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

# Human-in-the-Loop Investigation of Automation Requirements for Separation Management

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**16. Abstract**

The Separation Management Project is part of the Federal Aviation Administration's (FAA) Next Generation Air Transportation System (NextGen) Plan. Human factors researchers from the FAA's William J. Hughes Technical Center conducted a human-in-the-loop simulation to investigate variable lateral separation standards in the en route environment. Twelve Certified Professional Controllers participated in the study. We simulated reduced separation requirements (i.e., 3 miles) using a single sensor radar site adaptation as well as for aircraft with either Automatic Dependent Surveillance-Broadcast or Performance-Based Navigation equipment. We simulated increased separation (i.e., 10 miles) for Unmanned Aircraft Systems. In addition, we simulated variable wake turbulence separation requirements for the Airbus 380 and Very Light Jets. We also developed a set of support tools to assist the controllers in using the variable separation procedures. We identified several human factors issues, and the results are discussed in terms of the automation requirements necessary to support the variable separation concept.

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# Executive Summary

The Federal Aviation Administration (FAA) has been tasked to modernize the existing Air Traffic Control (ATC) system, increase airspace capacity, reduce flight delays, and control the operating costs of commercial aviation while maintaining its high standard of safety. The FAA has chosen to use the existing National Airspace System (NAS) Architecture and the Next Generation Air Transportation System (NextGen) Implementation Plan to make the transformation towards the future ATC system. NextGen will use existing technologies, such as Automatic Dependent Surveillance-Broadcast (ADS-B), Performance-Based Navigation (PBN), and the Global Positioning System (GPS), to increase the accuracy of aircraft navigation and surveillance as well as advances in flight deck avionics and ground-based ATC automation.

The FAA Office of En Route and Oceanic Services sponsored the Separation Management Project as part of the NextGen concept that is planned for implementation under the En Route Automation Modernization (ERAM). The purpose of the project is to demonstrate, validate, and establish automation requirements for Separation Management in the en route environment. The FAA's William J. Hughes Technical Center (WJHTC) Human Factors Team – Atlantic City (HFTAC), the Simulation & Analysis Team, and the MITRE Corporation's Center for Advanced Aviation System Development are collaborating to investigate future separation management issues. In the present study, HFTAC researchers conducted a human-in-the-loop (HITL) simulation to examine variable aircraft separation standards in the en route environment.

The typical aircraft separation standard in the en route environment is 5 nautical miles (9.26 km) of lateral separation or 1,000 feet (304.8 m) of vertical separation under Reduced Vertical Separation Minima (RVSM). In the terminal environment there is different radar coverage and the aircraft separation standard is 3 nautical miles (5.56 km) of lateral separation or 1,000 feet of vertical separation. However, the Air Traffic Control Procedure Manual (FAA Order 7110.65) states that *3-mile lateral separation* may be used in the en route environment under special circumstances where radar coverage allows. The critical requirement for 3-mile separation is a *Single Sensor Radar Site Adaptation*. Currently, facilities have not widely implemented 3-mile separation areas in the en route environment. In our study, however, we simulated different radar coverages that allowed for a 3-mile separation area within a sector where most of the airspace would normally require 5-mile separation procedures.

In addition, we examined other cases in which 3-mile reduced separation may be allowed in the future with supporting technologies and other cases in which increased separation may be required. ADS-B technology uses the GPS to identify an aircraft's location accurately and to broadcast the data to ground control facilities and other aircraft. In our simulation, aircraft with ADS-B equipment were allowed 3-mile separation from other aircraft that were also equipped. PBN technology uses the GPS and the aircraft's Flight Management System to fly designated routes with little or no course deviation. Aircraft using Required Navigation Performance (RNP) procedures and Area Navigation (RNAV) equipment were allowed 3-mile separation from other aircraft flying the precision navigation route.

In the future, Unmanned Aircraft Systems (UAS) controlled by remote pilots may operate in the same airspace as civilian aircraft. UAS can have large operating distances that create communication delays between pilots and controllers and control instruction delays between pilots and their UAS.

To ensure safety, UAS required 10-mile separation from all other aircraft in our simulation. Also, aircraft with special wake turbulence characteristics may fly through the NAS with increasing frequency. The Airbus 380 is a very large aircraft that generates strong wake turbulence, and Very Light Jets (VLJs) are especially sensitive to wake turbulence. In our simulation, these aircraft created complex wake turbulence separation procedures that varied from 3 to 10 miles depending upon the weight classes of the aircraft.

In addition to investigating these variable separation standards, we developed a set of concept tools to support controller separation management and evaluated the tools in the simulation. The support tools are listed as follows.

1. Shading for the 3-mile Separation Area
2. Wake Turbulence Distance Indicator (Wake Tail)
3. Wake Turbulence Alert
4. Performance-Based Navigation Conformance Monitor
5. Route Amendment Graphic Tool
6. Conflict Probed Menus
7. Conflict Identification Data on the Radar Display
8. Improved Aircraft Halos

Twelve Certified Professional Controllers (CPCs) from Air Route Traffic Control Centers nationwide participated in the study. The participants completed the study in three sessions, with a different group of four controllers participating in each session. Each session consisted of three simulations days and two travel days. We assigned each group of participants to two Radar (R)-side/Data (D)-side controller teams who operated the same sector and traffic scenarios in an independent simulation. The simulation procedure consisted of four training scenarios and three 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 FAA WJHTC Research Development and Human Factors Laboratory. The simulation software consisted of the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) ATC simulator, the Target Generator Facility, and the JEDI version of the User Request Evaluation Tool (URET) prototype. The R-side position consisted of the DESIREE emulation of the ERAM with integrated conflict probe functions. The D-side position deployed the JEDI/URET prototype. We configured both positions on separate high-resolution 29″ displays. We selected Sector 18, a low-altitude sector, from our Genera Center (ZGN) airspace and generic traffic scenarios for the simulation.

We used three experimental conditions in a repeated measures design for the study. The first experimental condition was the Baseline condition in which participants controlled traffic using the standard 5-mile separation procedures without any of the support tools. The second experimental condition was the Reduced Separation condition in which participants controlled traffic using 3-mile separation procedures when applicable for the radar area and aircraft equipment, but did not use the support tools. The third experimental condition was the Support

Tools condition in which participants controlled traffic using 3-mile separation procedures when applicable for the radar area and aircraft equipment, and also used the support tools. Wake turbulence separation procedures were always required in all experimental conditions. Also, we configured the D-side position differently in the three experimental conditions. In the Baseline and Reduced Separation conditions, we configured the D-side position with the typical JEDI/URET prototype. In the Support Tools condition, we configured the D-side position with a full radar display and integrated conflict probe functions similar to the R-side position.

The first issue that we quickly discovered from the simulation was that using several different variable separation requirements was more complex for controllers than we had first thought. The participants told us that they were unaccustomed to paying attention to aircraft equipment and types for the appropriate separation requirements. To effectively use reduced aircraft separation, the controllers needed to quickly identify aircraft that had ADS-B and RNAV equipment and to remember the required separation procedures. The controllers needed to be especially vigilant for UAS and to remember that they had increased separation requirements. Also, the participants told us that the wake turbulence separation requirements were the most complex procedure in the simulation and the most difficult for controllers to remember.

The participants identified wake turbulence separation as the most important issue for en route controllers who currently encounter these situations much less than terminal area controllers. The participants advised us that controllers may use reduced separation procedures less often because they may not want to risk wake turbulence violations. The participants also identified increased separation requirements for aircraft, such as UAS, as another concern that may cause controllers to use reduced separation less often. However, increased separation requirements for UAS were not as difficult as wake turbulence because UAS required a consistent 10-mile separation instead of the variable wake turbulence requirements.

The participants' ratings of effectiveness were positive for a few of the support tools. The controllers thought that the shading for the single sensor radar area was an important tool to identify the boundary where 3-mile separation was allowed for arrivals and where 5-mile separation was required for departures. Also, the controllers thought that wake alerts and wake tails were good tools to help them avoid wake turbulence violations. However, the participants were unaccustomed to applying wake tails and thought that automation to display wake tails would improve their effectiveness. Finally, the participants advised us that improved aircraft halos will be an important tool for future aircraft separation requirements.

In contrast, the simulation measures did not show many benefits of the support tools. The results indicated that there were no improvements in sector capacity or efficiency and no differences in controller workload between the experimental conditions. However, almost every participant told us that they needed more practice time to become proficient with the support tools and more experienced with the variable separation procedures. In future research, we should plan for more participant training because of the complexity of the separation procedures and the number of tools available for controllers to use.

## 1. INTRODUCTION

The Federal Aviation Administration (FAA) has been tasked to modernize the existing Air Traffic Control (ATC) system, increase airspace capacity, reduce flight delays, and control the operating costs of commercial aviation while maintaining its high standard of safety. As reported by the Joint Planning and Development Office (JPDO, 2010), the FAA has chosen to use the existing National Airspace System (NAS) Architecture and the Next Generation Air Transportation System (NextGen) Implementation Plan to make the transformation towards the future ATC system. NextGen will use existing technologies, such as Automatic Dependent Surveillance-Broadcast (ADS-B), Performance-Based Navigation (PBN), and the Global Positioning System (GPS), to increase the accuracy of aircraft navigation and surveillance as well as advances in flight deck avionics and ground-based ATC automation. NextGen will modernize the air traffic controller's workstation and include improvements to the system's conflict alert, conflict probe, and flight data display (FAA, 2010).

The FAA Separation Management Project is part of the NextGen concept that is planned for implementation under the En Route Automation Modernization (ERAM). The purpose of the project is to demonstrate, validate, and establish automation requirements for Separation Management in the en route environment. The FAA's William J. Hughes Technical Center (WJHTC) Human Factors Team – Atlantic City (HFTAC) is collaborating with the Simulation & Analysis Team and the MITRE Corporation's Center for Advanced Aviation System Development to investigate future separation management issues. The FAA Office of En Route and Oceanic Services sponsored this research.

### 1.1 Background

The typical aircraft separation standard in the en route environment is 5 nautical miles (9.26 km) of lateral separation or 1,000 feet (304.8 m) of vertical separation under Reduced Vertical Separation Minima (RVSM). In the terminal environment there is different radar coverage and the aircraft separation standard is 3 nautical miles (5.56 km) of lateral separation or 1,000 feet of vertical separation. However, the FAA (2008) states in the Air Traffic Control Procedure Manual (FAA Order 7110.65) that *3-mile lateral separation* may be used in the en route environment under special circumstances where radar coverage allows. The critical requirement for 3-mile separation is a *Single Sensor Radar Site Adaptation*. Currently, facilities have not widely implemented 3-mile separation areas in the en route environment.

Our investigation of the Separation Management Concept began when we considered the human factors issues for Air Traffic Controllers operating a single en route sector with both 3- and 5-miles of variable separation areas. In conversations with supervisors at Air Route Traffic Control Centers (ARTCCs), we learned that Boston, Jacksonville, Miami, Cleveland, and Seattle Centers were already using 3-mile separation procedures in specific sectors where radar coverage allows.

We traveled to Boston ARTCC to gather information from the operations staff and observe controllers using 3-mile separation procedures. We learned that 3- and 5-mile variable separation procedures were working well at the Boston Center. We noted that the radar display sector map showed a line indicating the boundary between the 3- and 5-mile separation areas. However, there were no additional display features or automation to support 3-mile separation procedures. The system conflict alert, conflict probe, and aircraft J-ring were unchanged and supported only the 5-mile standard separation. The Boston Center staff and controllers told us that less than 5-mile separation procedures were not mandatory but were an available option for controllers to use at their discretion, where applicable. The staff and controllers we talked to believed that 3-mile separation areas have resulted in more efficient ATC operations and represent a significant benefit and cost savings for the FAA and airline companies.

### 1.1.1 Concept Scenarios

Our next step was to broaden the separation management concept to consider additional air traffic situations other than 3- and 5-mile variable separation areas for a single en route sector. On the basis of future ATC procedures and aircraft technologies, we defined seven different concept scenarios that will present new challenges and complexities for Air Traffic Controllers.

#### 1.1.1.1 Scenario #1: Variable Separation Areas

We defined this scenario as a sector with both 3- and 5-mile separation areas. We considered the following variants of this scenario with different ATC procedures.

1. **Standard** - Current procedures that allow 3-mile separation below Flight Level (FL) 180 and within the 40-miles range of the radar antenna.
2. **Extended** - Current procedures that e*xtend* the procedures to allow 3-mile separation above FL180 and out to 60 miles from the radar antenna.
3. **Terminal** - Current procedures that include terminal separation procedures (such as diverging courses and "green between").

The first variant considered allowing 3-miles of separation under the current standard procedures. The FAA (2008) Procedure Manual 7110.65 prescribes that 3-miles of separation may be used

- when radar site adaptation is set to single sensor,
- when significant operational advantages can be obtained,
- when within 40 miles of the antenna,
- when below FL180, and
- when facility directives specifically define the area where the separation can be applied.

The second variant considered extending 3-miles of separation beyond the standard procedures. This would allow 3-mile separation procedures above FL180 and out to 60 miles from the antenna using radar that is Mode-S capable. Although extended 3-mile separation is not operational anywhere in the NAS, Boston ARTCC has advocated its use because of the additional benefits and cost savings. Boston Center, in collaboration with Lincoln Laboratory, has conducted research indicating that radar with Mode-S capability is accurate enough to safely support the extended 3-mile separation procedures.

The third variant considered allowing terminal separation procedures, such as diverging courses and green between. The FAA Procedure Manual 7110.65 prescribes that aircraft that are not laterally separated may have vertical separation discontinued:

- When aircraft are on same or crossing courses and one aircraft has crossed the projected course of the other and the angular difference between their courses is at least 15 degrees (diverging courses).

- When aircraft are on opposite/reciprocal courses and the controller has observed that the radar targets have passed each other (green between).

