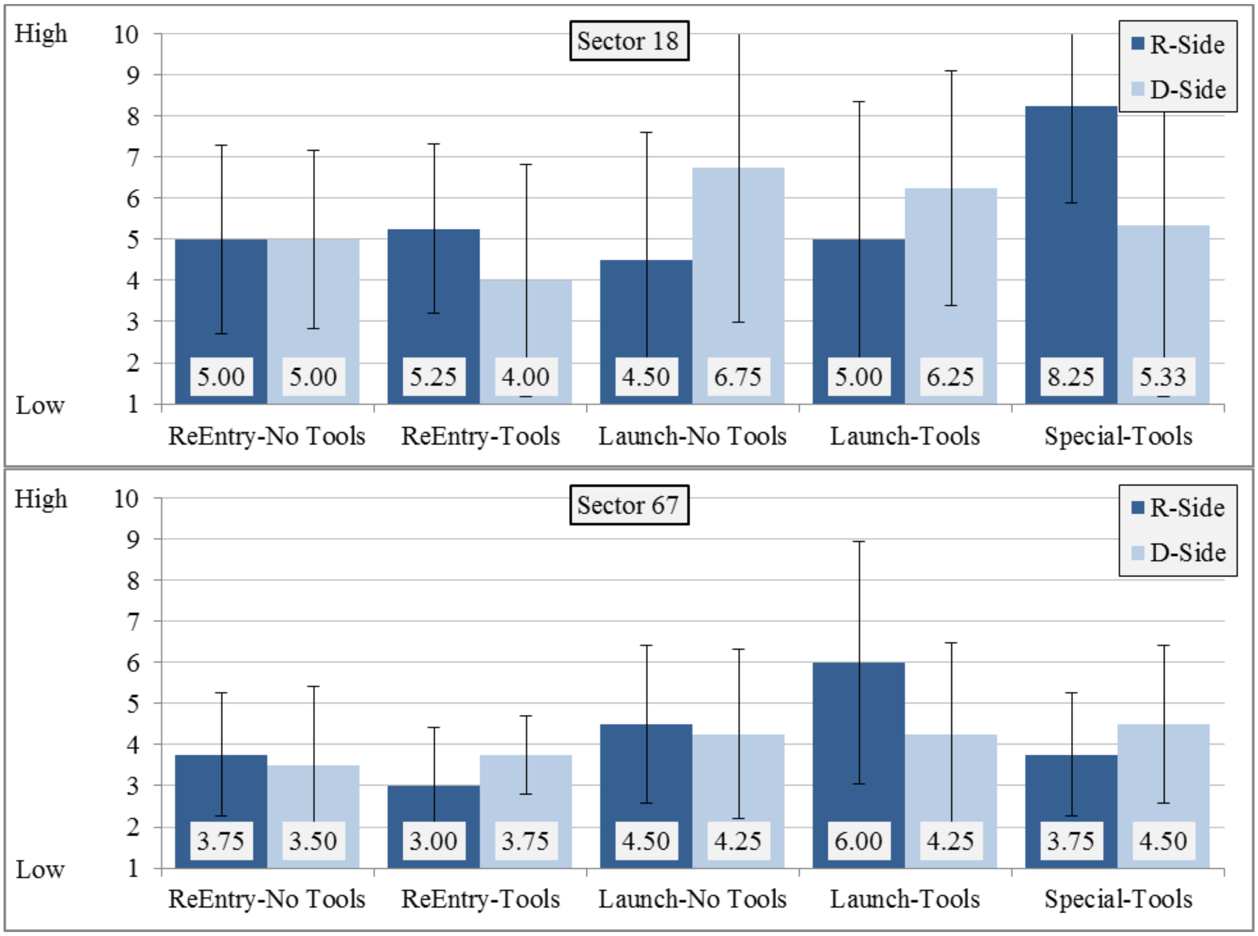

Figure F8. Rate your workload due to coordination with other sectors during this scenario.

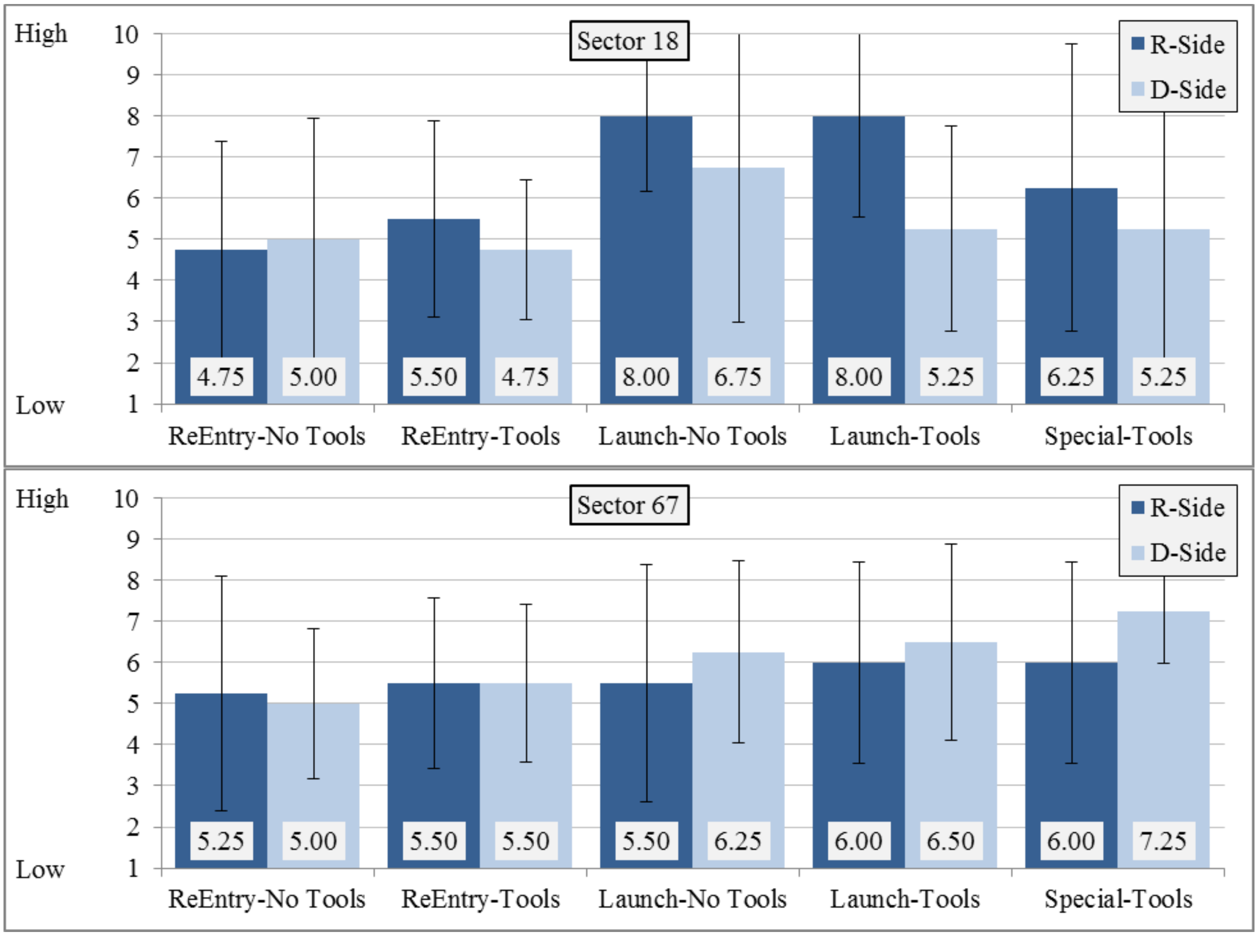

Figure F9. Rate your workload due to collaborating with your teammate.

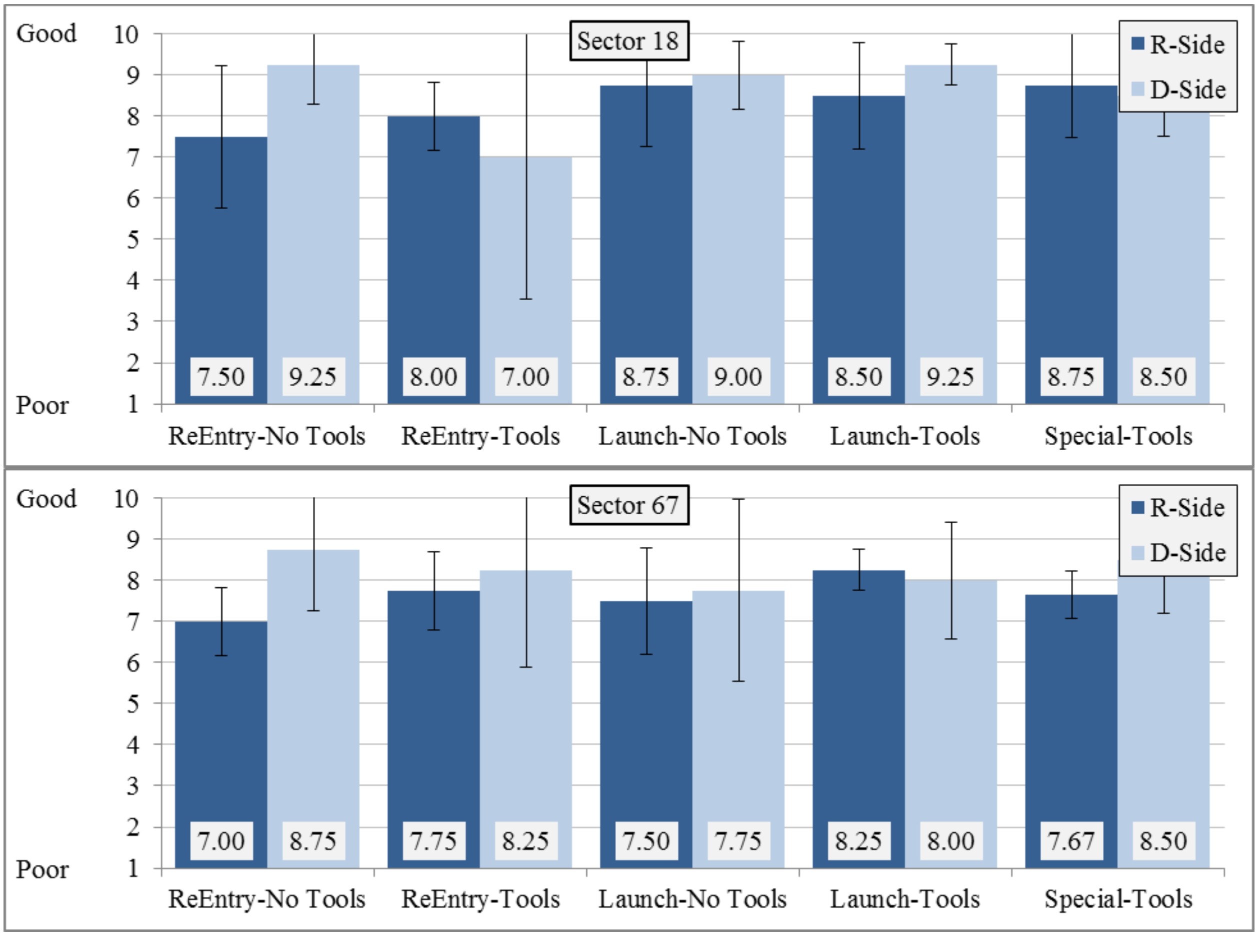

Figure F10. Rate your situation awareness for aircraft conflicts with the STC/DHV.

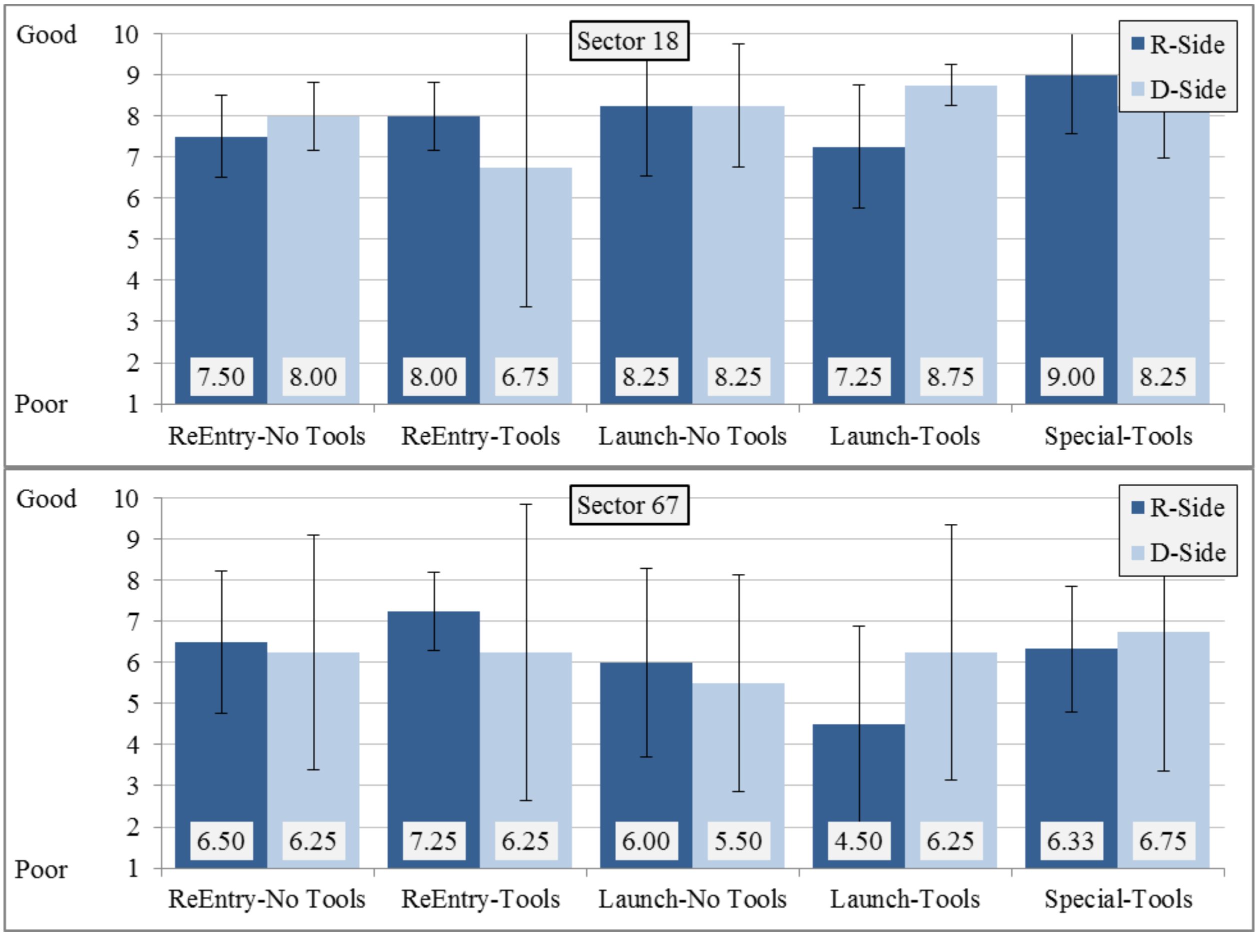

Figure F11. Rate your situation awareness for identifying opportunities for efficient aircraft routing during this scenario.