ERAM has planned features that can support 3-mile separation procedures. The aircraft position symbol will be different in 3- and 5-mile separation areas. The standard aircraft position symbol is an open diamond in a 5-mile separation area and a filled circle in a 3-mile separation area. The system applies a standard 5-mile aircraft J-ring or 3-mile J-ring where appropriate for the designated separation area. The system conflict alert logic changes where appropriate for 3- and 5-mile separation areas. In addition, the ERAM conflict probe should operate appropriately in 3- and 5-mile separation areas.

#### 1.1.1.2 Scenario #2: Asymmetric Separation Requirements

We defined this scenario as traffic situations that require asymmetric separation, such as wake turbulence. Wake turbulence considerations add complexity to simple 3- and 5-mile separation areas. In sector areas where 3- and 5-mile separation procedures are in operation, controllers must allow for additional separation between aircraft pairs where wake turbulence may exist.

The FAA Procedure Manual 7110.65 requires aircraft operating directly behind or behind and less than 1,000 feet below another aircraft to be separated by the following distances (FAA, 2008).

- Heavy behind Heavy (4 miles)
- Large/Heavy behind B757 (4 miles)
- Small behind B757 (5 miles)
- Small/Large behind Heavy (5 miles)

The Wake Turbulence Program is considering additional aircraft classes that will account for the wake produced and the wake sensitivity of different aircraft types. In the future, aircraft such as Very Light Jets (VLJs) and Unmanned Aircraft Systems (UAS) may require special wake turbulence considerations. Additional aircraft classes will add complexity for controllers to identify wake turbulence situations.

#### 1.1.1.3 Scenario #3: Nonstandard Separation Situations

We defined this scenario as controlling traffic in nonstandard separation situations. We considered the following two variants of this scenario:

1. **Less than Standard Separation** - In a sector area where radar coverage requires 5-mile separation procedures, specific aircraft are allowed 3-miles of separation.

2. **Greater than Standard Separation** - In a sector area where radar coverage allows 3-mile separation procedures, specific aircraft must have 5-miles of separation.

Controlling aircraft in nonstandard separation situations creates complexity for controllers because some aircraft are exceptions to the designated procedures in the sector area. Less than standard separation may be allowed for aircraft with special equipment, such as ADS-B. ADS-B technology may produce more accurate position tracks on equipped aircraft so that closer separation can be achieved safely. Greater than standard separation may be required for aircraft with special considerations, such as UAS. The UAS may have less efficient communications between controllers and remote pilots and may cause slower aircraft response times, therefore, requiring greater separation for safety.

#### 1.1.1.4 Scenario #4: Performance-Based Navigation Considerations

We defined this scenario as traffic situations that require special PBN procedures, such as Required Navigation Performance (RNP) and Area Navigation (RNAV) routes. Aircraft with PBN equipment are capable of flying RNP/RNAV routes with little or no course deviation. However, controllers must monitor aircraft for route conformance. The RNP/RNAV routes may be spaced closer than the required separation for the sector area. PBN considerations are similar to the nonstandard separation scenario that creates complexity for controllers by exception to the designated procedures in the sector area.

#### 1.1.1.5 Scenario #5: Nonradar Considerations

We defined this scenario as traffic situations that occur in areas without radar coverage, such as in Alaska and oceanic regions. In the future, ADS-B technology may be used for improved ATC in nonradar areas. ADS-B is a flight deck system that uses the GPS to locate aircraft and to broadcast the position and other flight data to ground facilities or other aircraft. ADS-B Out technology allows aircraft to broadcast position data to ground facilities without radar coverage. ADS-B In technology allows other aircraft to receive the position data to create an aircraft situation display for pilots in the flight deck.

#### 1.1.1.6 Scenario #6: Controller Data Entry of Intent Information

We defined this scenario as methods that could be used by controllers to enter intent information into the system to support separation management. The system conflict alert and the User Request Evaluation Tool (URET) conflict probe are limited because of frequent nuisance alerts when there is no impending loss of aircraft separation. The number of nuisance alerts can be reduced with better trajectory modeling provided by information about controller intentions. As separation management becomes more complex with different separation requirements, it will be even more important to improve the system conflict alert and conflict probe.

#### 1.1.1.7 Scenario #7: Conflict Probe Information on the Radar Display

We defined this scenario as the conflict probe information that could be shown on the radar display to support separation management. Controllers are not fully utilizing the URET conflict probe information, especially when the Radar (R)-side controller is operating the sector alone. In the current Display System Replacement (DSR), the URET conflict probe exists on a separate display and is usually operated by the Data (D)-side controller, or Radar Associate. The URET display is attached to an articulating arm that allows easy movement towards either the D-side or R-side position. However, when R-side controllers are working alone, URET is used less often.

In ERAM, conflict probe information will be integrated on the R-side radar display with the intent of making conflict probe information more easily accessible for controllers.

#### 1.1.2 Support Tools

Our next step was to conduct a cognitive walkthrough with Subject Matter Experts (SMEs) to identify the human factors issues for controllers in the previously described concept scenarios. As a result of the cognitive walkthrough, we proposed a set of seven support tools for separation management. We proposed a final support tool during preparation for the Separation Management Human-in-the-Loop (HITL) simulation while shaking down traffic scenarios.

##### 1.1.2.1 Shading for 3-mile Separation Areas

Our first proposal was to indicate a single sensor radar site 3-mile separation area on the radar map with a light gray background shading (see Figure 1). The shading will ensure that 3-mile separation areas are clearly marked and should eliminate possible confusion with 5-mile separation areas. The automation will remove the shaded area when there is a total radar failure and change the shaded area from 60 miles to 40 miles when there is a Mode-S failure.

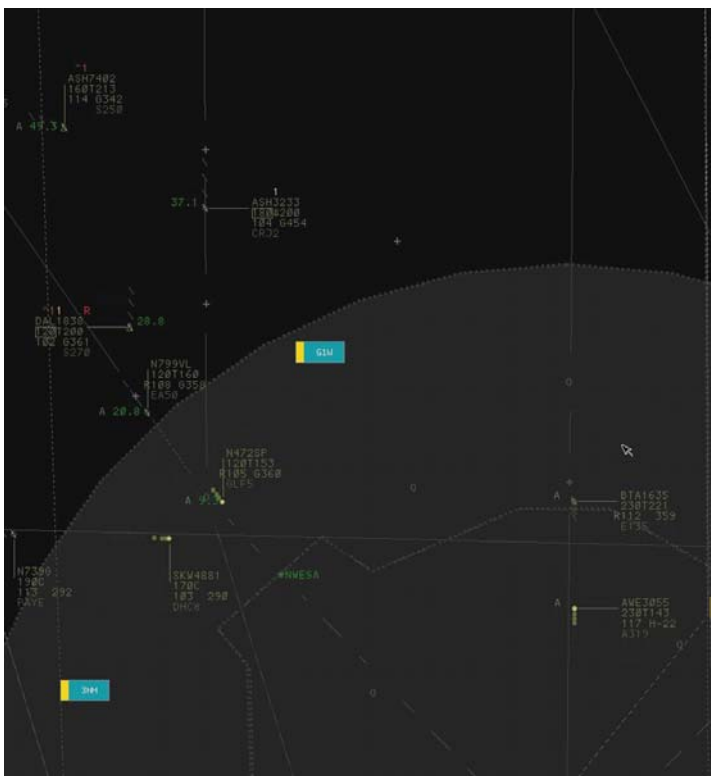

Figure 1. Shading for the 3-mile separation areas.

1.1.2.2 Wake Turbulence Distance Indicator

Our next proposal was a Wake Turbulence Distance Indicator, or Wake Tail, similar to an aircraft J-ring (see Figure 2). Unlike a J-ring that represents a 360 degrees protected area around an aircraft, the Wake Tail represents the appropriate minimum following distance between aircraft to avoid wake turbulence. The Wake Tail is a line trailing from the lead aircraft position symbol towards the following aircraft position symbol for a length that indicates the minimum wake turbulence separation distance for the aircraft pair. Automation will determine the appropriate distance for the Wake Tail based upon aircraft weight class. The controller can apply and remove the Wake Tail with a Q-command that specifies the two aircraft. The controller can also hover the trackball cursor over the Wake Tail, and automation will draw a dashed line to the trailing aircraft as a reminder of the aircraft pairing.


Figure 2. Wake turbulence distance indicator.

1.1.2.3 Wake Turbulence Alert

In addition, we proposed Wake Turbulence Alert automation similar to the system conflict alert (see Figure 3). The Wake Turbulence Alert will use aircraft trajectory modeling to predict the position of aircraft wake remnants. When the Wake Turbulence Alert automation predicts that aircraft will violate the minimum separation distance for wake turbulence, an advanced alert will notify the controller. The time parameter for the advanced alert will be short term (e.g., 2 minutes) and will show blinking aircraft datablocks similar to the system conflict alert. However, a Wake Alert indicator on the aircraft datablocks (e.g., red W) will distinguish it from the conflict alert. The controller can suppress the Wake Turbulence Alert similar to the way controllers suppress the system conflict alert.

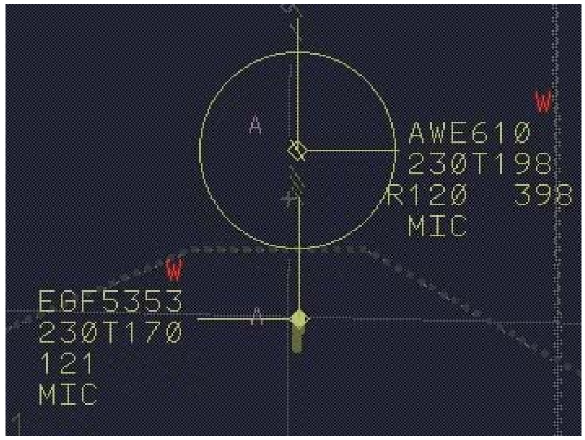


Figure 3. Wake turbulence alert.

<u>1.1.2.4 Performance-Based Navigation Conformance Monitor</u>

Our next proposal was a PBN Conformance Monitor that will support controllers while monitoring RNP/RNAV aircraft for route conformance (see Figure 4). On the rare occasion when an aircraft deviates from its designated RNP/RNAV route, a radar display symbol will indicate that the aircraft is not in conformance. An out-of-conformance indicator in the aircraft datablock (e.g., red R) will distinguish it from conflict and wake alerts. Also, in contrast to conflict and wake alerts, the Conformance Monitor Alert will not use blinking aircraft datablocks because loss of separation may not apply. Additional datablock features will indicate the aircraft has filed an RNAV route (e.g., box around interim altitude field) and is established on the RNAV route (e.g., downward pointing double arrow between altitude fields). These features will help controllers distinguish between RNAV and non-RNAV aircraft even when controllers vector aircraft off their filed routes. Automation will enter the appropriate interim altitude for an aircraft established and descending on the RNAV route.


Figure 4. Performance-based navigation conformance monitor.

### 1.1.2.5 Route Amendment Graphic Tool

We proposed a tool that will assist controllers with data entry of trajectory changes when vectoring aircraft for separation or weather avoidance (see Figure 5). A graphic tool will allow controllers to draw route deviations on the radar display with a series of line segments that indicate the intended aircraft flight path. The line segments are connected by nodes the controller can manipulate to modify the flight path. When the controller is satisfied with the drawn flight path, automation will enter the route deviations into the system as a route amendment to improve aircraft trajectory modeling. The automation will also identify the headings to assist the controller with aircraft clearances.

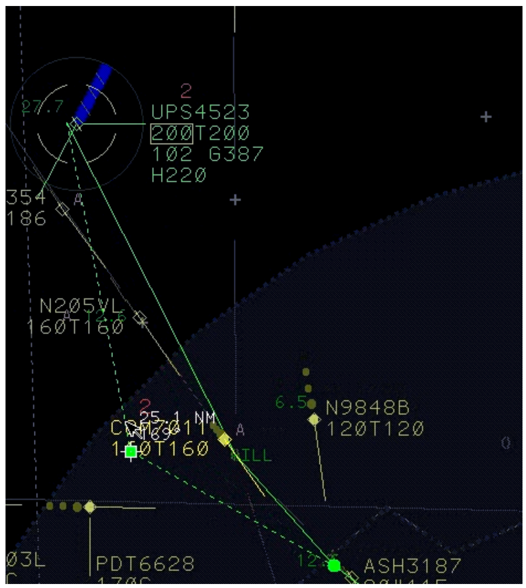


Figure 5. Route amendment graphic tool.

### 1.1.2.6 Conflict Probed Menus

We proposed a tool that will allow controllers to easily enter altitude, heading, and airspeed data into the system using flyout menus (see Figure 6). The tool will also identify potential conflicts in altitude, heading, and airspeed changes using probed menus. Automation will use color coding (e.g., red, yellow, green) to indicate altitude, heading, or airspeed menu entries that will result in an aircraft conflict, near conflict, or no conflict. Controller altitude field data entries and scratchpad data entries for heading and airspeed will be used by the system to improve the trajectory modeling for conflict alert and conflict probe.

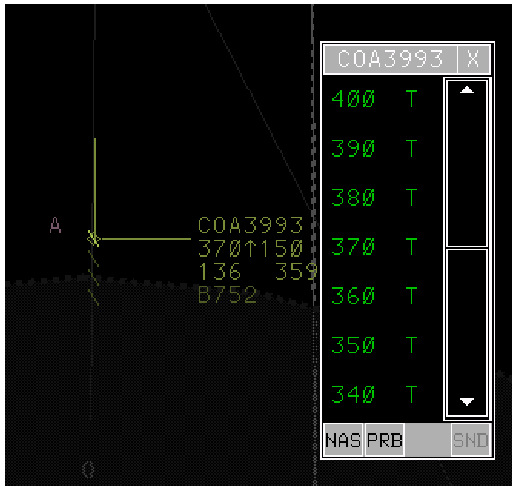


Figure 6. Conflict probed menus.

1.1.2.7 Conflict Identification Data on the Radar Display

Our next proposal was to show conflict identification and conflict trajectory information on the controller R-side display similar to how this information is currently presented on the URET Aircraft List and Graphic Plan Display (see Figure 7). When the conflict probe initially detects loss of separation, the number of conflicts and the type of conflict (i.e., red, yellow or blue) will be shown on Line 0 of the aircraft datablock. The controller can display the conflict trajectory by selecting the conflict number on the datablock.