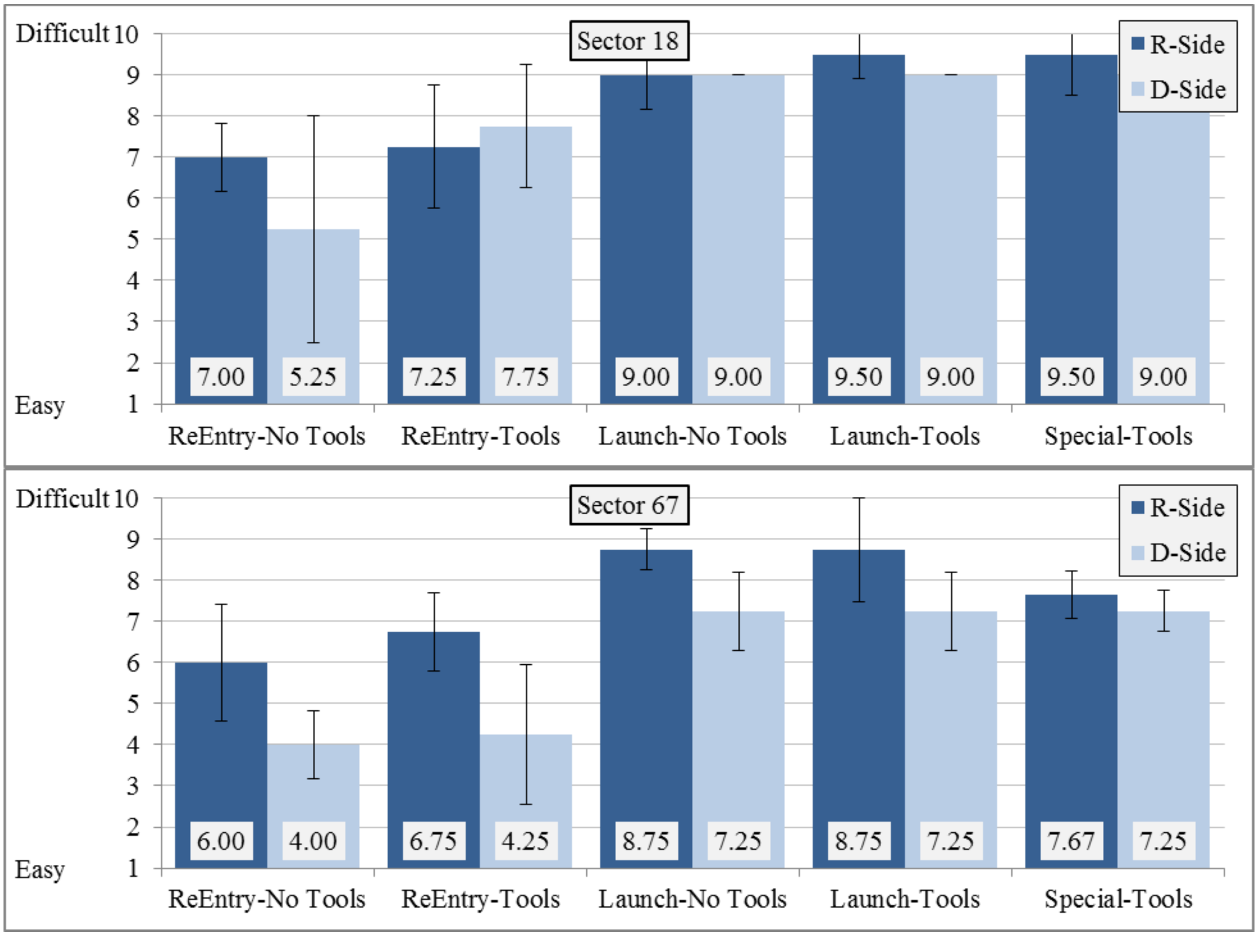

Figure F12. Rate the difficulty of this scenario.

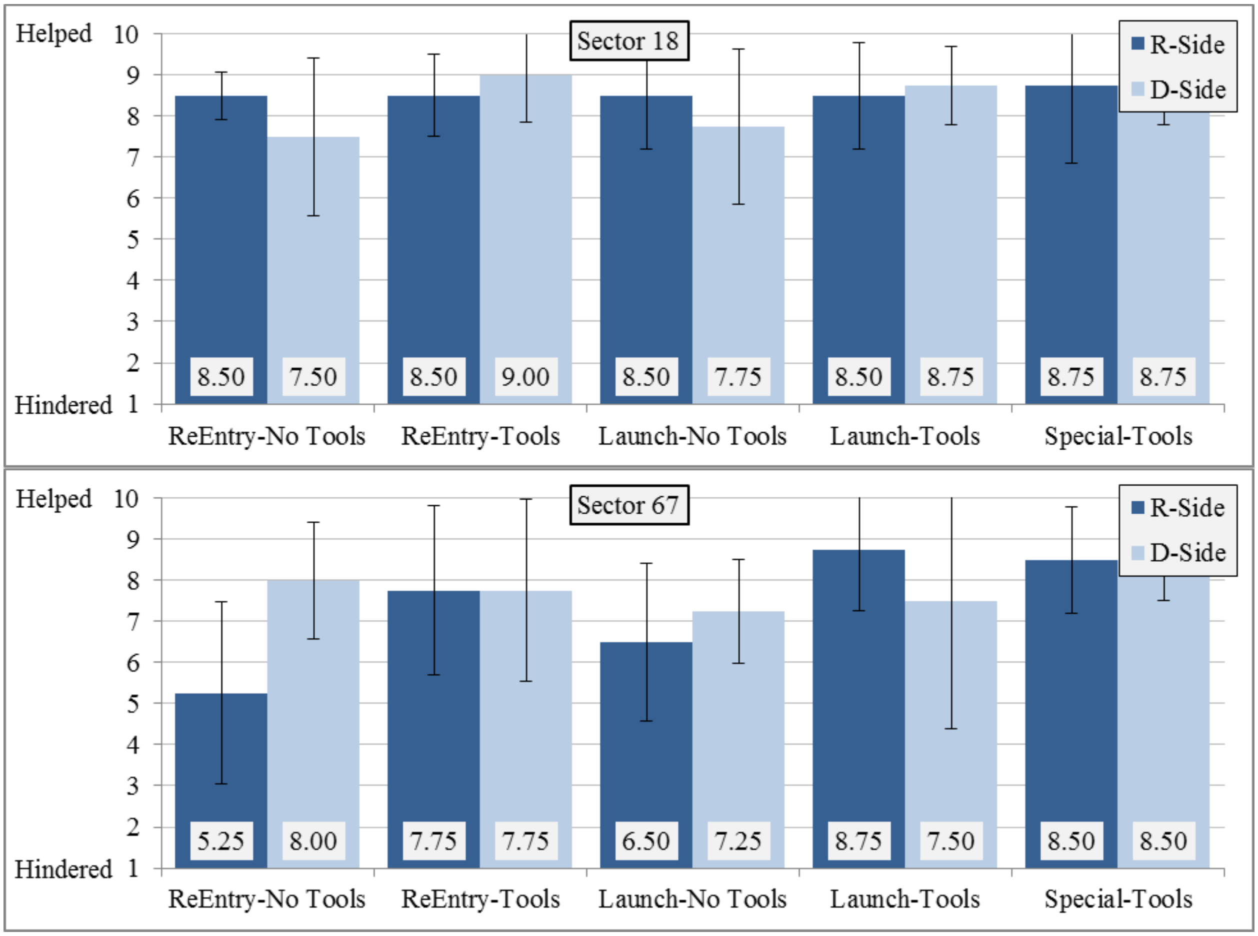

Figure F13. Detecting aircraft-to-airspace conflicts.

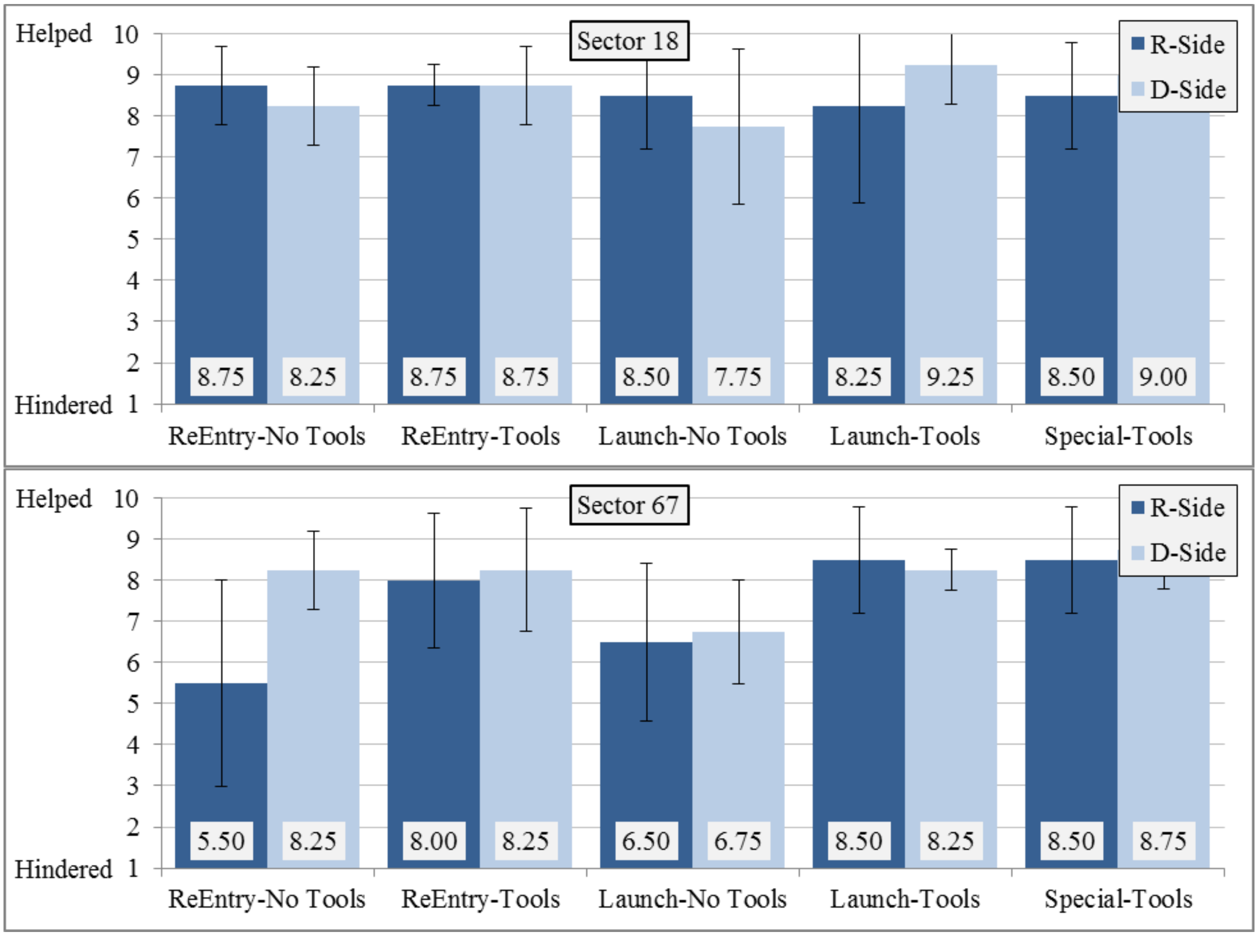

Figure F14. Maintaining situation awareness for aircraft-to-airspace conflicts.