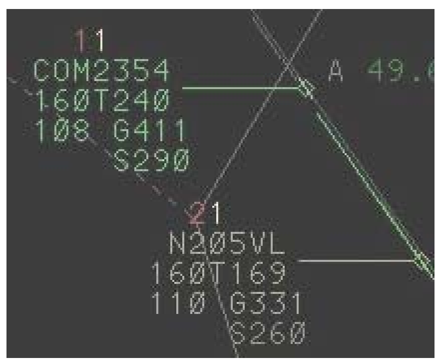


Figure 7. Conflict identification data on the radar display.

1.1.2.8 Improved Aircraft Halos

We developed the last proposal for an improved aircraft J-ring, or Halo, during preparation for the Separation Management simulation (see Figure 8). Currently, ERAM supports 3 miles of separation for a single sensor radar site with an appropriate aircraft Halo size. In the future, however, additional Halo sizes may be required for different aircraft separation requirements. We propose automation that will determine the required separation for an aircraft (e.g., 3, 5, or 10 miles) and display the appropriate Halo size. In some cases, an aircraft may have more than one separation requirement, depending upon aircraft equipment and type. For example, aircraft with ADS-B equipment may need only 3 miles of separation from other aircraft with ADS-B equipment but may require 5 miles of separation from aircraft without ADS-B equipment. In these cases, automation may not be able to determine the appropriate Halo size. We propose a dual Halo (e.g., 3 and 5 miles) that reminds controllers that the aircraft has more than one separation requirement.

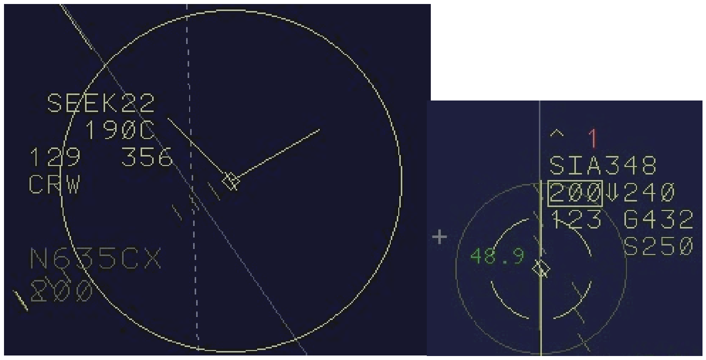


Figure 8. Improved aircraft halos.

## 1.2 Purpose

The purpose of the Separation Management Project is to demonstrate, validate, and establish automation requirements for separation management in the en route environment. We conducted the present study to identify the human factors issues for Air Traffic Controllers, using future separation management concepts and our proposed support tools in a HITL simulation. In the simulation, we investigated different experimental conditions that varied in terms of the required aircraft separation procedures and the availability of support tools for controllers to use.

# 2. METHOD

## 2.1 Participants

We recruited 12 Certified Professional Controllers (CPCs) from ARTCCs nationwide to serve as voluntary participants in the study. All participants were current controllers who were qualified at their facility and held a current medical certificate. All 12 of the participants were male controllers who had received some ERAM training at their facility. The principal investigator informed the controllers of their rights as participants in a research study.

Table 1 shows a summary of the participants' responses to a Biographical Questionnaire. On average, the participants had over 22 years of experience controlling traffic. They rated their current skill level and motivation to participate in the experiment as very high on a 10-point rating scale (1 = *lowest*, 10 = *highest*).

Table 1. Means and Standard Deviations for the Biographical Questionnaire

| Questionnaire Item | Mean | (*SD*) |
|---|---|---|
| Age of participant | 46.7 | (3.52) |
| Years of experience as an Air Traffic Controller, including FAA and military | 22.7 | (2.53) |
| Years of experience as a Certified Professional Controller for the FAA | 19.8 | (2.76) |
| Years of experience controlling traffic in the en route environment | 18.9 | (4.22) |
| Years of experience controlling traffic in the terminal environment ($n = 4$) | 1.9 | (3.26) |
| Number of the past 12 months actively controlling traffic | 12.0 | (0.00) |
| Skill level as a Certified Professional Controller | 9.2 | (1.03) |
| Motivation level to participate in this experiment | 9.5 | (0.67) |

## 2.2 Research Personnel

An Engineering Research Psychologist (ERP) served as the principal investigator and conducted the simulation study. 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. Two Human Factors Specialists assisted the principal investigator by operating the simulation software and eye-tracking device. A Hardware and Software Engineer prepared the simulator and ensured the equipment was operating properly.

Two SMEs served as over-the-shoulder observers during the study. The SMEs provided performance ratings and written comments after each traffic scenario. In preparation for the simulation, the SMEs developed the practice and test scenarios.

Six simulation pilots operated pilot workstations and supported the study. The simulation pilots communicated with controllers using proper ATC phraseology and maneuvered the simulation aircraft based upon controller instructions.

## 2.3 Simulation Environment

### 2.3.1 Research Facility

We conducted the study in the FAA WJHTC, Research Development and Human Factors Laboratory (RDHFL). The RDHFL 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 Generator Facility (TGF), and the JEDI/URET prototype. All three 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 test 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 the present study, DESIREE emulated the ERAM system and received input from the TGF to display aircraft targets and flight data on the R-side controller display. DESIREE also acted as a "ghost" controller and automated the aircraft handoff functions for the adjacent sectors in the simulation.

The 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 it can be implemented without the ERAM using DESIREE. The JEDI/URET presented the Aircraft List and Graphic Plan Display windows on the D-side controller display. The JEDI/URET and DESIREE shared data through a Host Automation Gateway (HAG) so that JEDI/URET operated as if connected to ERAM, and DESIREE was able to display conflict probe and trial planning information on both the R-side and D-side controller displays.

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. The TGF consists of multiple simulation pilot workstations operated by trained personnel who communicate with controllers and enter flight plan changes based upon controller instructions.

#### 2.3.3 Airspace

HFTAC researchers and SMEs designed a generic ARTCC (ZGN) with several sectors for use in ATC simulations. ZGN provides a realistic environment for controlling traffic, and the sectors are easy for controllers to learn. The sectors consist of navigational aids with names that are easy to remember, simple radio frequencies, and basic operating procedures.

For the present study, we used a generic low altitude sector identified as ZGN18 (see Figure 9). We selected this sector because it has characteristics and traffic patterns similar to the sectors we observed at Boston ARTCC that are using 3-mile separation procedures. ZGN18 has a rectangular shape and extends for approximately 120 NM (222 km) from North to South, approximately 85 NM (157 km) from East to West, and from the surface to FL230 in altitude. ZGN18 serves as a low altitude sector that receives aircraft from adjacent en route sectors and feeds aircraft to a terminal region with one major airport and three satellite airports. Arrival routes flow in a general south-bound direction and departure routes flow in a general northbound direction. ZGN18 contains several intersections that contribute to sector complexity. We designated a 3-mile separation area around a radar site centered on the Genera (GEN) main airport and extending into ZGN18, similar to a Boston ARTCC sector. We created a Genera RNP/RNAV arrival route with programmed descents and speed reductions along the GAARY, PEORA, ILL, and GEN NAVAIDS.

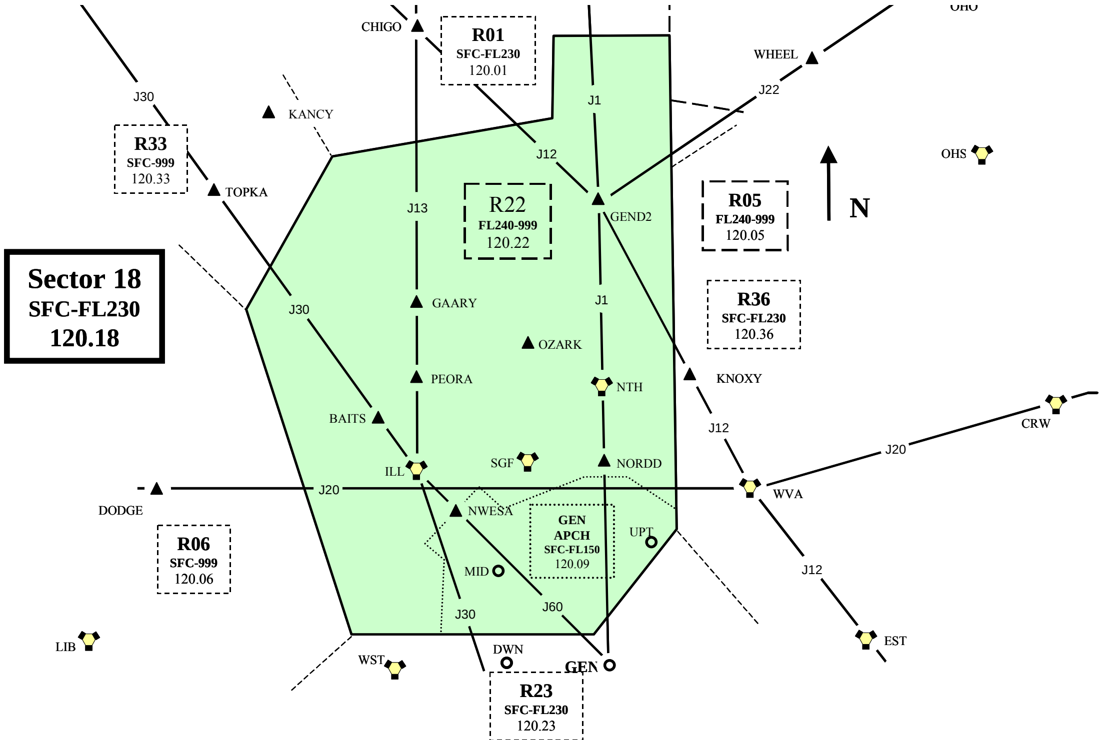


Figure 9. Generic Sector 18, low altitude airspace.

### 2.3.4 Traffic Scenarios

We selected traffic scenarios from previous studies in the RDHFL and modified them to meet the objectives of the present study. The study consisted of training sessions with eight practice scenarios and two testing sessions with three test scenarios in each session. All scenarios consisted of a mix of arrival, departure, and overflight traffic with the aircraft equipment and types necessary to create the required separation management concept scenarios. All practice and test scenarios began with low traffic that steadily increased throughout the entire scenario.

The SMEs developed practice scenarios with varying traffic levels to train controllers to use the generic airspace, separation management support tools, and new separation procedures. For initial training, we developed four practice scenarios with low traffic levels that were 45 minutes in duration. For later training, we developed four more practice scenarios with high-traffic levels that were also 45 minutes in duration. The high-traffic practice scenarios consisted of traffic levels that were nearly identical to the test scenarios we used in the testing sessions.

The SMEs developed six test scenarios with high-traffic levels that were 45 minutes in duration. The test scenarios were nearly identical with the same overall number of aircraft and the same mix of arrival, departure, and overflight traffic. The test scenarios had the same aircraft equipment and types necessary to create the separation management concept scenarios. However, the aircraft call signs were different in each test scenario so that controllers performing the problems sequentially would not recognize the scenarios. Table 2 shows a summary of the traffic characteristics for the test scenarios.

Table 2. Summary of Traffic Mix and Aircraft Equipment and Types in the Test Scenarios

| **General Traffic Mix** | **Number of Aircraft** | **%** |
|---|---|---|
| Total Aircraft in Scenario | 61 | 100% |
| Arrivals | 31 | 51% |
| Departures | 14 | 23% |
| Overflights | 16 | 26% |
| **Aircraft Equipment and Types** | **Number of Aircraft** | **%** |
| Automatic Dependent Surveillance (ADS-B) | 58 | 95% |
| Area Navigation (RNAV) | 30 | 49% |
| Unmanned Aircraft Systems (UAS) | 3 | 5% |
| Airbus 380s (A380) | 3 | 5% |
| Very Light Jets (VLJs) | 3 | 5% |

#### 2.3.5 Separation Procedures

Using the separation management concept scenarios presented in the introduction, we created traffic situations that required controllers to use variable separation procedures. The simulation included the following situations.

1. Single Sensor Radar Site Adaptation
2. Automatic Dependent Surveillance
3. Required Navigation Performance and Area Navigation Routes
4. Unmanned Aircraft Systems
5. Aircraft with Special Wake Turbulence Characteristics

In a single sensor radar site adaptation, 3-mile lateral separation may be used between aircraft that are both within 40 miles of the radar antenna and below FL180. In the simulation, we extended the area to include 60 miles from the radar antenna centered at the GEN main airport. Therefore, only part of ZGN18 allowed controllers to use 3-mile lateral separation between aircraft; most of the sector required 5-mile separation. Also, in the last 5 minutes of the traffic scenarios, we simulated a radar failure that cancelled 3-mile lateral separation and required 5-mile separation for the entire sector.

In the simulation, aircraft with ADS-B equipment were allowed to use 3-mile lateral separation. The opportunity for reduced separation applied only if both aircraft had ADS-B equipment. Our simulation assumed only ADS-B Out technology in which accurate GPS position data were broadcast to ground controllers. Aircraft with RNP/RNAV equipment were allowed to use 3-mile lateral separation when established on the RNAV route. The opportunity for reduced separation applied only if both aircraft had RNP/RNAV equipment and both aircraft were established on the RNAV route. For complexity, the Genera RNAV route overlaid another arrival route with the same navigation fixes for aircraft that were not RNAV equipped. The non-RNAV arrival route required the 5-mile separation between aircraft.

The simulation included UAS that required an exceptionally large 10-mile lateral separation. Although no aircraft in the NAS today have such a large separation requirement, we wanted to investigate the human factors issues for controllers required to use greater than 5-mile standard separation. The UAS flew overflight routes in the traffic scenarios and required 10-mile separation from all aircraft, regardless of single sensor radar areas or aircraft equipment that would allow reduced separation. Table 3 shows a summary of the special procedures used for lateral aircraft separation in the simulation.

Table 3. Summary of the Special Procedures Used for Lateral Aircraft Separation

| Traffic Situation | Required Separation |
|---|---|
| Single Sensor Radar Site Adaptation, both aircraft within designated area | 3 miles |
| Automatic Dependent Surveillance (ADS-B), both aircraft equipped | 3 miles |
| Area Navigation (RNAV), both aircraft equipped and established on route | 3 miles |
| Unmanned Aircraft Systems (UAS), from all other aircraft – no exceptions | 10 miles |

The last situation included aircraft with special wake turbulence characteristics. The A380 is a very large aircraft that produces strong wake turbulence. In the simulation, aircraft following an A380 required variable separation depending upon the trailing aircraft's weight class. The required wake turbulence separation ranged from 10 miles for VLJs to 4 miles for another A380 trailing. VLJs are especially sensitive to wake turbulence and require variable separation depending upon the leading aircraft's weight class. In the simulation, the required wake turbulence separation ranged from 10 miles for A380s to 4 miles for another VLJ leading. Table 4 shows a summary of the special procedures used for wake turbulence separation in the simulation.

Table 4. Summary of the Special Procedures Used for Wake Turbulence Separation

| Traffic Situation | Required Separation |
|---|---|
| A380 leading VLJ aircraft | 10 miles |
| A380 leading Large aircraft | 8 miles |
| A380 leading Small aircraft | 7 miles |
| A380 leading B757 aircraft | 6 miles |
| A380 leading Heavy aircraft | 5 miles |
| A380 leading A380 aircraft | 4 miles |
| VLJ trailing A380 aircraft | 10 miles |
| VLJ trailing Heavy aircraft | 8 miles |
| VLJ trailing B757 aircraft | 7 miles |
| VLJ trailing Small aircraft | 6 miles |
| VLJ trailing Large aircraft | 5 miles |
| VLJ trailing VLJ aircraft | 4 miles |

*Note*. VLJ = Very Light Jet.

## 2.4 Equipment

### 2.4.1 Controller Workstations

We configured the controller workstations for R-side and D-side team operations with a single sector. The R-side controller workstation consisted of a high-resolution (2,048 x 2,048) 29″ radar display, keyboard, trackball, and Keypad Selection Device. The R-side controller wore an oculometer that tracks and records eye movements. The D-side controller workstation consisted of a high-resolution (2,048 x 2,048) 29″ display, keyboard, and mouse. The JEDI/URET prototype was deployed on the D-side controller display. The controllers used a Voice Switching and Control System (VSCS) panel to communicate with the simulation pilots. In addition, all controllers used a Workload Assessment Keypad (WAK) to record their workload ratings during the simulation.

### 2.4.2 Simulation Pilot Workstations

The study required six simulation pilot workstations linked together in a network with the controller workstations. Each simulation pilot workstation consists of a computer monitor, keyboard, and mouse. A section of the computer monitor depicts a situation display of the airspace and aircraft in the simulation similar to the controller display. The remaining display area contains a list of aircraft assigned to the simulation pilot, flight data, and a user interface to enter flight plan changes into the system. Each simulation pilot was responsible for several aircraft at a time during the simulation. Three simulation pilots supported each controller team. The simulation pilots used the RDHFL communications system to talk to controllers.

### 2.4.3 Communications System

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

### 2.4.4 Workload Assessment Keypad

The controllers used the RDHFL 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 they 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 several beeps and illuminating the keypad buttons. The controllers provide their workload ratings by pressing one of the 10 buttons (1 indicates *very low workload* and 10 indicates *very high workload*). If controllers do not respond before the time-out period, the system records a code to indicate there was no response. In the present study, we selected 2 minutes as the rating time interval and 30 seconds as the time-out period.

2.4.5 Oculometer

We equipped the R-side controller with an oculometer consisting of an eye- and head-tracking system. The oculometer records the point-of-gaze and pupil diameter of participants by using near infrared reflection outlines from the pupil and cornea (Applied Science Laboratories, 1991; see also Willems, Allen, and Stein, 1998, for an extensive description of both the hardware and software used for eye tracking). Willems, et al. reported that the exposure to the infrared illumination while wearing the oculometer is less than 4% of the intensity of that experienced when outside on a sunny day.

2.4.6 Audio-Visual Recording System

We used the RDHFL audio-video recording system to record controller voice communications and actions during the simulation. We placed an overhead video camera above each R-side and D-side controller team to record the controllers' upper bodies and arm actions. The audio-video recording served as a record of the simulation that the researchers can review, if needed.

2.5 Materials

2.5.1 Informed Consent Statement

Each participant read and signed the Informed Consent Statement (see Appendix A) before beginning the experiment. The Informed Consent Statement describes the purpose of the study and the rights and responsibilities of the participants, as well as ensures participants that their data will be confidential and anonymous.

2.5.2 Biographical Questionnaire

Each participant completed the Biographical Questionnaire (see Appendix B) 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.

2.5.3 Post-Scenario Questionnaire

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

2.5.4 Exit Questionnaire

The participants completed the Exit Questionnaire (see Appendix D) after performing all traffic scenarios. The purpose of the Exit Questionnaire was to collect data regarding each controller's experience in the entire experiment. The controllers provided ratings about the realism of the simulation including the generic airspace, traffic scenarios, and ATC equipment. The controllers also provided ratings to compare the experimental conditions tested in the simulation. The Exit

Questionnaire included ratings and open-ended questions about controller information requirements for separation management as well as requested ideas for either improving the support tools or developing new ones. The controllers were able to comment about anything they experienced during the entire experiment that they considered relevant to the study.

#### 2.5.5 Observer Rating Form

After each test scenario, the SMEs used the Observer Rating Form (see Appendix E) to provide performance ratings for each of the R-side/D-side controller teams. The Observer Rating Form was developed by ERPs and SMEs in the RDHFL 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 consisted 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.

### 2.6 Experimental Design

#### 2.6.1 Independent Variables

We used three experimental conditions in a repeated measures design for the study. Each controller participated in all three experimental conditions as the R-side controller and each controller participated in the three conditions as the D-side controller. In the three experimental conditions, we manipulated the separation procedures and support tools that were available for controllers to use. The first experimental condition was the Baseline condition, where participants controlled traffic using the standard 5-mile separation procedures without any of the support tools. The airspace did not have a 3-mile separation area designated for a single sensor radar site. The second experimental condition was the Reduced Separation condition, where the same airspace had an active 3-mile separation area. The participants controlled traffic using 3-mile separation procedures, where applicable, for aircraft equipment and types, but did not have access to any of the support tools. The third experimental condition was the Support Tools condition, where the controllers had full access to the support tools. The airspace had an active 3-mile separation area and participants controlled traffic using 3-mile separation procedures, where applicable. Wake turbulence separation procedures were always required in all three experimental conditions.

In addition, we configured the D-side workstation differently in the three experimental conditions. In the Baseline and Reduced Separation conditions, we configured the D-side workstation with the JEDI/URET prototype showing the Aircraft List and Graphic Plan Display. In the Support Tools condition, we configured the D-side workstation with a full radar display similar to the R-side workstation. The D-side had access to the same ERAM functions and Separation Management support tools as the R-side controller. In this configuration, we integrated the conflict probe features into the D-side radar display just as they were integrated into the R-side radar display. In addition, we synchronized the R-side and D-side displays for sharing information. When the D-side controller used any of the ERAM functions or Separation Management support tools (e.g., Leader Line Offset, J-rings, and Wake Tails), the features would also change the R-side display. Likewise, R-side features would also change the D-side display. Table 5 shows a summary of the simulation features for each of the three experimental conditions.

Table 5. Summary of the Simulation Features for each Experimental Condition

| Simulation Features | Baseline | Reduced Separation | Support Tools |
|---|---|---|---|
| Single Sensor Radar Site Adaptation | No | Yes | Yes |
| Reduced Separation for ADS-B and RNAV equipped aircraft | No | Yes | Yes |
| Increased Separation for UAS | No | Yes | Yes |
| Special Wake Turbulence Separation for A380s and VLJs | Yes | Yes | Yes |
| Separation Management Support Tools | No | No | Yes |
| D-side workstation as fully functional radar display | No | No | Yes |
| D-side display synchronized to R-side display | No | No | Yes |

*Note*. ADS-B = Automatic Dependent Surveillance-Broadcast; RNAV = Area Navigation; UAS = Unmanned Aircraft Systems; VLJs = Very Light Jets.

### 2.6.2 Simulation Measures

#### 2.6.2.1 System Effectiveness Measures

The RDHFL simulation software has an extensive data collection system that records aircraft track and status information during the simulation. We analyzed the aircraft track and status data to produce objective system effectiveness measures in the critical areas of safety, capacity, and efficiency, as well as communications (Buckley, DeBaryshe, Hitchner, & Kohn, 1983; Stein & Buckley, 1992). For the present study, the primary measure of safety was loss of aircraft separation. The measures of capacity were aircraft acceptance and handoffs made. The measures of efficiency were aircraft distance flown through the sector. We used the data recorded by the communications system to analyze the frequency and duration of controller and pilot communications.

#### 2.6.2.2 Human Factors Measures

The Post-Scenario Questionnaire was the main source of subjective data that measured controller performance, situation awareness, and workload in each of the experimental conditions. We used the WAK and the ATWIT method to provide an additional measure of workload using a real-time technique as controllers performed the traffic scenarios. We used the oculometer to track controller eye movements and examine their scanning patterns in each of the experimental conditions. We analyzed the eye-movement data to determine where eye fixations occur and the duration of the fixations.

#### 2.6.2.3 Observer Ratings

The SMEs used the Observer Rating Form to provide subjective ratings of controller performance in each of the experimental conditions. The SMEs were experienced observers who were used to training controllers and evaluating ATC performance. SMEs often detect controller actions that affect safety, capacity, and efficiency that cannot be measured by objective techniques.

2.6.2.4 Support Tools Usage

The RDHFL simulation software recorded keyboard data entry and trackball inputs. We analyzed the keyboard and trackball data to determine how often the controllers were using the separation management support tools and other controller functions. The Post-Scenario Questionnaire and Exit Questionnaire consisted of several questions about support tools usage and asked controllers to evaluate the user interface.

## 2.7 Procedure

### 2.7.1 Daily Schedule

Table 6 shows the daily schedule of activities for the participants in the study. Each group of participants consisted of four controllers who were released from their facility for one week to participate in the experiment. The participants traveled to the FAA WJHTC on Monday and departed on Friday. On Tuesday, Wednesday, and Thursday, the controllers participated in the experiment and performed practice and test scenarios. At the end of each day, we had 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 what to expect as participants 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.

Table 6. Daily Schedule of Activities

| Tuesday | | Wednesday | | Thursday | |
|---|---|---|---|---|---|
| **Time** | **Activity** | **Time** | **Activity** | **Time** | **Activity** |
| 8:00-9:15 | Project Briefing | 8:00-8:45 | Practice Scenario 5 | 8:00-8:45 | Practice Scenario 7 |
| 9:15-9:45 | Break | 8:45-9:15 | Break | 8:45-9:15 | Break |
| 9:45-10:30 | Practice Scenario 1 | 9:15-10:00 | Practice Scenario 6 | 9:15-10:00 | Practice Scenario 8 |
| 10:30-11:00 | Break | 10:00-10:30 | Break | 10:00-10:30 | Break |
| 11:00-11:45 | Practice Scenario 2 | 10:30-11:15 | Test Scenario 1 | 10:30-11:15 | Test Scenario 4 |
| 11:45-1:00 | Lunch | 11:15-1:00 | Lunch | 11:15-1:00 | Lunch |
| 1:00-1:45 | Practice Scenario 3 | 1:00-1:45 | Test Scenario 2 | 1:00-1:45 | Test Scenario 5 |
| 1:45-2:15 | Break | 1:45-2:15 | Break | 1:45-2:15 | Break |
| 2:15-3:00 | Practice Scenario 4 | 2:15-3:00 | Test Scenario 3 | 2:15-3:00 | Test Scenario 6 |
| 3:00-3:30 | Break | 3:00-3:30 | Break | 3:00-3:30 | Break |
| 3:30-4:30 | Question & Answer | 3:30-4:30 | Group Discussion | 3:30-4:30 | Exit Briefing |

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 Sessions

Table 7 summarizes the training plan and presentation of the practice scenarios for participants in the study. Tuesday was the first practice session. Wednesday and Thursday mornings were also practice sessions. On Tuesday, the controllers performed four low traffic practice scenarios to become familiar with the simulation equipment, generic airspace, separation management support tools, and new separation procedures. In the morning, we assigned the four participants to two R-side/D-side teams, and the controllers completed two practice scenarios. The controllers trained in the Baseline condition of the experiment for the first scenario and the Support Tools condition for the second scenario. In the afternoon, each R-side team member switched to the D-side position, and each D-side team member switched to the R-side position and repeated the two practice scenarios. By the end of the day, all participants had received initial training on both the R-side and D-side positions.

Table 7. Training Plan and Presentation of the Practice Scenarios

| **Participants** | **Scenario 1 Low Traffic** | **Scenario 2 Low Traffic** | **Scenario 3 Low Traffic** | **Scenario 4 Low Traffic** |
|---|---|---|---|---|
| 1, 3, 5, 7, 9, and 11 | R-side Baseline | R-side Support Tools | D-side Baseline | D-side Support Tools |
| 2, 4, 6, 8, 10, and 12 | D-side Baseline | D-side Support Tools | R-side Baseline | R-side Support Tools |
| **Participants** | **Scenario 5 High Traffic** | **Scenario 6 High Traffic** | **Scenario 7 High Traffic** | **Scenario 8 High Traffic** |
| 1, 3, 5, 7, 9, and 11 | R-side Reduced Separation | R-side Support Tools | D-side Reduced Separation | D-side Support Tools |
| 2, 4, 6, 8, 10, and 12 | D-side Reduced Separation | D-side Support Tools | R-side Reduced Separation | R-side Support Tools |

*Note.* Baseline: 5-mile Separation Procedures, No Support Tools;
Reduced Separation: 3-mile Separation Procedures, No Support Tools;
Support Tools: 3-mile Separation Procedures, Support Tools Available.