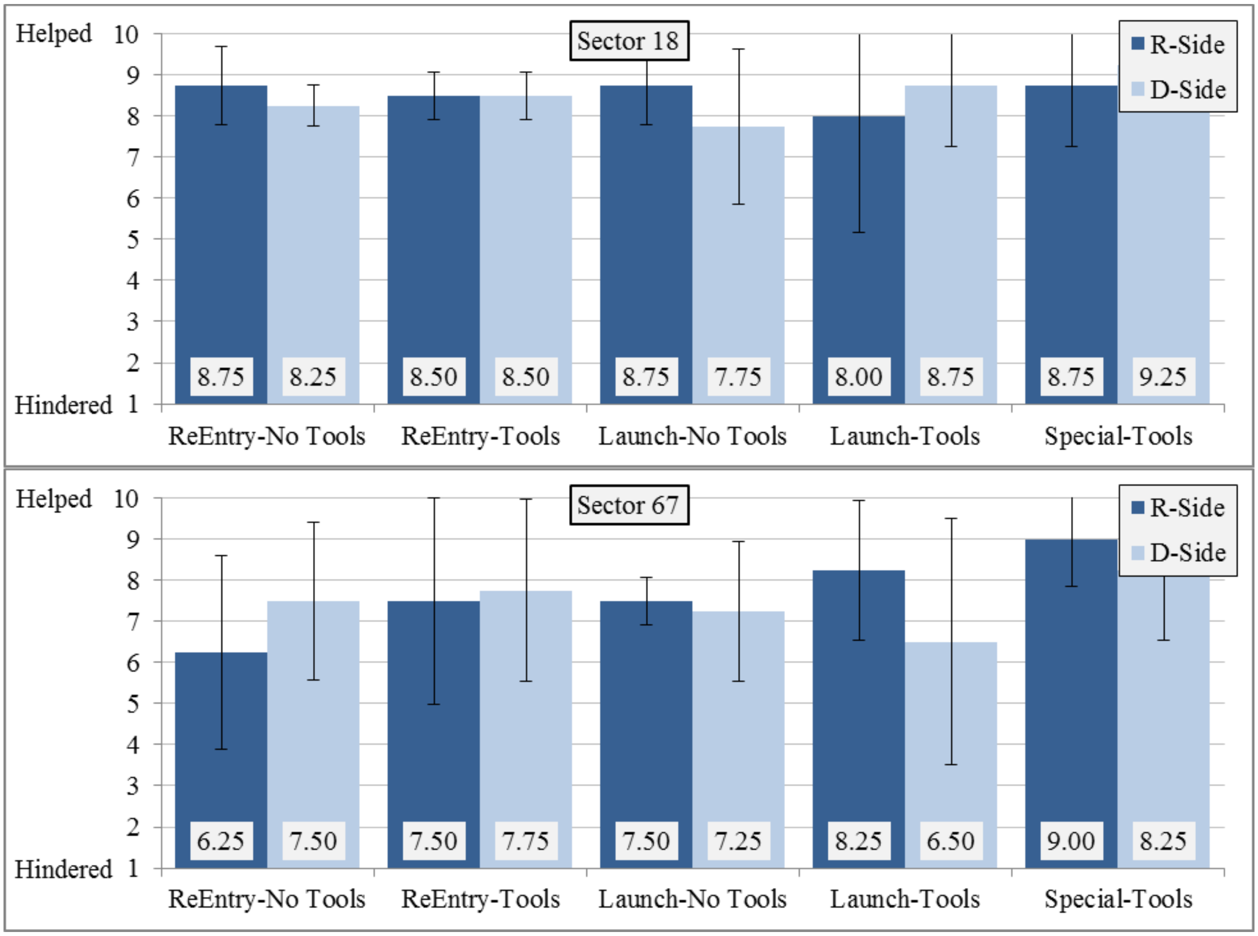

Figure F15. Resolving aircraft-to-airspace conflicts.

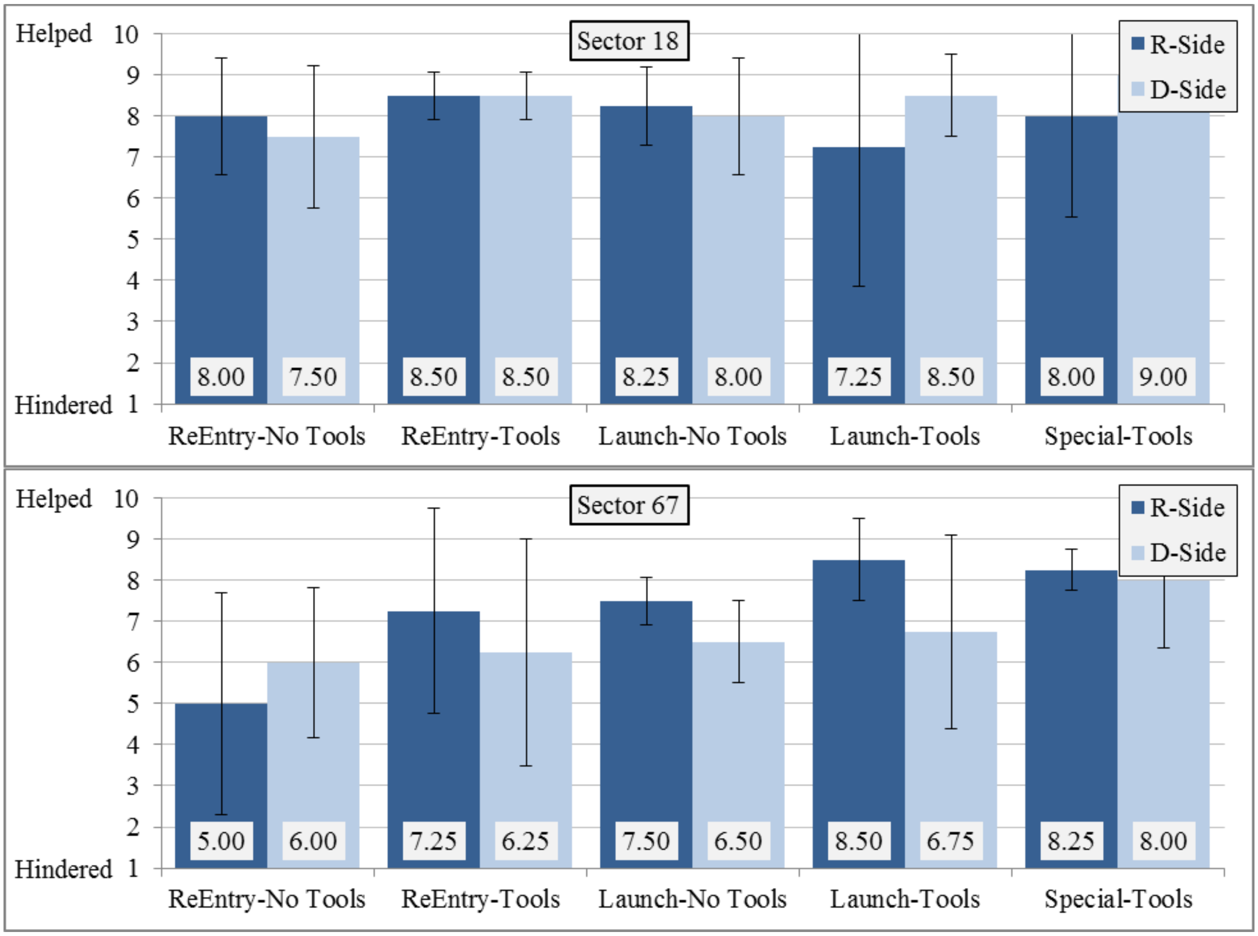

Figure F16. Routing or planning flights.

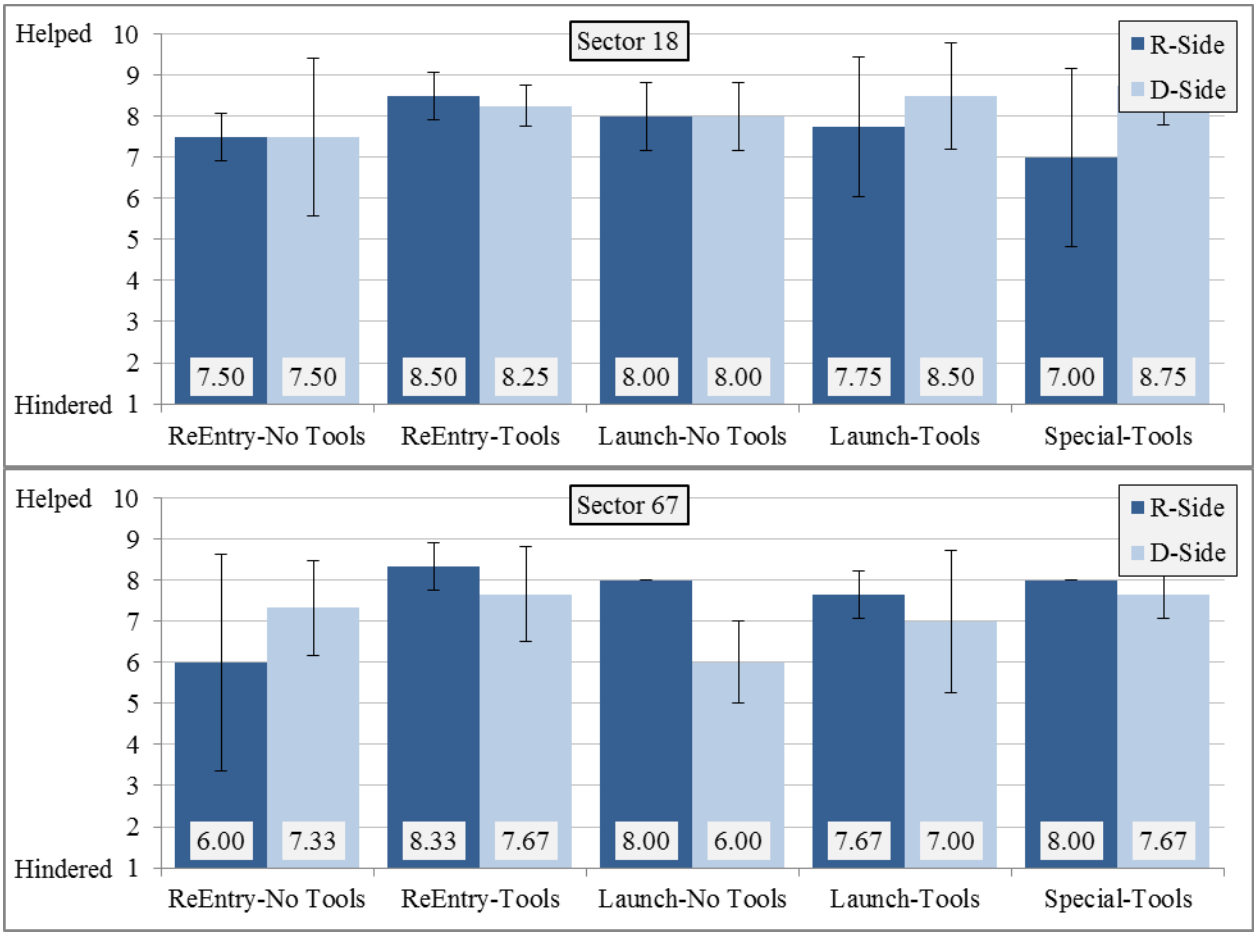

Figure F17. Managing sector/position resources.

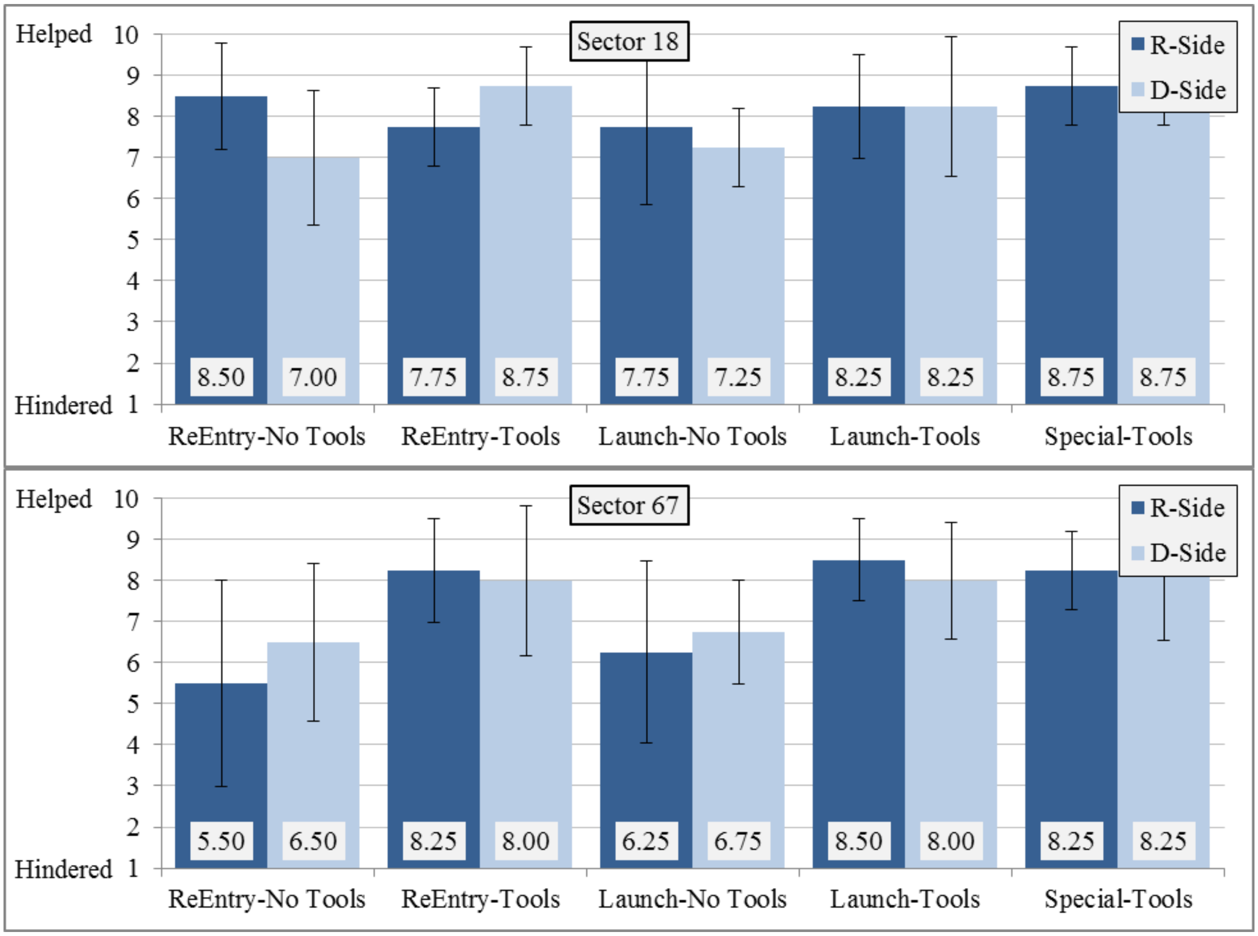

Figure F18. Supporting the just-in-time STC activation.