Each day on Wednesday and Thursday, the controllers performed two high-traffic practice scenarios that were nearly identical to the test scenarios. The high-traffic practice scenarios helped the controllers to learn how to move aircraft more efficiently using the new separation management support tools and procedures. On Wednesday, controllers took the R-side and D-side positions that they were assigned when they first began training and completed two practice scenarios. The controllers practiced the Reduced Separation condition in the first scenario and the Support Tools condition in the second scenario. On Thursday, the team members switched R-side and D-side positions and repeated the two practice scenarios.

We did not collect simulation effectiveness data during the training sessions. However, we used the same data collection equipment during training as we did in the testing sessions. The controllers used the WAK during each practice scenario. They completed the Post-Scenario Questionnaire and the SMEs completed the Observer Rating Form after each high-traffic practice scenario. The R-side controller wore the oculometer during the last high-traffic practice scenario to become comfortable with the device.

### 2.7.3 Testing Sessions

Table 8 shows the presentation order of the experimental conditions for participants in the study. We counterbalanced the experiment by changing the presentation order of the three experimental conditions for each R-side/D-side controller team. Wednesday and Thursday were testing sessions. For each session, team members remained in the same R-side and D-side positions throughout the day. After completing the practice scenarios, the controllers completed three high-traffic test scenarios. The controllers switched R-side and D-side positions between testing sessions. Using this procedure, all participants completed three test scenarios as both the R-side and D-side controller.

Table 8. Presentation Order of the Experimental Conditions

| Participants | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|
| 1 and 7 | R-side Baseline | R-side Reduced Separation | R-side Support Tools | D-side Baseline | D-side Reduced Separation | D-side Support Tools |
| 2 and 8 | D-side Baseline | D-side Reduced Separation | D-side Support Tools | R-side Baseline | R-side Reduced Separation | R-side Support Tools |
| 3 and 9 | R-side Support Tools | R-side Baseline | R-side Reduced Separation | D-side Support Tools | D-side Baseline | D-side Reduced Separation |
| 4 and 10 | D-side Support Tools | D-side Baseline | D-side Reduced Separation | R-side Support Tools | R-side Baseline | R-side Reduced Separation |
| 5 and 11 | R-side Reduced Separation | R-side Support Tools | R-side Baseline | D-side Reduced Separation | D-side Support Tools | D-side Baseline |
| 6 and 12 | D-side Reduced Separation | D-side Support Tools | D-side Baseline | R-side Reduced Separation | R-side Support Tools | R-side Baseline |

*Note.* Baseline: 5-mile Separation Procedures, No Support Tools;
Reduced Separation: 3-mile Separation Procedures, No Support Tools;
Support Tools: 3-mile Separation Procedures, Support Tools Available.

We used all data collection equipment during each test scenario. The controllers used the WAK during each test scenario. They completed the Post-Scenario Questionnaire, and the SMEs completed the Observer Rating Form after each test scenario. The R-side controller wore the oculometer for each test scenario. We used the audio-video recording system during the testing sessions.

## 3. RESULTS AND DISCUSSION

We analyzed most of the data from the experiment using inferential statistics. We used a one-way Analysis of Variance (ANOVA) for a repeated measures design to evaluate the differences between the experimental conditions. For each analysis, we set our significance level to be $p < .05$ and report the $F$ values of significant results. We used Tukey's Honestly Significant Difference (HSD) post hoc comparisons to evaluate each significant result. We will use graphs and tables to summarize the results of the experiment. The graphs will show the means of the experimental conditions with extending error bars that indicate one standard deviation from the mean.

### 3.1 System Effectiveness Measures

#### 3.1.1 Aircraft Accepted and Handed Off

As measures of sector capacity, we recorded the number of aircraft accepted and handed off by controllers for each scenario. The number of aircraft accepted included departures from the terminal area as well as handoffs from the adjacent en route sectors. The number of aircraft handed off included arrivals to the terminal area and handoffs to the adjacent en route sectors. Figure 10 shows the mean number of aircraft accepted into the sector and handed off from the sector for each of the experimental conditions. The number of aircraft accepted ranged from 45 to 50 aircraft per scenario and the number handed off ranged from 34 to 39 aircraft. Some participants accepted and handed off a few more aircraft than other participants. However, the analyses indicated that there were no statistical differences between the experimental conditions for either measure of capacity. We calculated aircraft throughput for the sector as the ratio of the number of aircraft handed off to the number of aircraft accepted. The computed percentages were very close for the Baseline (77.2%), Reduced (77.5%), and Tools (76.6%) conditions.

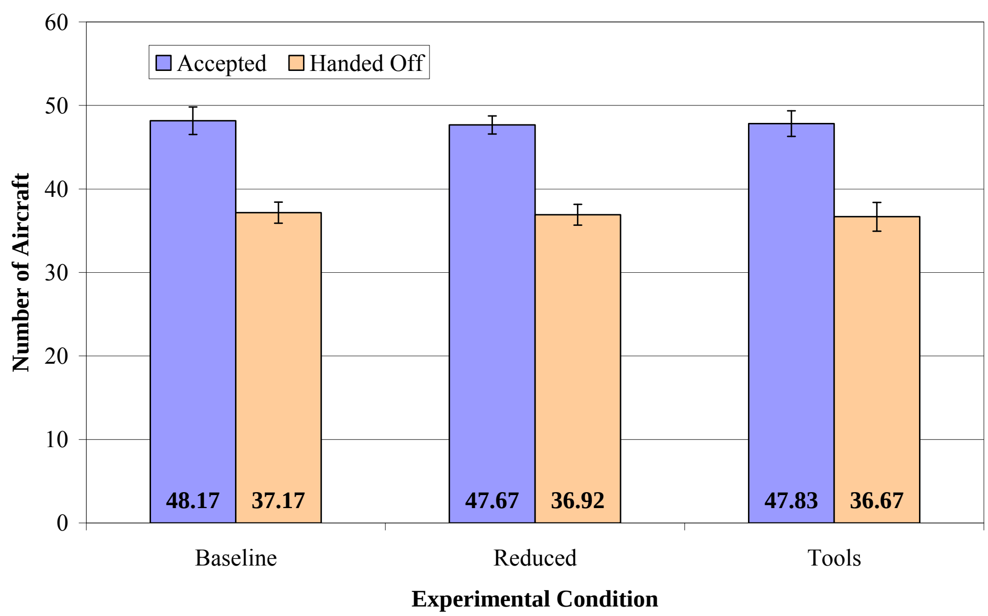


Figure 10. Mean number of aircraft accepted and handed off for each of the experimental conditions.

3.1.2 Aircraft Flight Distance

The aircraft's flight distance is a measure of efficiency and affects aircraft fuel consumption in combination with other factors. When the controllers accepted handoffs, they could expedite the aircraft through their sector with direct routings and decrease flight distance. In contrast, the controllers could vector aircraft off their routings because of traffic or other reasons and increase flight distance. Figure 11 shows the mean flight distance for each aircraft accepted into the sector for each of the experimental conditions. The mean flight distance ranged from 49 to 57 NM (90 to 105 km) per aircraft in each scenario. The participants had the opportunity to use reduced separation requirements and the support tools to decrease aircraft flight distance and improve efficiency. However, the analyses indicated that there were no statistical differences between the experimental conditions for aircraft flight distance. The results indicated that the Reduced and Tools conditions were no more efficient than the Baseline condition in which 5-mile standard aircraft separation was always required.

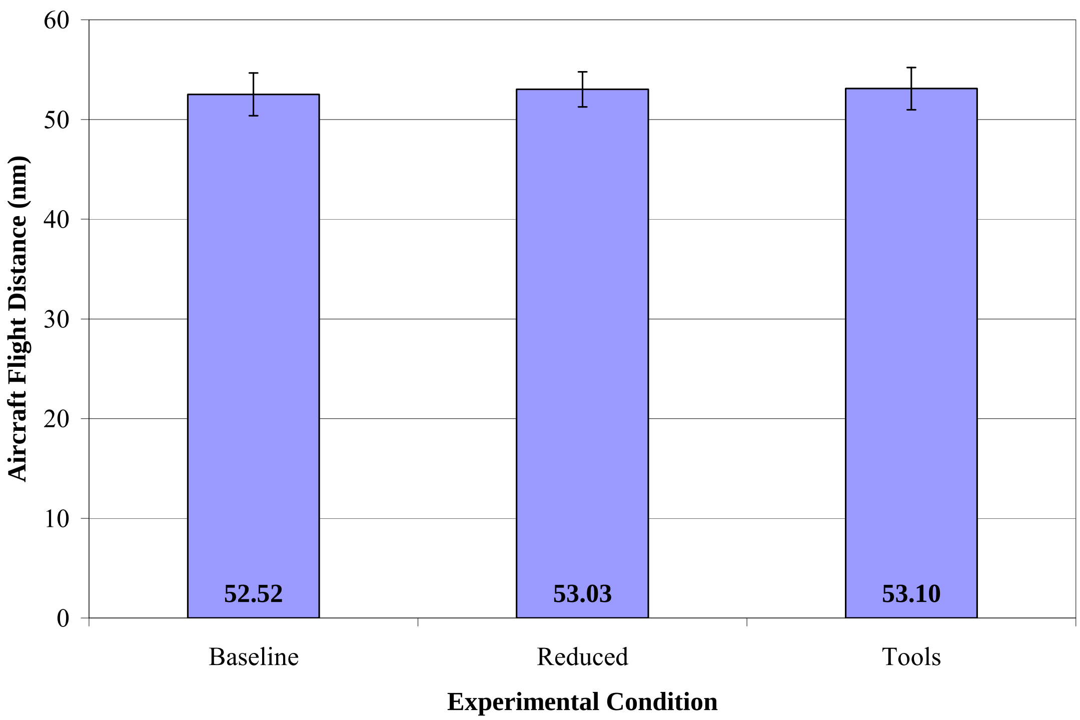


Figure 11. Mean aircraft flight distance for each of the experimental conditions.

3.1.3 Controller-to-Pilot Communications

Communications are a major source of workload for controllers. Decreasing communications can reduce controller workload and allow controllers to focus on other air traffic operations. Figure 12 shows the mean number and duration of controller-to-pilot communications for each of the experimental conditions. The mean number of controller communications ranged from 145 to 281 individual transmissions per scenario. The total duration of communications ranged from 7 to 17 minutes per scenario, which represented from 15% to 38% of the 45-minute scenarios. The mean transmission duration ranged from 2 to 6 seconds. Although we did not expect the reduced separation requirements and support tools to affect controller communications, we analyzed the data for potential differences. The results indicated that there were no statistical differences between the experimental conditions for the communications measures.

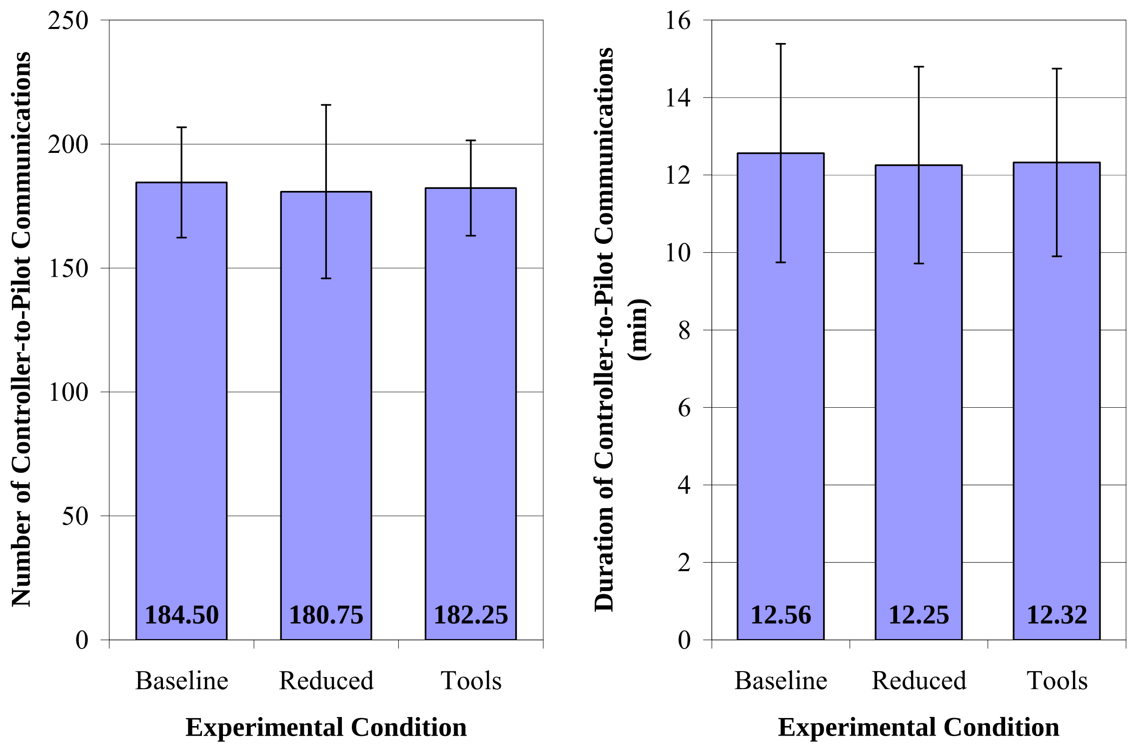


Figure 12. Mean number and duration of controller-to-pilot communications for each of the experimental conditions.

## 3.2 Human Factors Measures

### 3.2.1 Controller Performance Ratings

The participants rated their own performance on a 10-point scale ranging from 1 (*extremely poor*) to 10 (*extremely good*) after completing each traffic scenario. Figure 13 shows the mean overall performance ratings from the R-side and D-side controllers for each of the experimental conditions. In general, the participants rated their overall performance as very high (with mean ratings greater than 7). There was a large degree of variability in these data that included three ratings as low as 1 and nine ratings as high as 10. The differences between the experimental conditions were small and not statistically significant. Also, there were no differences between the R-side and D-side controller ratings. In addition to overall performance ratings, we asked controllers to rate their performance for identifying aircraft conflicts and separating aircraft efficiently. The results indicated that there were no significant differences for these additional performance ratings.