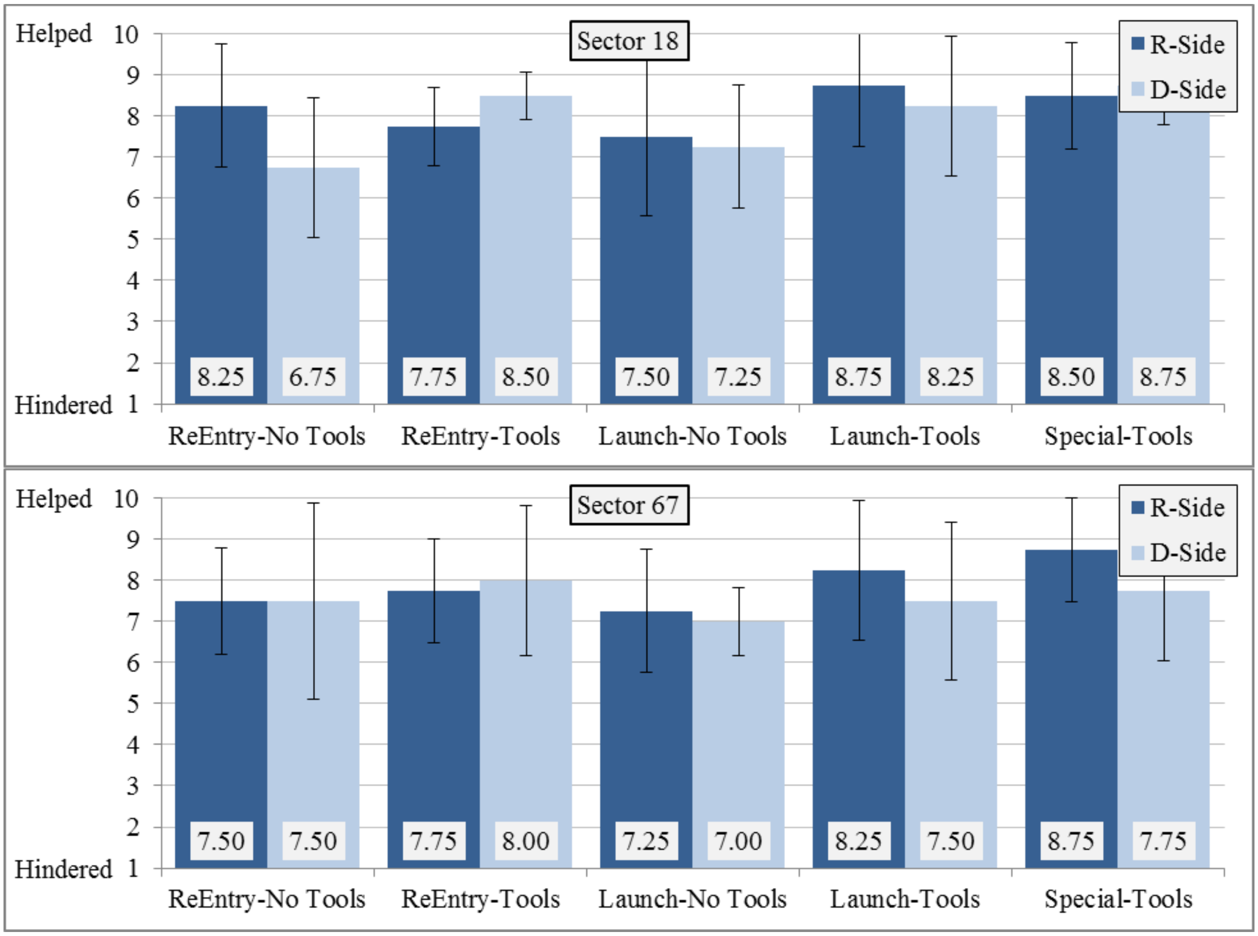

Figure F19. Managing the STC before notification.

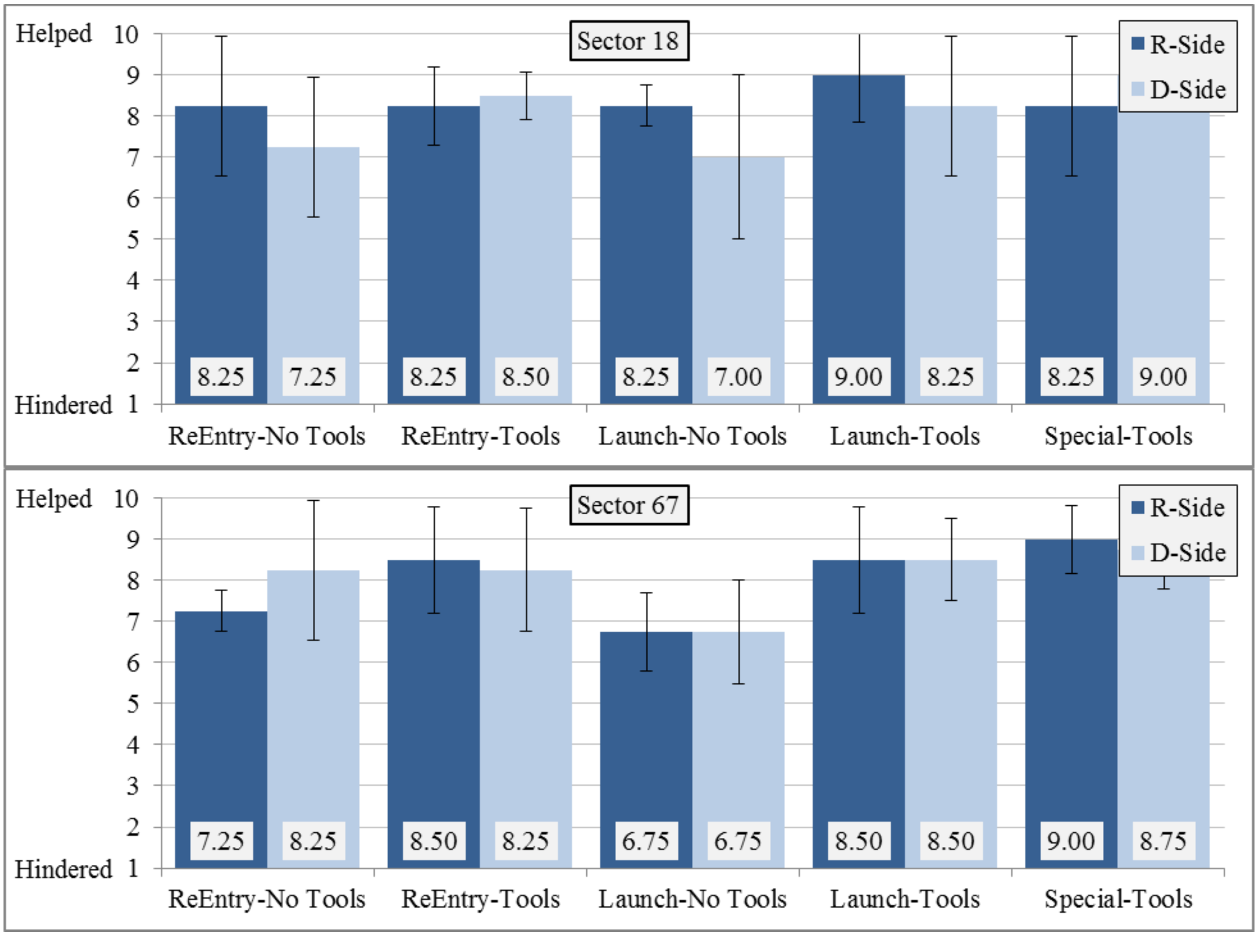

Figure F20. Managing the STC after notification.

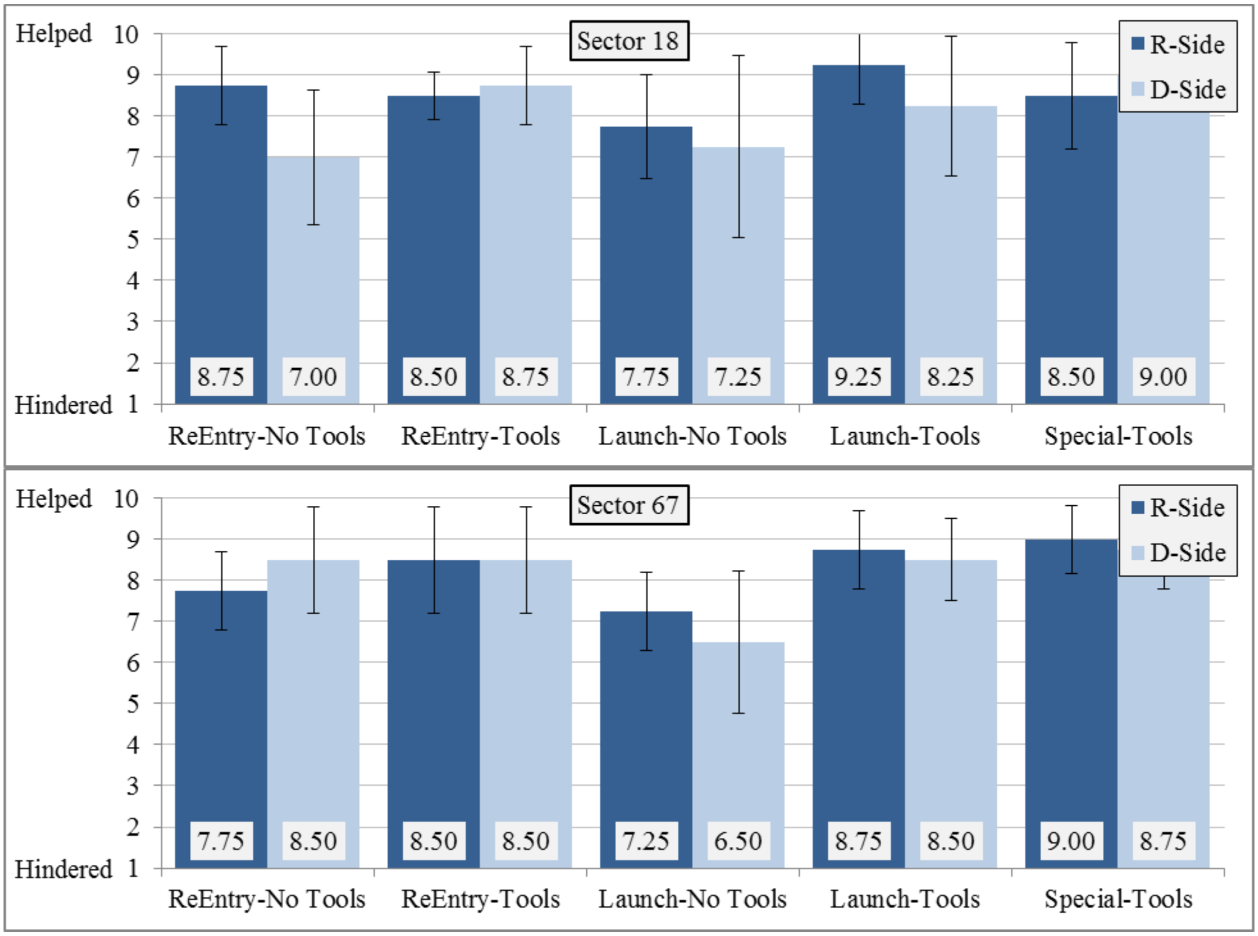

Figure F21. Managing the STC during activation.

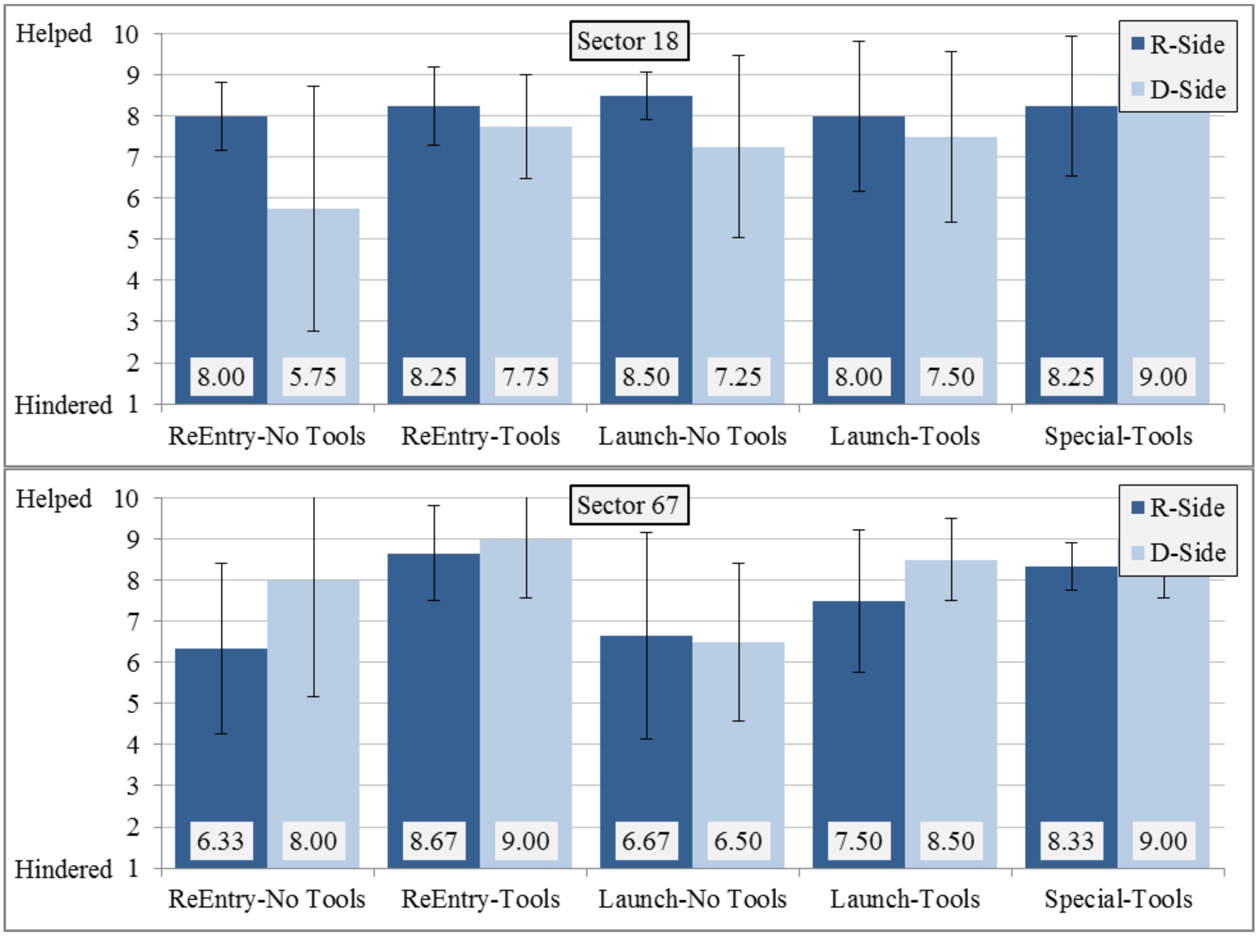

Figure F22. Supporting reactive separation from the DHV.

Appendix G: Observer Ratings

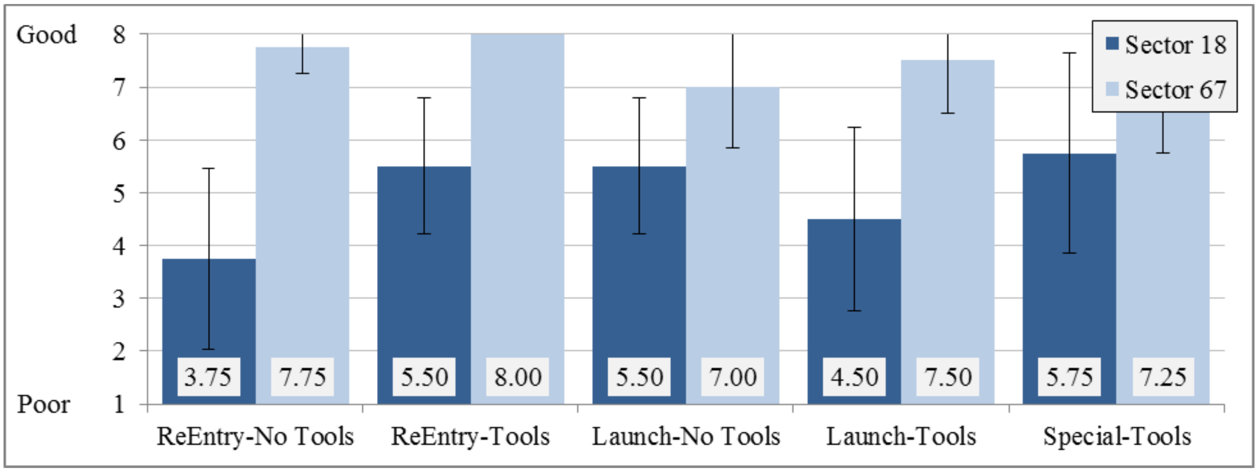

Figure G1. Maintaining separation and resolving potential conflicts.

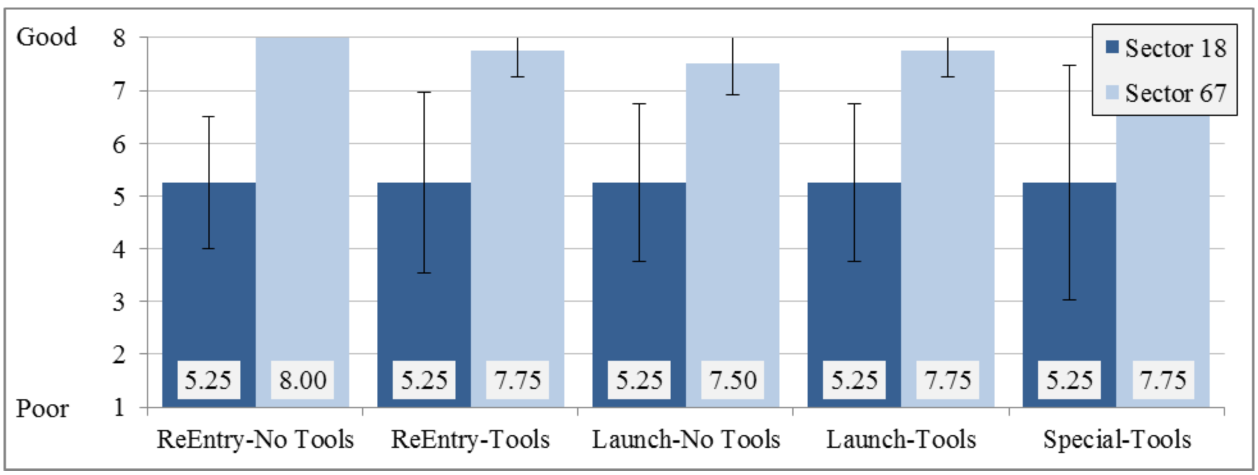

Figure G2. Sequencing aircraft efficiently.

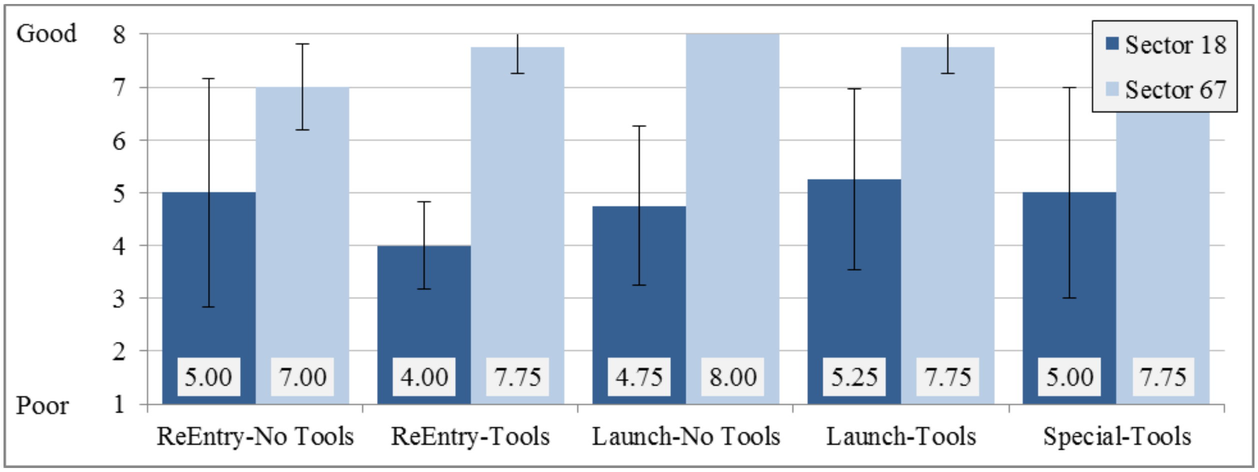

Figure G3. Using control instructions effectively/efficiently.

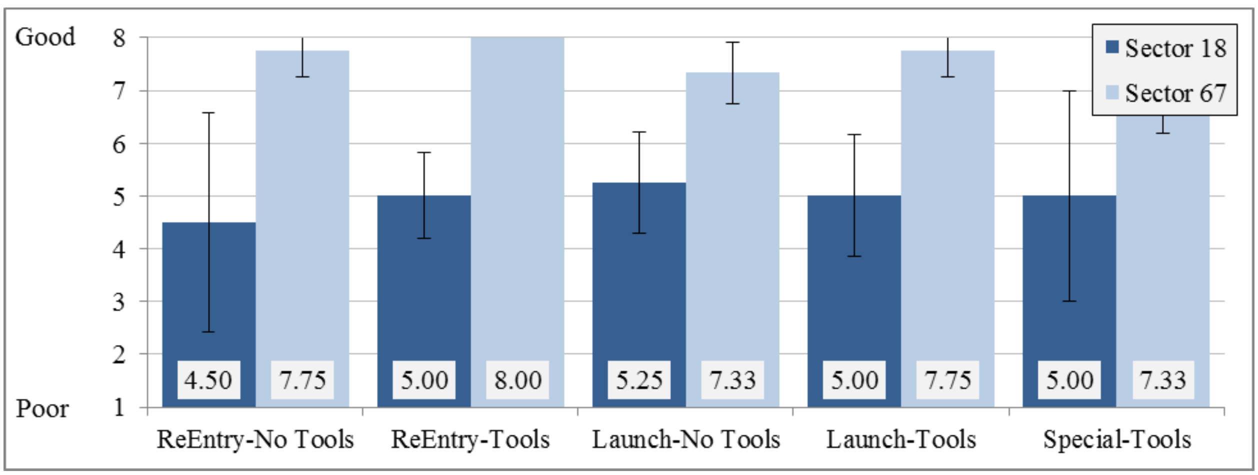

Figure G4. Overall safe and efficient traffic flow scale rating.

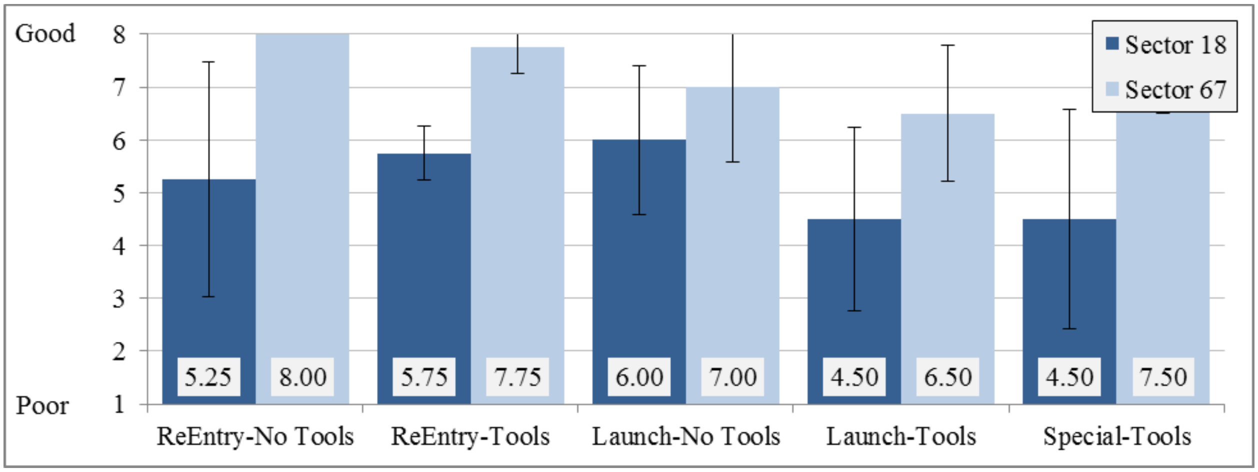

Figure G5. Maintaining awareness of aircraft positions.