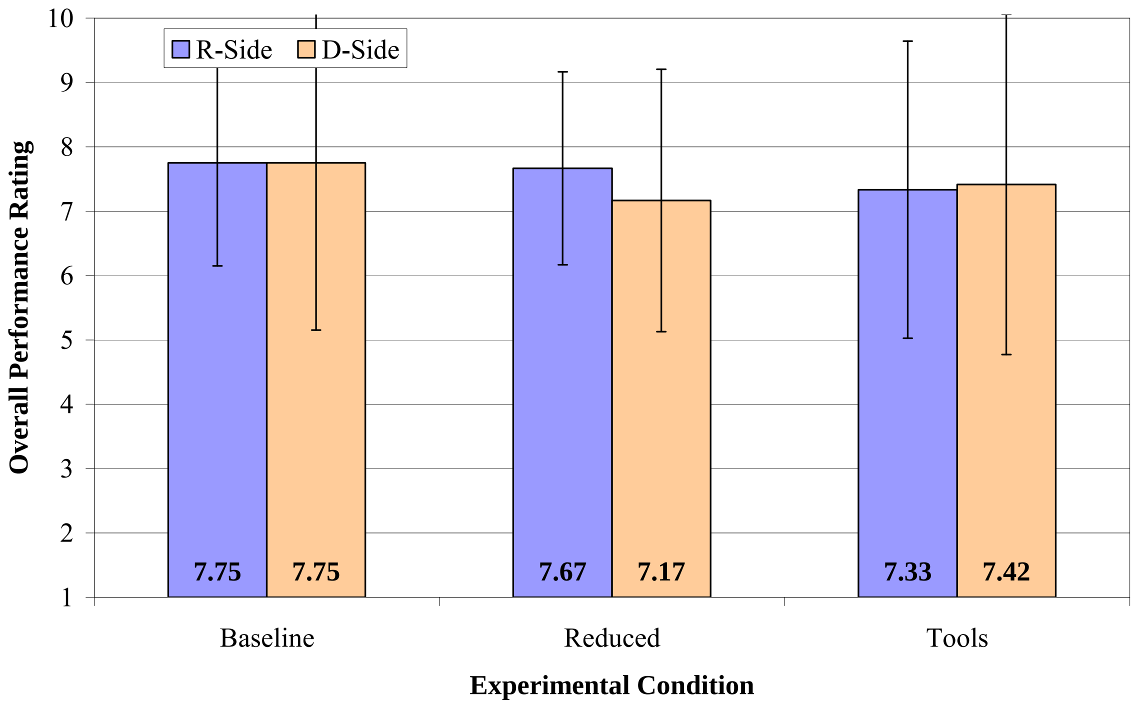


Figure 13. Mean overall performance ratings by controller position for each of the experimental conditions.

3.2.2 Controller Situation Awareness Ratings

The participants rated their own situation awareness on a 10-point scale ranging from 1 (*extremely poor*) to 10 (*extremely good*) after completing each traffic scenario. Figure 14 shows the mean overall situation awareness ratings from the R-side and D-side controllers for each of the experimental conditions. In general, the participants rated their overall situation awareness as very high (with mean ratings of 7 or greater). The results indicated that the R-side controllers rated their overall situation awareness differently in the experimental conditions, $F(2, 22) = 3.80$, $p = .038$; however, there were no differences for the D-side controllers. The post hoc comparisons indicated that the R-side controllers rated their situation awareness higher in Baseline relative to the Reduced and Tools conditions. The controllers' situation awareness in Baseline may have been higher because they were more familiar with the standard 5-mile separation procedures used in this condition. The Reduced and Tools conditions used variable separation procedures that were much more complex and may have made controllers feel less aware of the traffic situation and separation requirements.

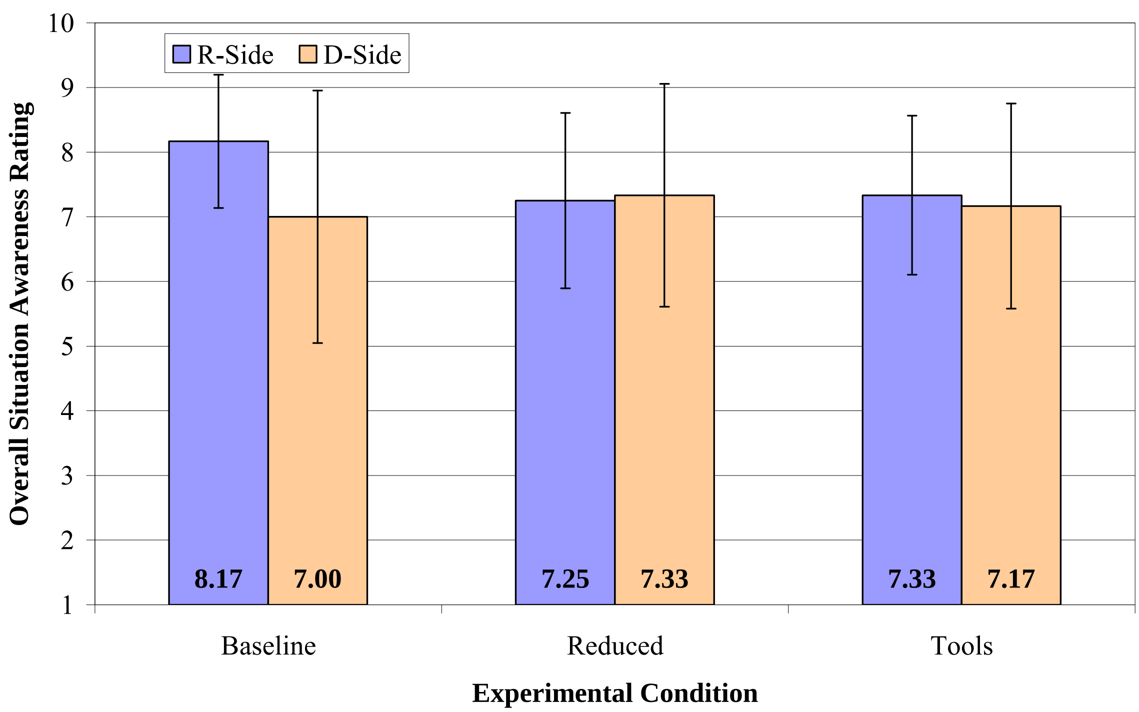


Figure 14. Mean overall situation awareness ratings by controller position for each of the experimental conditions.

3.2.3 Controller Workload Ratings

The participants used the WAK devices to provide workload ratings, every 2 minutes, on a 10-point scale ranging from 1 (*very low*) to 10 (*very high*). We calculated the mean for each participant by averaging across the 22 time intervals and then we calculated the mean across participants for each experimental condition. If participants were performing other tasks, they may not have provided a workload rating for the time interval. We treated these data as missing responses, and they accounted for about 10% of all workload ratings in the simulation. Figure 15 shows the mean WAK workload ratings from the R-side and D-side controllers for each of the experimental conditions. In general, controller workload was moderate with mean ratings between 3 and 5. The R-side controllers rated their workload as higher than the D-side controllers. However, the analyses indicated that there were no statistical differences between the experimental conditions for either the R-side or D-side controllers. In addition to WAK workload ratings, the participants provided workload ratings after each scenario. The results were similar for both the real-time and post-scenario rating methods and confirmed that there were no significant differences between the experimental conditions for the workload ratings. The more complex separation procedures in the Reduced and Tools conditions did not affect controller workload relative to Baseline. Also, there were no differences between the Reduced and Tools conditions, indicating that the support tools did not affect controller workload.

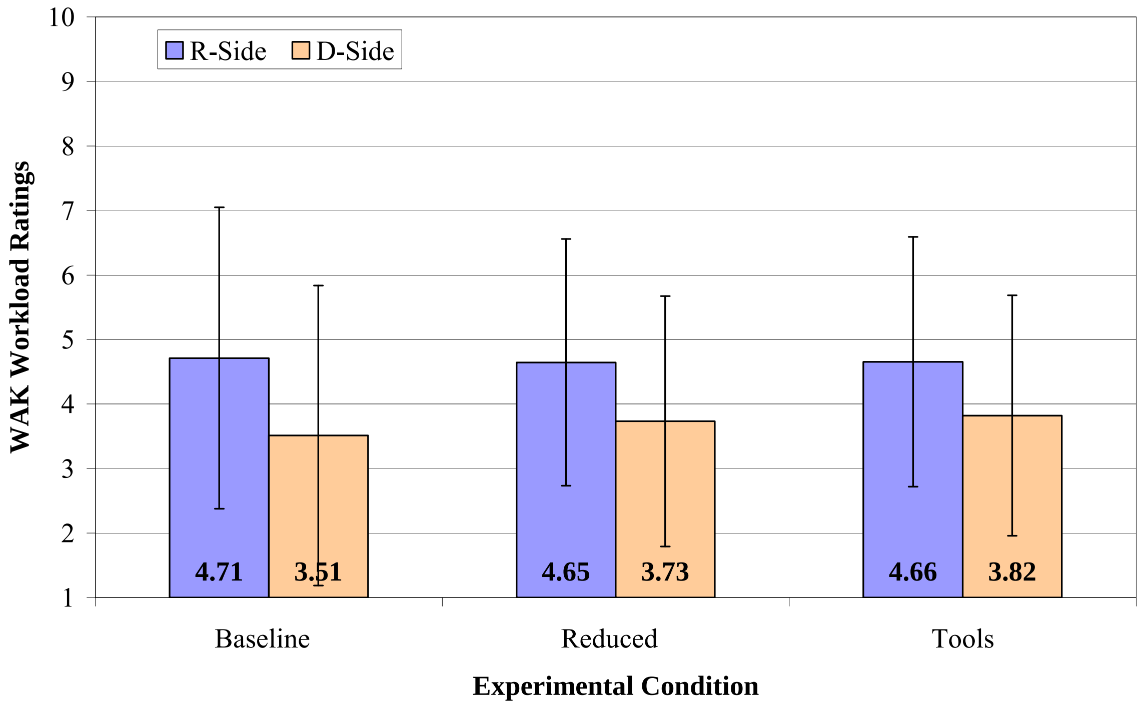


Figure 15. Mean WAK workload ratings by controller position for each of the experimental conditions.

3.2.4 Eye Movements

We used the oculometer to collect data for the R-side controllers' eye fixations and movements. For each fixation, the system recorded the point on the display where the participants' eyes were focused and the object of their focus (e.g., aircraft datablock, target symbol, or flight data list). We defined a *dwell* as a series of consecutive fixations on the same object. The processed data consisted only of dwells on aircraft objects. We used the number of dwells and dwell time to describe the controllers' scanning patterns in the simulation. Figure 16 shows the mean number of dwells and dwell time for the controllers' eye movements in each of the experimental conditions. The number of dwells ranged from 1,423 to 6,761 per scenario, and the mean dwell time ranged from slightly less than 1 second to 4 seconds per scenario. In general, the number of dwells was slightly less in the Tools condition and the mean dwell time was slightly greater; however, the variability was very large in these data. In fact, the analyses indicated that there were no statistical differences between the experimental conditions. In addition, we examined controller eye movements in data subsets for (a) Aircraft within the single sensor radar area, (b) ADS-B aircraft only, (c) RNAV aircraft only, and (d) UAS only. The results indicated that there were no significant differences for these separate analyses.

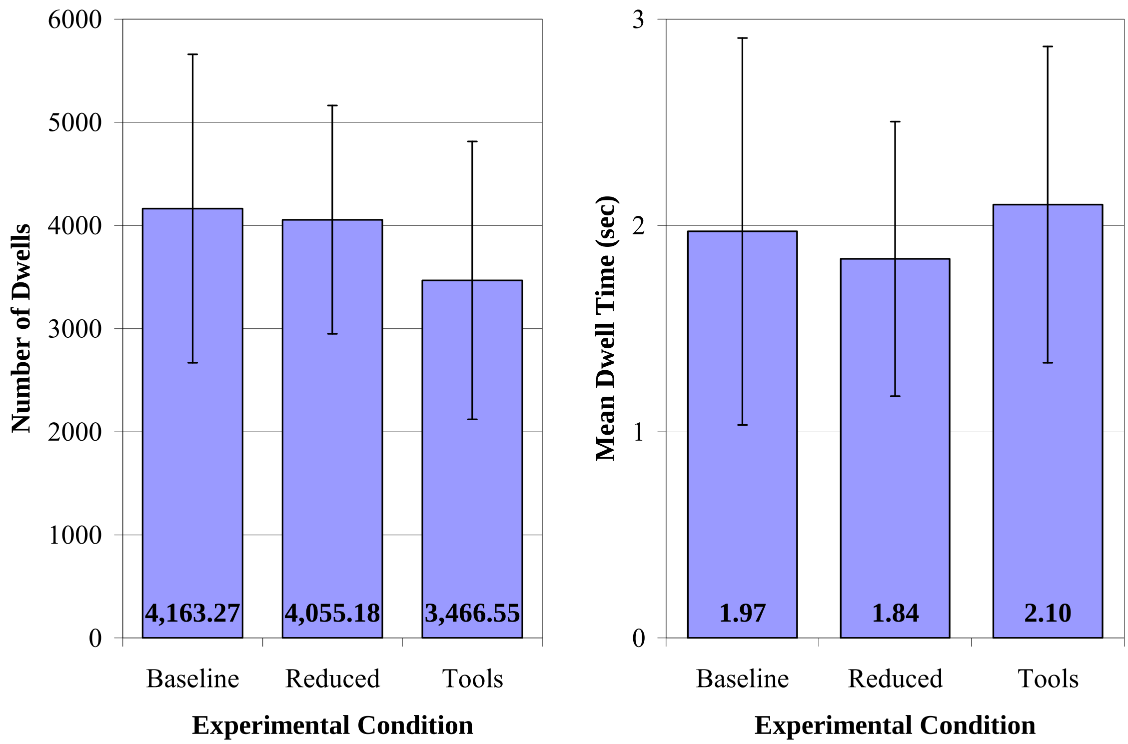


Figure 16. Mean number of R-side controller eye dwells and dwell time for each of the experimental conditions.