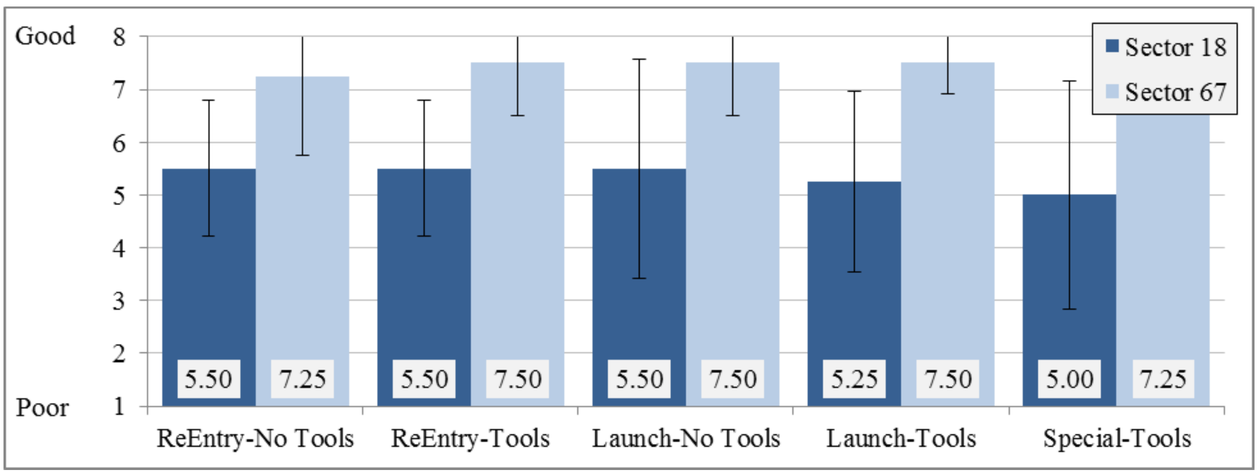

Figure G6. Giving and taking handoffs in a timely manner.

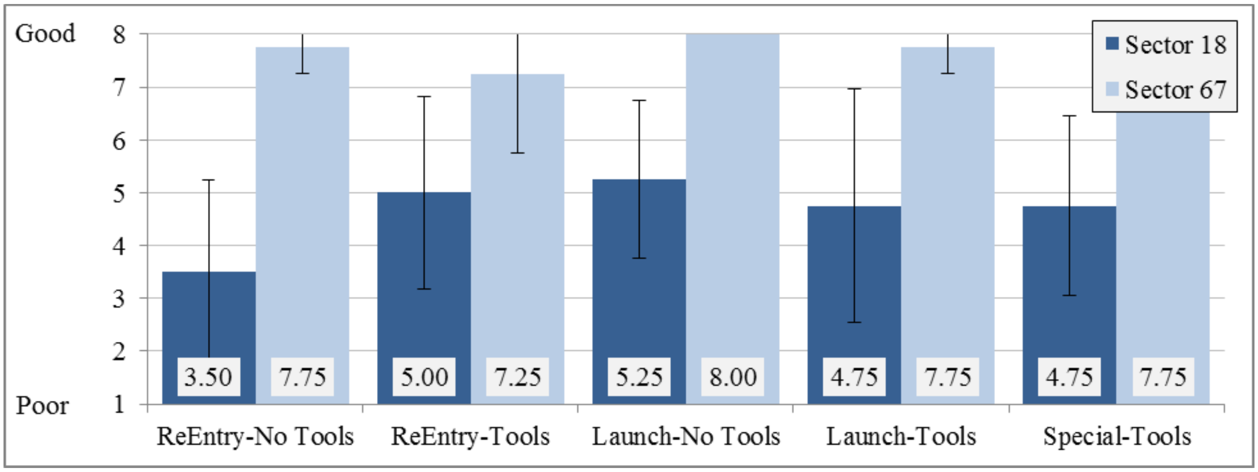

Figure G7. Ensuring positive control.

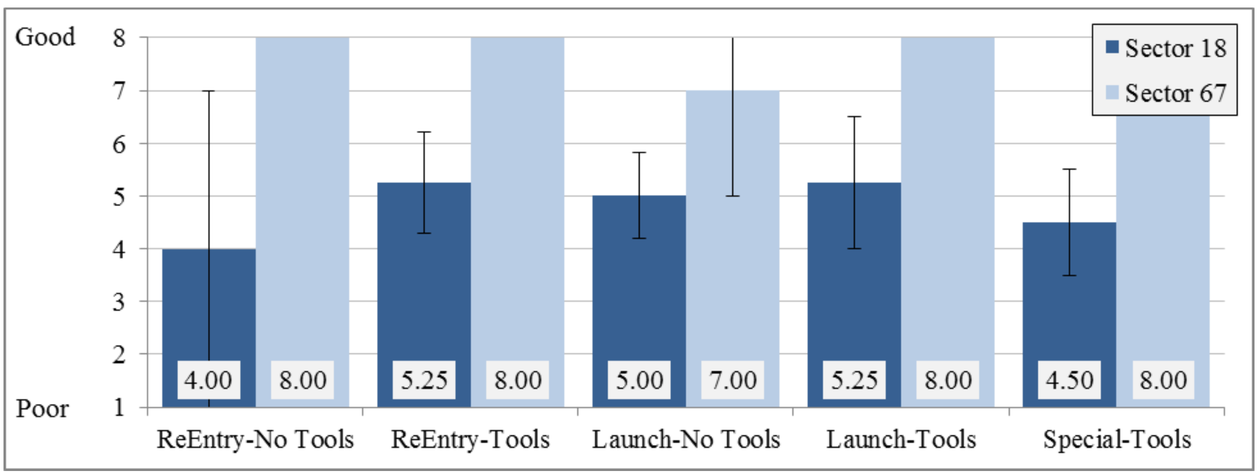

Figure G8. Detecting pilot deviations from control instructions.

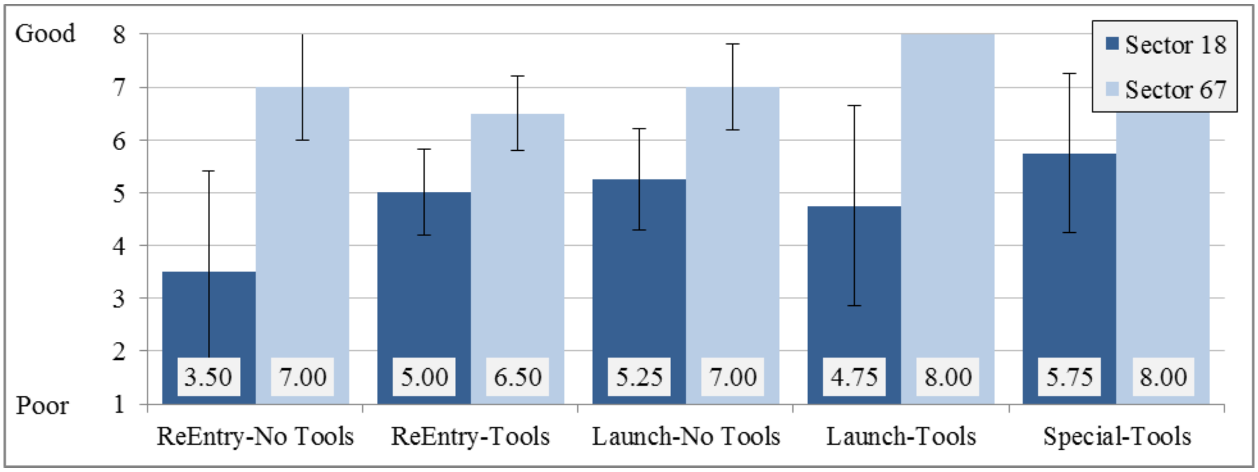

Figure G9. Correcting own errors in a timely manner.

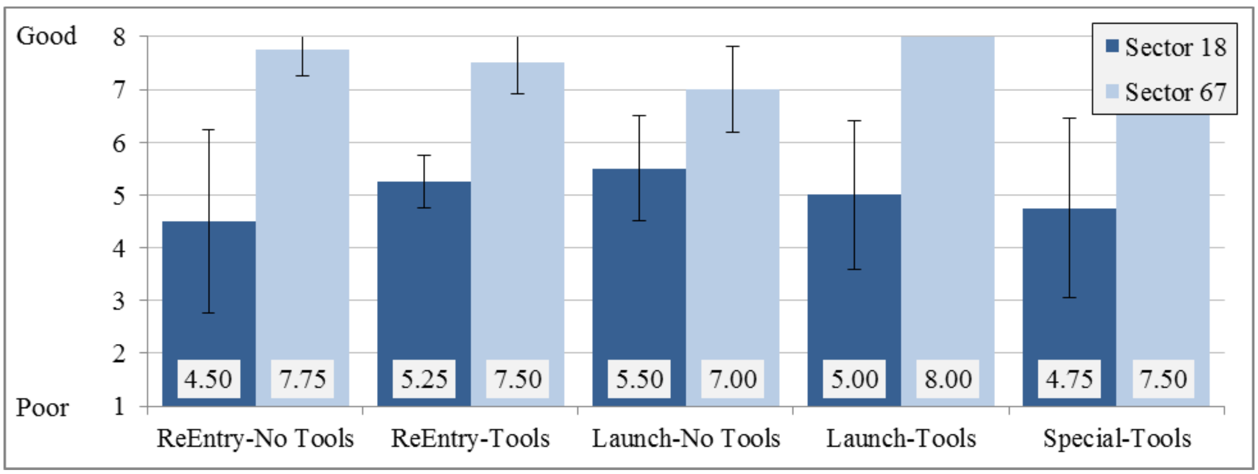

Figure G10. Overall attention and situation awareness scale rating.

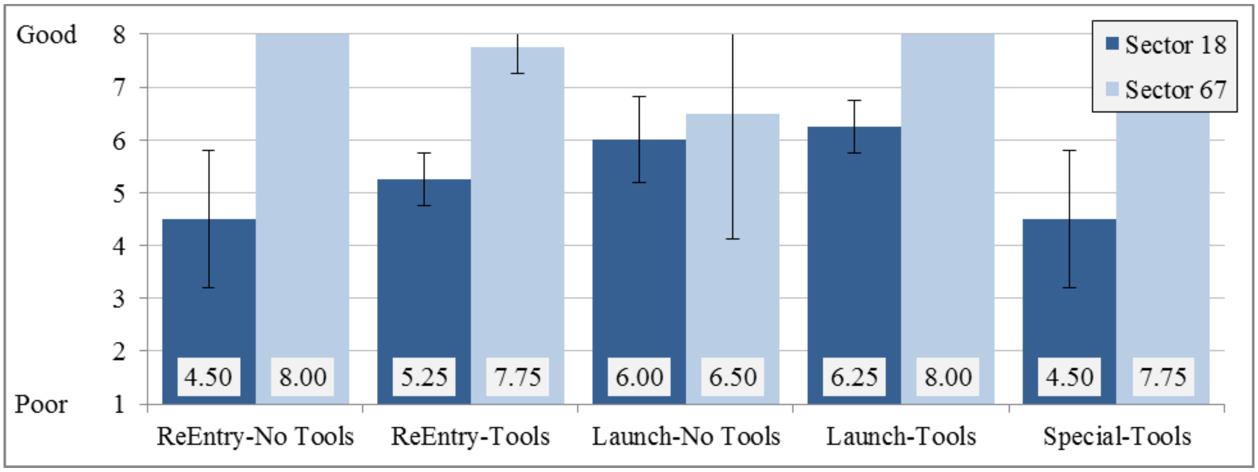

Figure G11. Taking actions in an appropriate order of importance.

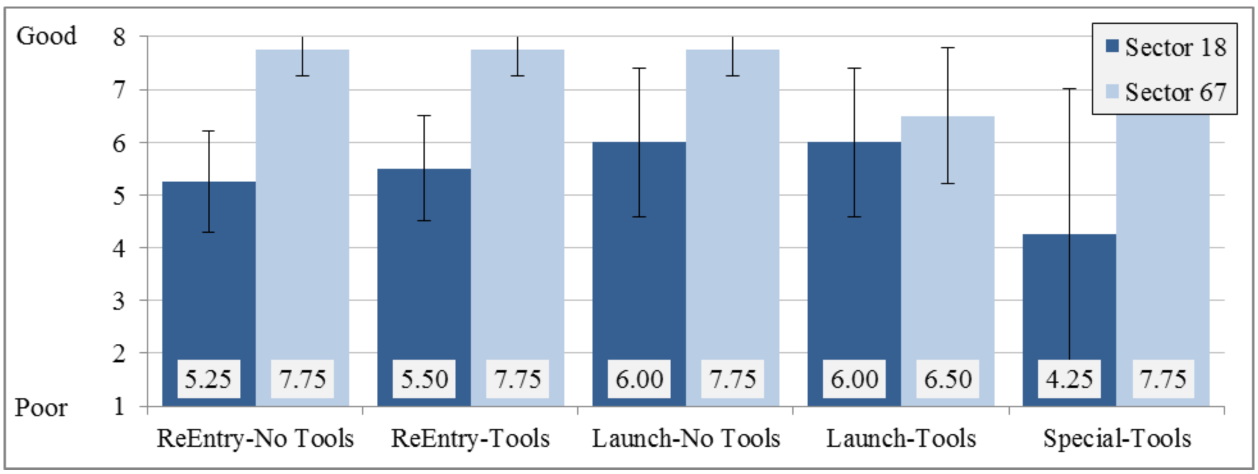

Figure G12. Preplanning control actions.