3.3 Observer Ratings

Two SMEs observed participants and rated their effectiveness in 26 different areas of ATC performance. The ratings included six primary scales and three to five subscales within each category. Each observer rated one of the controller teams on 8-point scales ranging from 1 (*least effective*) to 8 (*most effective*). Figure 17 shows the mean observer ratings for the first three primary scales of Safety & Efficiency, Attention & Awareness, and Prioritizing in each of the experimental conditions. Figure 18 shows the mean observer ratings for the remaining three primary scales of Providing Information, Knowledge, and Communicating in each of the experimental conditions. In general, observer ratings were high across the scales (with mean ratings ranging from 5 to 7). The differences between the experimental conditions were small and not statistically significant for any of the rating scales. The observers' written remarks included comments about some controllers and pilots having difficulty with RNAV phraseology. There was some confusion about identifying RNAV aircraft and remembering the appropriate wake turbulence separation requirements, especially in the Reduced condition. Also, the observers noted that many controllers wanted the 10-mile Halo support tool in the Reduced condition.

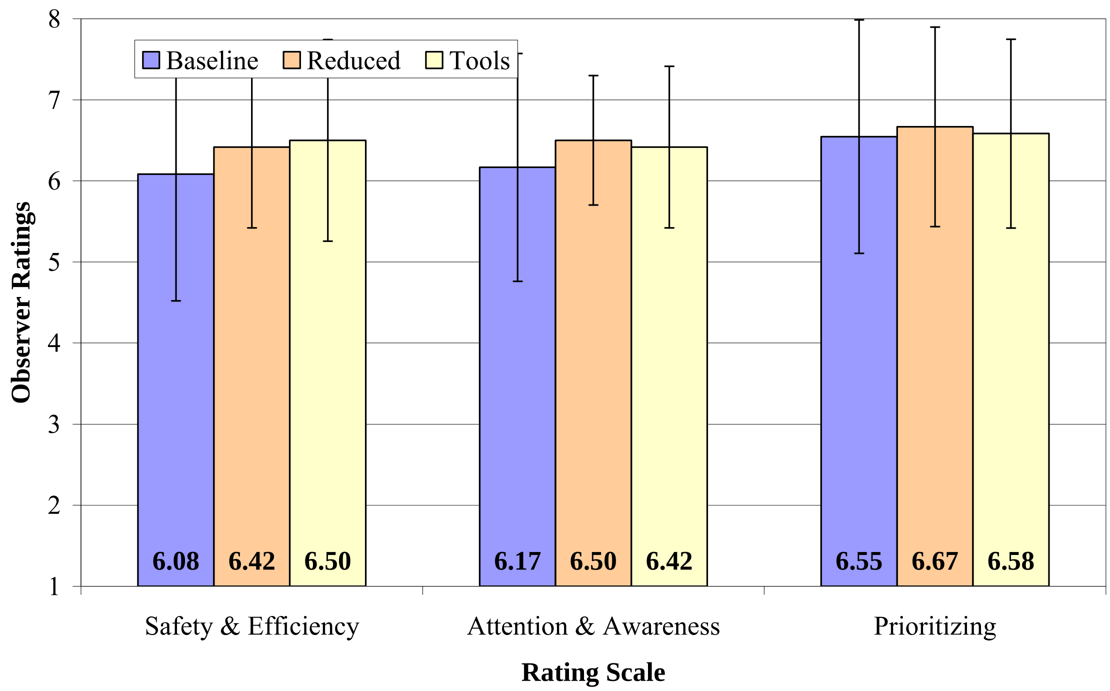


Figure 17. Mean observer ratings for safety & efficiency, attention & awareness, and prioritizing in each of the experimental conditions.

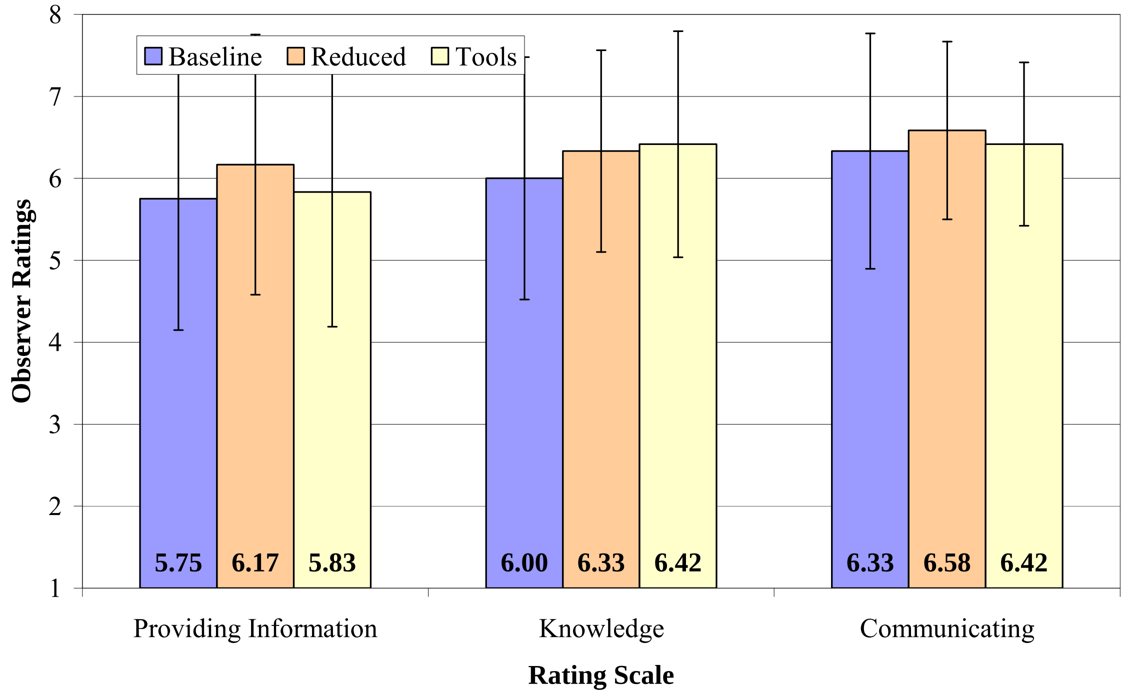


Figure 18. Mean observer ratings for providing information, knowledge, and communicating in each of the experimental conditions.

## 3.4 Support Tools Usage

### 3.4.1 Wake and RNAV Alerts

Wake and RNAV alerts were recorded by the simulation software as participants controlled traffic in the scenarios. Wake alerts occurred when the automation predicted an aircraft's trajectory would lead into another aircraft's wake remnants. RNAV alerts are most useful when they alert controllers to a pilot deviation from an RNAV route. However, there were no planned pilot deviations in the simulation. Most RNAV alerts occurred when the controllers vectored aircraft off their filed RNAV routes for traffic or other reasons. Wake and RNAV alerts were support tools that were always active in the Tools condition. In the Baseline and Reduced conditions, wake and RNAV alerts were not visible to controllers; however, they were recorded in the background for investigation in the data analyses. Figure 19 shows the mean number of wake and RNAV alerts for each of the experimental conditions. Wake alerts did not occur often in the simulation. On average, there were less than two wake alerts per scenario that lasted less than 16 seconds per alert. RNAV alerts were a little more frequent, ranging between four to seven alerts per scenario that lasted nearly 4.5 minutes per alert. The analyses for both alerts indicated that there were no statistical differences between the experimental conditions.

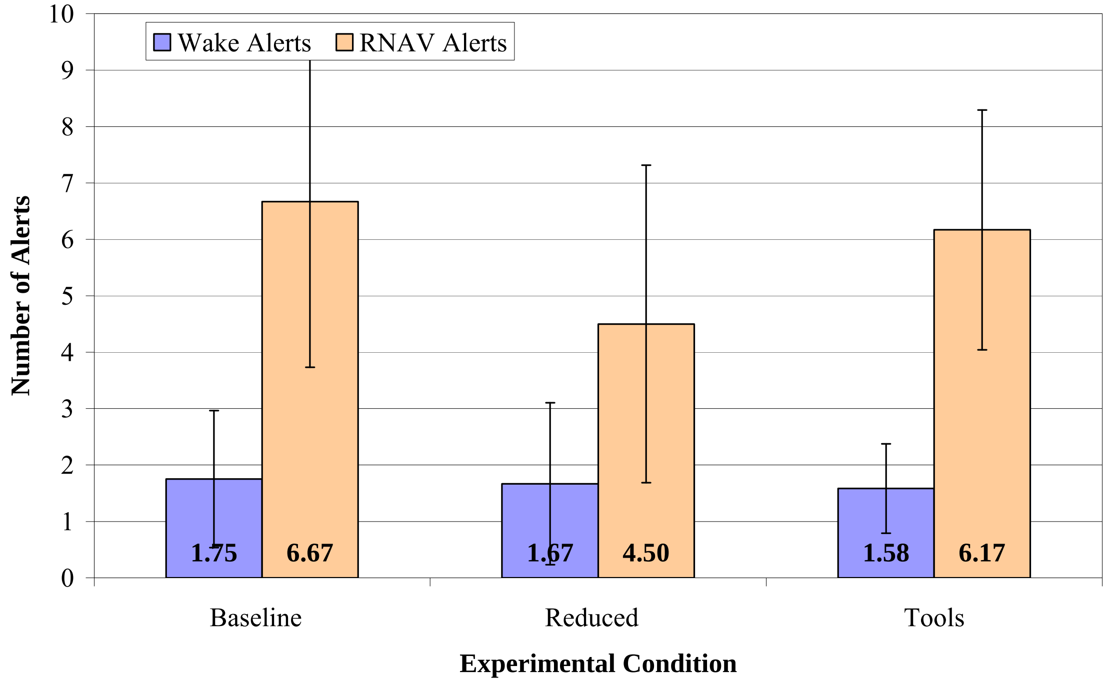


Figure 19. Mean number of wake and RNAV alerts for each of the experimental conditions.

As an additional descriptive analysis, we categorized all the wake alerts in the entire simulation by the aircraft weight classes. Table 9 shows the frequency of wake alerts by the leading and trailing aircraft weight classes for each of the experimental conditions. Over 55% of the wake alerts occurred for large aircraft, which was not surprising because large aircraft represented 52% of the aircraft in each scenario. A380s accounted for 15% of wake alerts as the leading aircraft even though they represented only 5% of the aircraft in each scenario. Small aircraft accounted for 22% and VLJs accounted for 7% of wake alerts as the trailing aircraft. Small aircraft represented 15% and VLJs represented 5% of the aircraft in each scenario. All 4 of the wake alerts for VLJs were in the Reduced condition relative to none in the Tools condition. These data confirmed that the A380 was a risk for loss of separation because of its large wake turbulence separation requirements. Also, small aircraft and VLJs were a risk while trailing heavier aircraft. The support tools may have helped controllers avoid wake turbulence situations, especially with VLJs.

Table 9. Frequency of Wake Alerts by Aircraft Weight Class and Experimental Condition

| Leading Aircraft Weight | Experimental Condition | | | Trailing Aircraft Weight | Experimental Condition | | |
|---|---|---|---|---|---|---|---|
| | Baseline Freq. | Reduced Freq. | Tools Freq. | | Baseline Freq. | Reduced Freq. | Tools Freq. |
| A380 | 3 | 4 | 2 | A380 | 2 | 1 | 1 |
| Heavy | 4 | 5 | 6 | Heavy | 1 | 1 | 1 |
| Large | 14 | 10 | 9 | Large | 11 | 8 | 13 |
| Small | 0 | 0 | 0 | Small | 5 | 5 | 3 |
| UAS | 0 | 1 | 2 | UAS | 2 | 1 | 1 |
| VLJ | 0 | 0 | 0 | VLJ | 0 | 4 | 0 |
| **Total** | **21** | **20** | **19** | **Total** | **21** | **20** | **19** |

*Note*. UAS = Unmanned Aircraft Systems; VLJ = Very Light Jet.

### 3.4.2 Wake Tails

Aircraft wake tails were a support tool that was available to controllers only in the Tools condition. Therefore, we did not perform an analysis to examine the differences in the experimental conditions. Instead, we conducted a descriptive analysis similar to the wake alerts to determine when controllers used wake tails. Table 10 shows the frequency of wake tails applied by the leading and trailing aircraft weight classes for the R-side and D-side controllers. The controllers applied the wake tails most frequently to A380s (38%), followed by large aircraft (31%), and heavy aircraft (28%). The controllers applied wake tails to UAS (3%) the least. Large aircraft (38%) were in the trailing position for most of the wake tails, followed by small aircraft (22%), and VLJs (22%). These results indicated that the controllers were effectively using the wake tails to identify the most risky wake turbulence situations with leading A380s and trailing small aircraft and VLJs. The D-side controllers applied three times as many wake tails as the R-side controllers. In the Tools condition, the R-side and D-side displays were synchronized so that when the D-side applied wake tails they were also displayed on the R-side position. These results indicated that the D-side controllers took a large role identifying potential wake turbulence situations to the R-side controllers.

Table 10. Frequency of Wake Tails Applied by Aircraft Weight Class and Controller Position

| **Leading Aircraft Weight** | **Controller Position** | | **Trailing Aircraft Weight** | **Controller Position** | |
|---|---|---|---|---|---|
| | **R-side Freq.** | **D-side Freq.** | | **R-side Freq.** | **D-side Freq.** |
| A380 | 2 | 10 | A380 | 1 | 1 |
| Heavy | 3 | 6 | Heavy | 1 | 2 |
| Large | 2 | 8 | Large | 3 | 9 |
| Small | 0 | 0 | Small | 2 | 5 |
| UAS | 0 | 0 | UAS | 1 | 0 |
| VLJ | 1 | 0 | VLJ | 0 | 7 |
| **Total** | **8** | **24** | **Total** | **8** | **24** |

*Note*. UAS = Unmanned Aircraft Systems; VLJ = Very Light Jet.