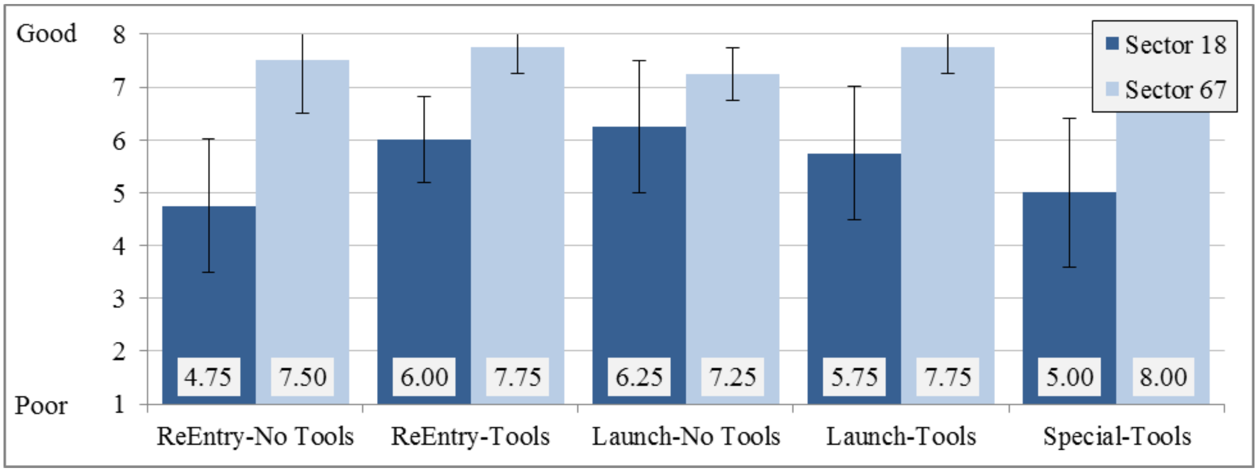

Figure G13. Handling Control Tasks for Several Aircraft.

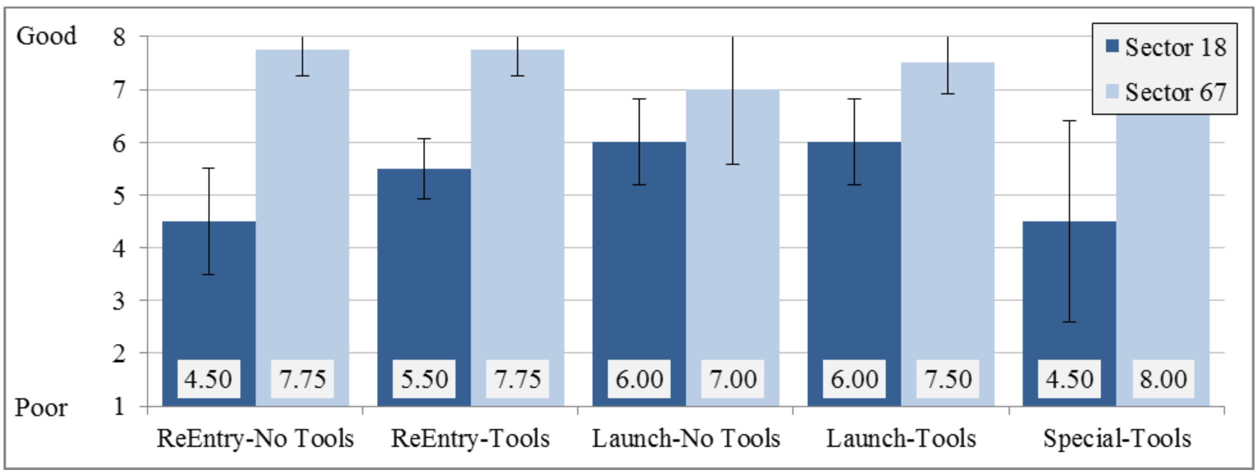

Figure G14. Overall Prioritizing Scale Rating.

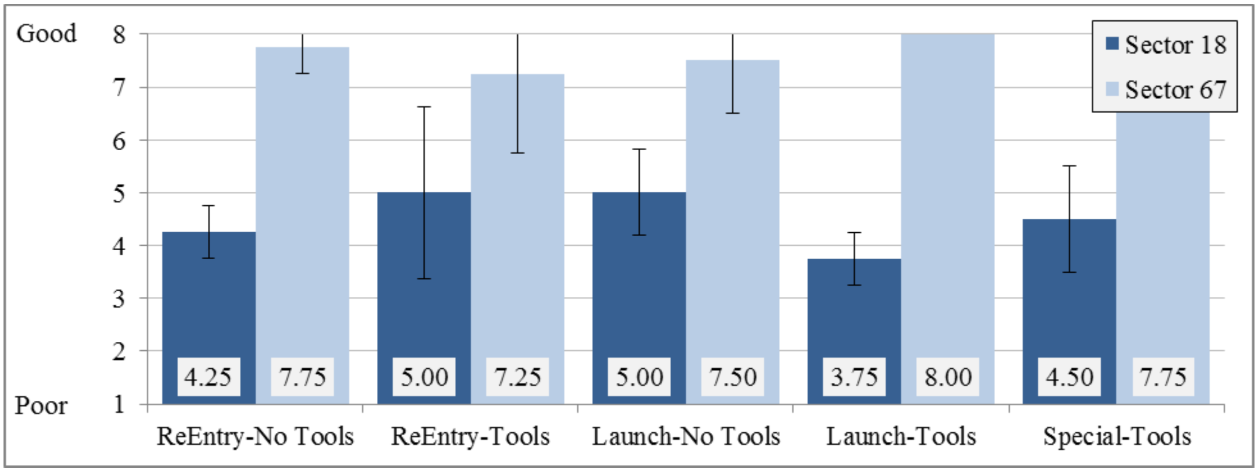

Figure G15. Providing essential air traffic control information.

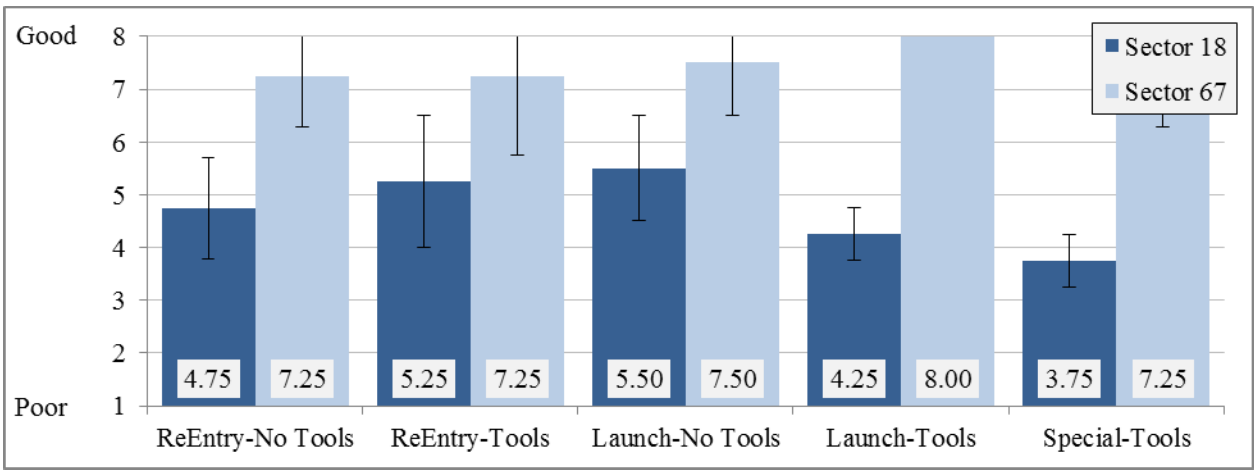

Figure G16. Providing additional air traffic control information.

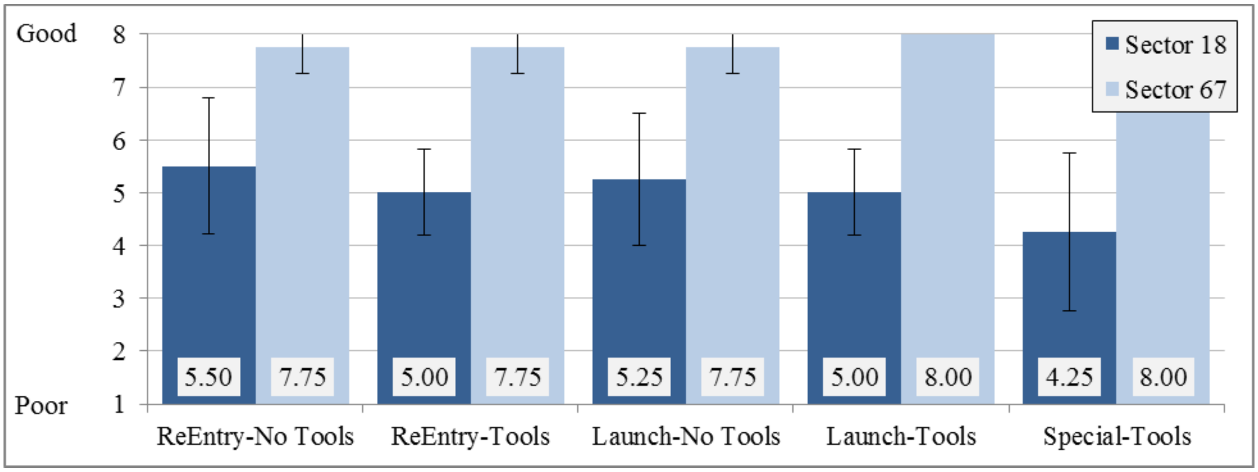

Figure G17. Providing coordination.

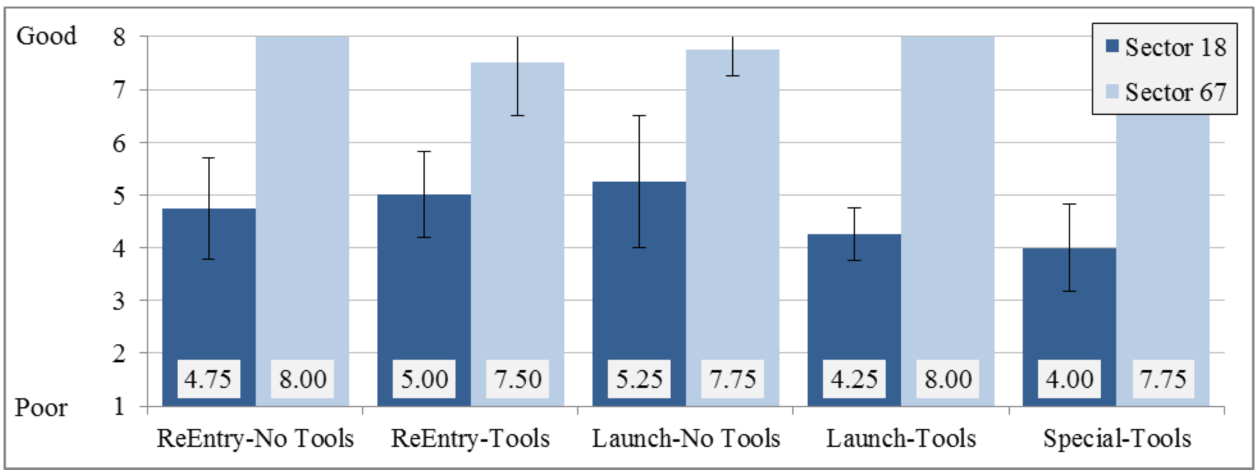

Figure G18. Overall providing control information scale rating.

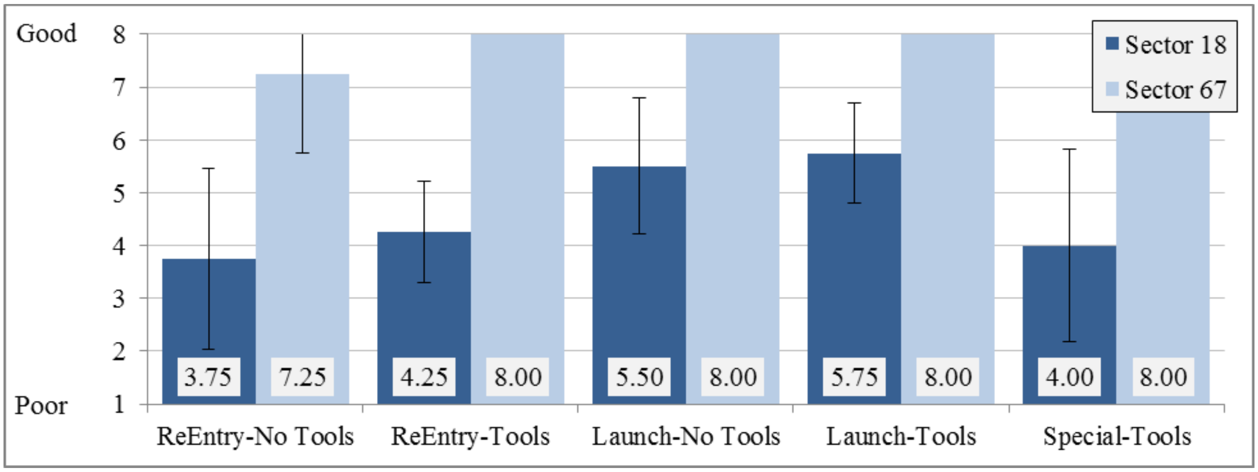

Figure G19. Showing knowledge of loas and sops.

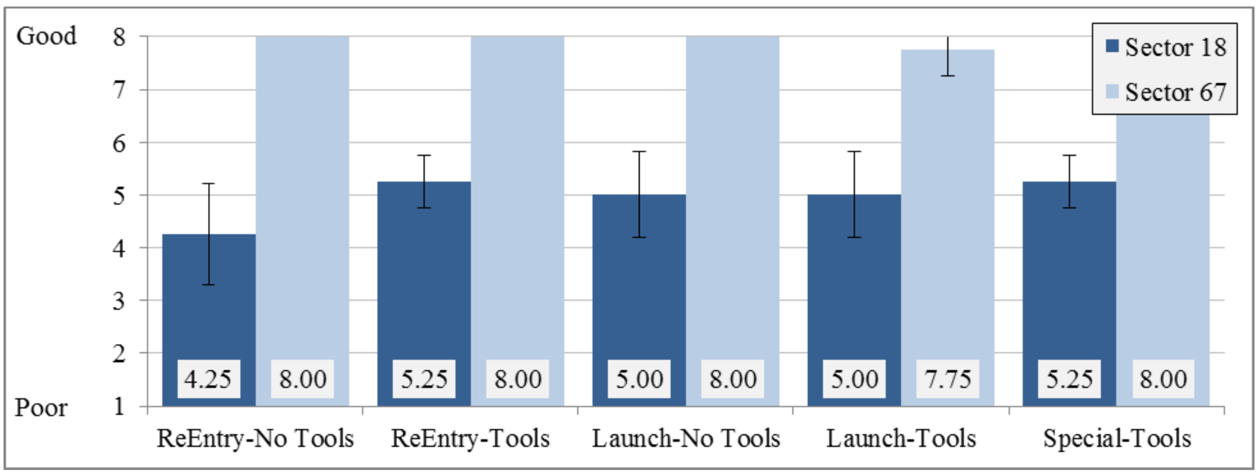

Figure G20. Showing knowledge of aircraft capabilities and limitations.

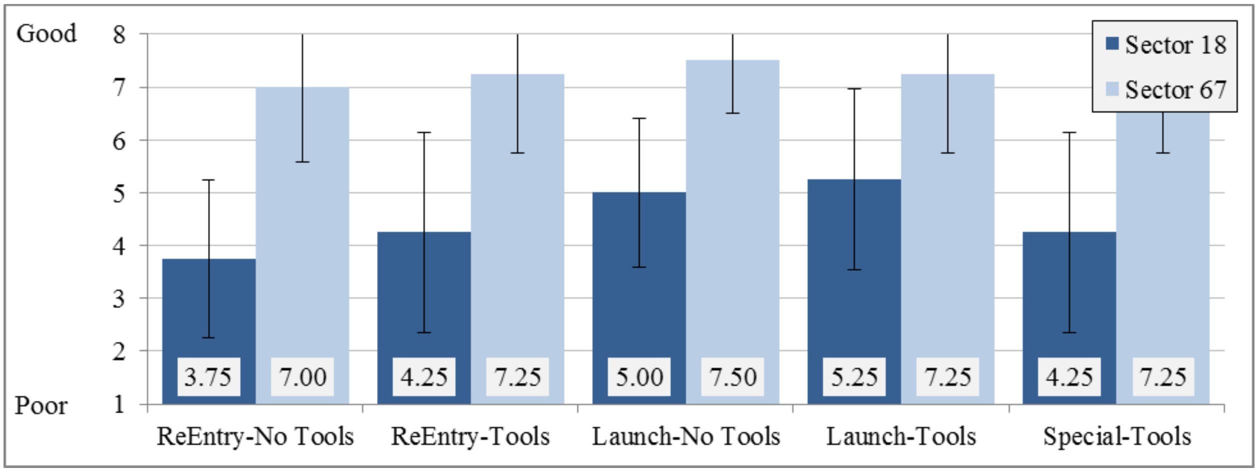

Figure G21. Showing effective use of equipment.

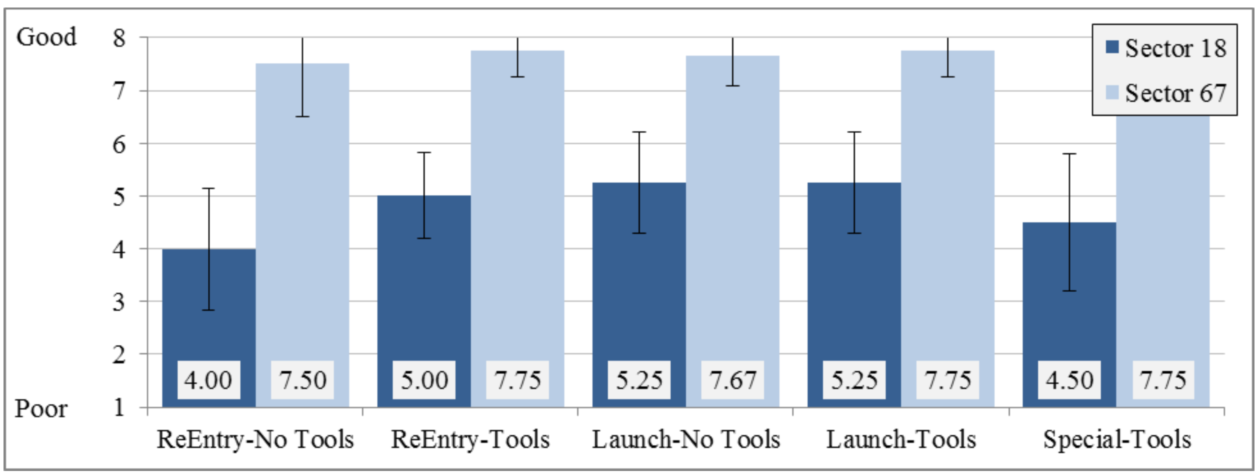

Figure G22. Overall technical knowledge scale rating.

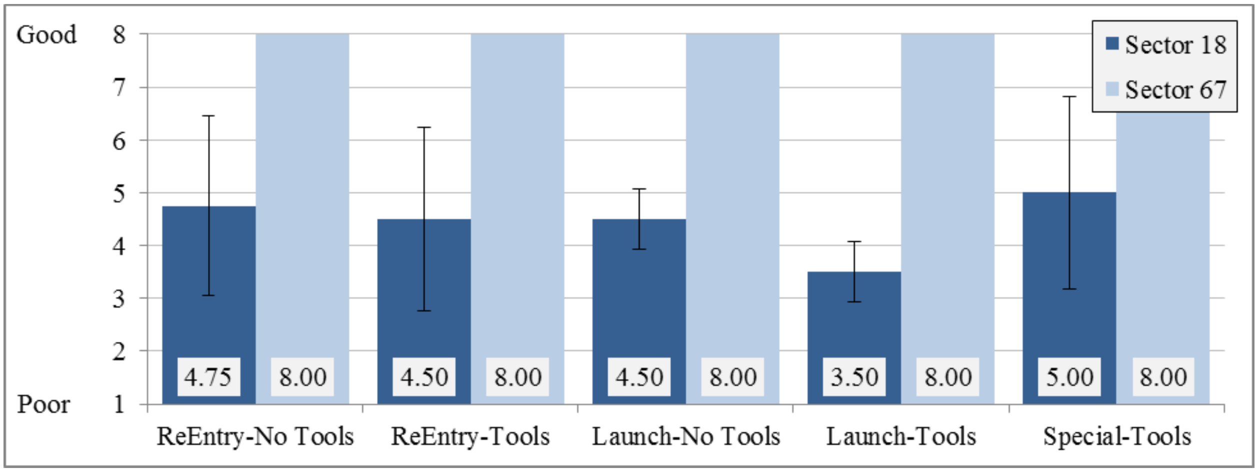

Figure G23. Using proper phraseology.

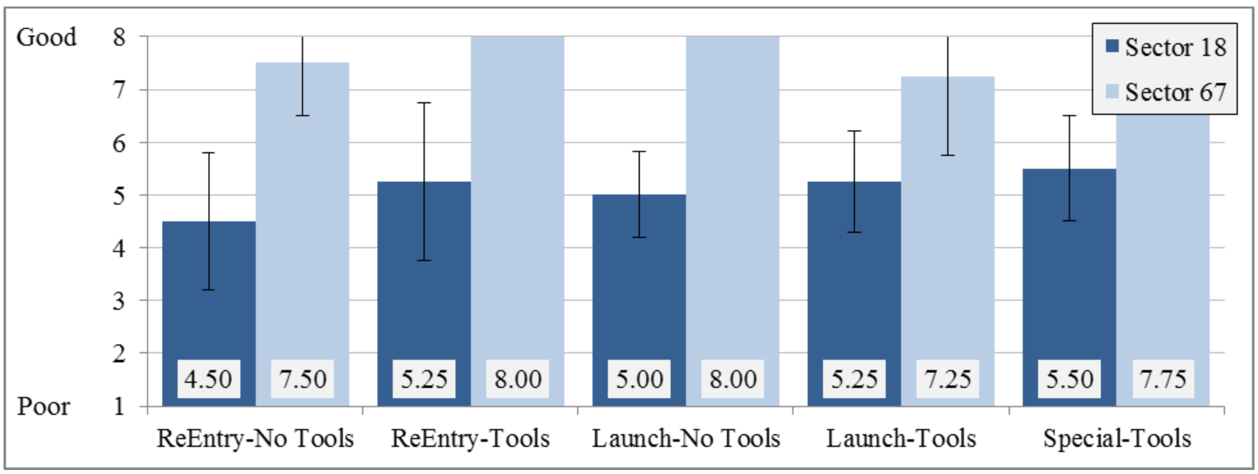

Figure G24. Communicating clearly and efficiently.

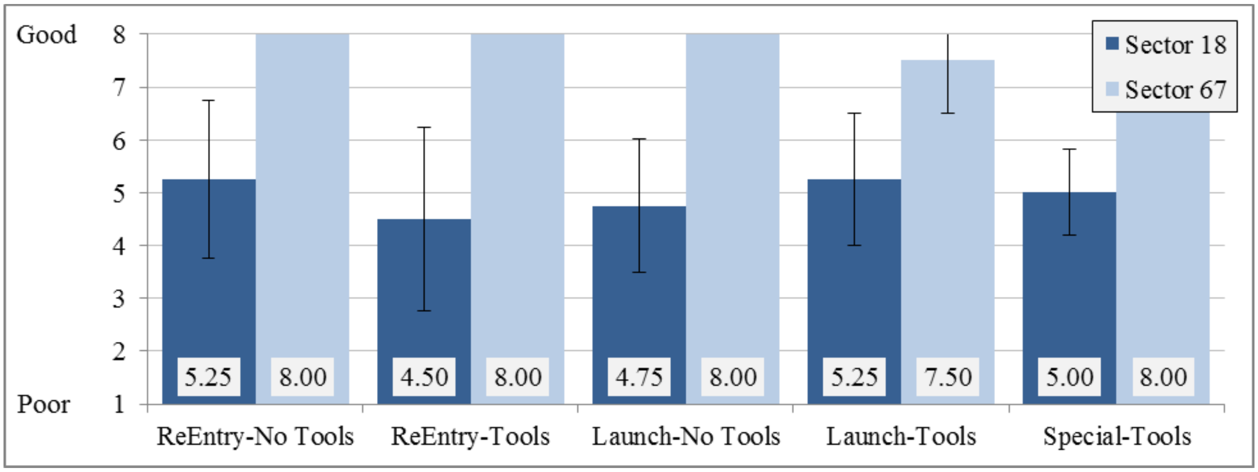

Figure G25. Listening to pilot readbacks and requests.

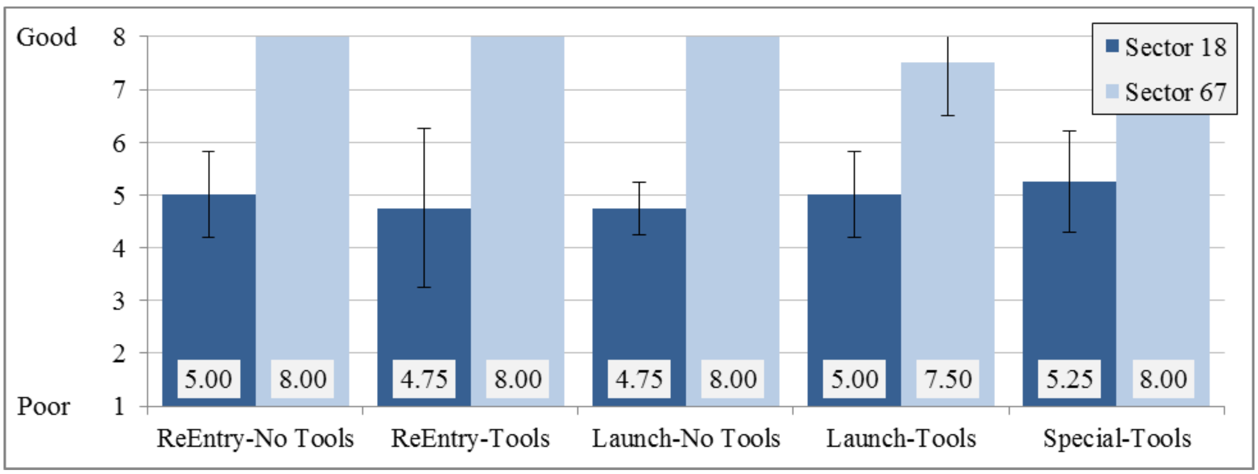

Figure G26. Overall communicating scale rating.