### 3.4.3 Aircraft Halos

The controllers used different halo sizes depending upon the experimental condition. In the Baseline condition, the controllers used only 5-mile halos because there were no reduced separation requirements. In the Reduced condition, the controllers used both 3-mile and 5-mile halos while using reduced separation procedures. In the Tools condition, the controllers used 3-miles, 5-miles, and the improved halos for 3/5-miles and 10-miles as support tools. Figure 20 shows the mean number of halos used by the R-side and D-side controllers for each of the experimental conditions. The results indicated that the R-side controllers used halos differently in the experimental conditions, $F(2, 22) = 14.32$, $p < .01$; however, there were no differences for the D-side controllers. The post hoc comparisons indicated that the R-side controllers used more halos in Reduced relative to the Baseline and Tools conditions. It is not clear why R-side controllers used so many more halos in the Reduced condition. Some controllers used halos as a reminder for the required wake turbulence separation in the Reduced condition because halos were the best tool available to them without having wake tails. However, it is uncertain how frequently controllers used halos for this purpose.

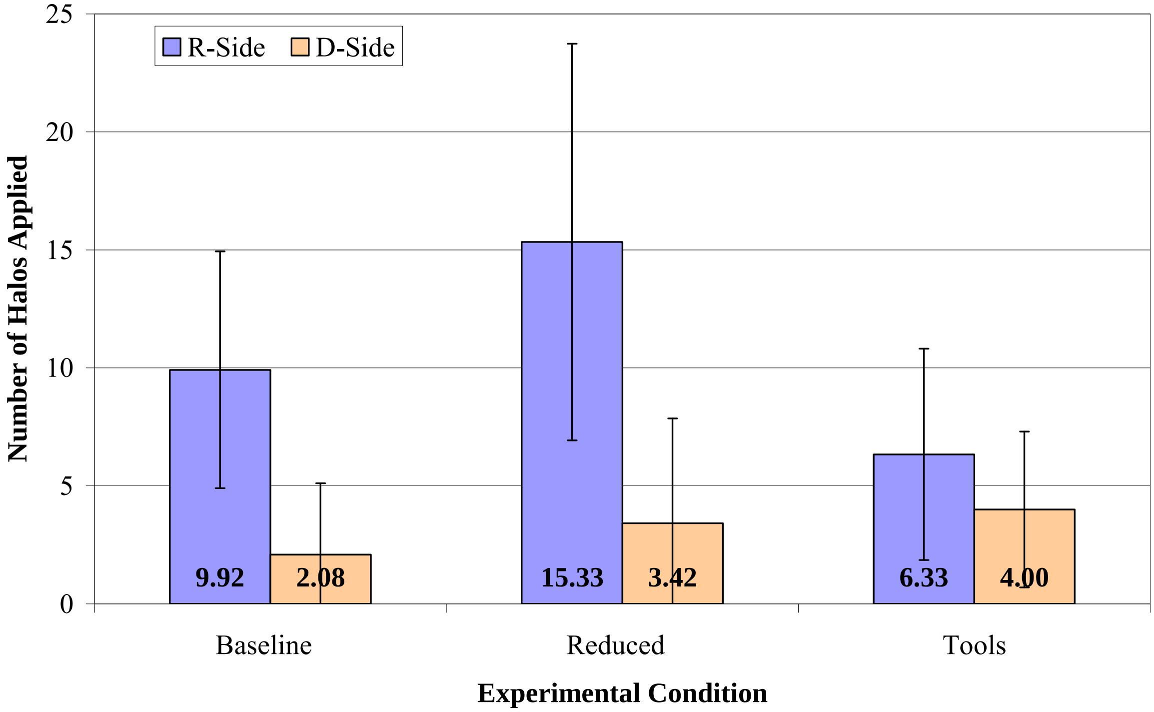


Figure 20. Mean number of halos applied by controller position for each of the experimental conditions.

In the Tools condition, automation determined the halo size, but controllers decided when they would use halos. Halo usage usually indicates when controllers require visual information regarding aircraft separation distances. As an additional descriptive analysis, we categorized all the halos used in the Tools condition for the entire simulation. Table 11 shows the frequency of halos applied by the halo size for the R-side and D-side controllers. The controllers used the 3-mile halos most frequently (29%), followed by 3/5-mile halos (27%), and 10-mile halos (24%). The controllers used 5-mile halos (20%) the least. In general, the R-side controllers used halos more frequently than the D-side controllers. However, the D-side controllers used more 10-mile halos than the R-side controllers. The controllers used halos the most for aircraft within the single sensor radar area, which was the only situation that the automation allowed 3-mile halos. The controllers frequently used 3/5-mile halos for the majority of aircraft (92%) with ADS-B or RNAV equipment. The controllers frequently used 10-mile halos for UAS that represented only 5% of aircraft in scenarios. Finally, the controllers frequently used 5-mile halos for the few aircraft (3%) that were not equipped for reduced separation and were not flying within the single sensor radar area. Also, these results indicated that the D-side controllers took a large role using 10-mile halos for UAS to support the R-side controllers.

Table 11. Frequency of Halos Applied by Halo Size and Controller Position

| | Controller Position | |
|---|---|---|
| | R-side | D-side |
| **Halo Size** | **Freq.** | **Freq.** |
| 3-mile Halos | 28 | 8 |
| 5-mile Halos | 17 | 8 |
| 3/5-mile Halos | 20 | 13 |
| 10-mile Halos | 11 | 19 |
| **Total** | **76** | **48** |

3.4.4 Route Amendment and Conflict Identification

The Route Amendment Graphic Tool and Conflict Identification & Route Display were support tools that were available to controllers only in the Tools condition. The Route Amendment Graphic Tool allowed the controllers to show an aircraft route on the radar display, modify the route using the trackball, and easily complete the route amendment without having to use the CRD for data entry. The Conflict Identification & Route Display tool integrated JEDI/URET data on the radar display. The tool displayed the number of conflicts on aircraft datablocks and allowed the controllers to show the conflict routes by selecting the number with the trackball. Both tools could be used by either the R-side controller or the D-side controller using a fully functional radar display in the Tools condition. Table 12 shows the frequency of use for both tools by the R-side and D-side controllers. The results indicated that the controllers did not use either support tool very often. Five of the R-side controllers used the Route Amendment Graphic Tool and only one controller used the Conflict Identification & Route Display tool to display conflict routes. The D-side controllers used the tools more frequently than the R-side controllers. Six of the D-side controllers used the Route Amendment Graphic Tool and eight controllers used the Conflict Identification & Route Display tool. Although frequency of use was low, the results indicated that the D-side controllers took a role using both tools to support the R-side controllers. Both the R-side and D-side controllers were more likely to use the Conflict Identification & Route Display tool to display red conflict routes relative to yellow conflict routes. The red conflict routes showed predicted loss of aircraft separation, whereas the yellow conflict routes showed near loss of separation.

Table 12. Frequency of Route Amendment and Conflict Identification Tool Usage by Controller Position

| | Controller Position | |
|---|---|---|
| | R-side | D-side |
| Support Tool | Freq. | Freq. |
| Route Amendment Graphic Tool | 7 | 31 |
| Conflict Identification & Route Display, Total | 3 | 29 |
| - Red Conflict Routes Displayed | 3 | 25 |
| - Yellow Conflict Routes Displayed | 0 | 4 |

3.5 Support Tools Effectiveness

After each Tools scenario was completed, the participants rated the effectiveness of each support tool on a 9-point scale ranging from 1 (*negative effect*) to 9 (*positive effect*); a rating of 5 indicated a *neutral* or *no effect*. Table 13 shows the mean participant effectiveness ratings for each support tool from the R-side and D-side controllers. In general, the participant tool effectiveness ratings were positive. The shading for the single sensor radar area and wake tails were rated as the most effective tools. The route amendment graphic tool was also rated as positive, but ratings were variable. The RNAV route conformance monitor and the conflict probed flyout menus were rated as the least effective. The participants' written comments were positive about the shaded area and wake tails. The participants thought the shaded area helped a great deal with spacing arrivals efficiently and climbing departures as early as possible. The wake tails were helpful to identify the appropriate wake turbulence separation requirements. Some controllers commented that they liked the wake tails, but forgot to use them as much as they could have. There was a simulation problem because the conflict probed flyout menus did not always show color. Some controllers commented that they ignored the probe and that some red alerts were not valid. The participants also commented that the RNAV route conformance monitor was not useful, so they often ignored it.

Table 13. Means and Standard Deviations for the Participant Ratings of Support Tool Effectiveness by Controller Position

| | Controller Position | | | |
|---|---|---|---|---|
| | R-side | | D-side | |
| **Support Tool** | **Mean** | **(*SD*)** | **Mean** | **(*SD*)** |
| Shading for Single Sensor Radar Area | 7.5 | (0.90) | 7.6 | (1.44) |
| Wake Turbulence Distance Indicator (Wake Tails) | 6.9 | (1.22) | 6.8 | (1.36) |
| Wake Turbulence Alert | 5.2 | (0.98) | 5.4 | (1.62) |
| RNAV Route Conformance Monitor | 4.8 | (0.98) | 5.0 | (1.61) |
| Route Amendment Graphic Tool | 6.0 | (1.73) | 6.0 | (1.48) |
| Conflict Probed Flyout Menus | 5.4 | (0.67) | 4.9 | (1.00) |
| Conflict Identification Data on the R-side Display | 5.7 | (1.10) | 5.8 | (1.03) |

*Note*. RNAV = Area Navigation.

After the entire simulation was completed, the participants rated the importance of the information provided by each support tool on a 10-point scale ranging from 1 (*not important*) to 10 (*very important*). Table 14 shows the mean participant importance ratings for each support tool. The participants' importance ratings were high for most of the tools. The shading for the single sensor radar area and wake tails were rated as the most important information for controllers. Only the RNAV route conformance monitor was rated as less than 5 on the scale. The participants' written comments indicated that the shaded area was very important to identify the 3-mile zone and the concept was much better than a simple map line. The participants also commented that the wake tails were very important, but they suggested some automation so that controllers would not always have to manually apply wake tails in important situations. Some participants commented that the conflict probed menus and conflict identification tool showed important information. However, controllers are unaccustomed to seeing this information on the radar display, and it was frequently ignored. The participants also thought that younger controllers who are currently in training may make better use of conflict probe information on the radar display.

Table 14. Means and Standard Deviations for the Participant Ratings of Information Importance for the Support Tools

| **Support Tool** | **Mean** | **(*SD*)** |
|---|---|---|
| Shading for Single Sensor Radar Area | 9.5 | (0.80) |
| Wake Turbulence Distance Indicator (Wake Tails) | 7.6 | (1.68) |
| Wake Turbulence Alert | 7.1 | (1.83) |
| RNAV Route Conformance Monitor | 4.9 | (2.19) |
| Route Amendment Graphic Tool | 7.3 | (2.83) |
| Conflict Probed Flyout Menus | 7.3 | (1.79) |
| Conflict Identification Data on the R-side Display | 6.7 | (2.27) |

*Note*. RNAV = Area Navigation.

## 4. CONCLUSIONS

We conducted a high-fidelity, HITL simulation to identify the human factors issues for controllers, using future separation management concepts and support tools. In the simulation, we examined three different experimental conditions, which we varied the separation procedures and support tools that were available for controllers to use. The first issue we quickly discovered was that using several different variable separation requirements and procedures were more complex for controllers than we had first thought. Our background research indicated that 3-mile separation procedures were already approved for the en route environment by FAA Order 7110.65, where radar coverage allows. Our visit to the Boston ARTCC indicated that controllers were already using 3- and 5-mile variable separation procedures in their sectors with a single sensor radar site adaptation. The staff and controllers at Boston ARTCC told us that the procedures were working very well without any supporting automation.

The participants in our simulation, however, told us that aircraft separation was very complex using different separation requirements depending upon aircraft equipment and types. To effectively use reduced aircraft separation, the controllers needed to quickly identify aircraft that had ADS-B and RNAV equipment and remember the required separation procedures. The controllers needed to be especially vigilant for UAS and remember that they had increased separation requirements. Also, the participants told us that the wake turbulence separation requirements were the most complex procedure in the simulation and the most difficult for controllers to remember. In comparison, the participants reported that using reduced separation requirements within a clearly delineated boundary determined by a single sensor radar was an easy procedure.

The participants identified wake turbulence separation as the most important issue for en route controllers, who currently encounter these situations much less than terminal area controllers. Although wake turbulence separation has always been a requirement in the en route environment, controllers will encounter more wake turbulence situations when aircraft such as A380s and VLJs become more prevalent in the NAS. Also, wake turbulence situations can occur more frequently when controllers try to tighten aircraft spacing using reduced separation procedures. Therefore, the participants advised us that controllers may use reduced separation procedures less often because they may not want to risk wake turbulence violations. In addition, the participants commented that reduced separation procedures may be more risky in the en route environment because aircraft fly faster than in the terminal area.

The participants identified increased separation requirements for aircraft, such as UAS, as another concern that may cause controllers to use reduced separation less often. Although we were not aware of any aircraft that required greater than 5-mile lateral separation, we wanted to investigate the human factors issues in these situations. The participants reported that UAS added complexity to the traffic situation, and they were a risk for loss of aircraft separation. However, increased separation requirements for UAS were not as difficult as wake turbulence because UAS required a consistent 10-mile separation from all other aircraft instead of variable separation, depending upon the leading and trailing aircraft weight classes. Also, there was only one UAS type in the simulation and only a few UAS appeared in each scenario, reducing complexity relative to the numerous potential wake turbulence situations.

In general, the reduced separation procedures did not increase sector capacity or improve efficiency as we expected in the Reduced and Tools conditions relative to the Baseline condition. The results indicated that the controllers did not accept or hand off more aircraft, and the aircraft flight distances were no different in the three experimental conditions. Also, the participant and SME performance ratings were no different. The reasons why we did not observe more benefits for reduced separation may be because of the wake turbulence and increased separation procedures for UAS that were included in the Reduced and Tools conditions. As the participants advised, wake turbulence and increased separation for specific aircraft added a great deal of complexity and presented risks for loss of aircraft separation. The participants were more comfortable and rated their situation awareness as higher in the less complex Baseline condition.

In addition, we instructed the participants to use reduced separation, when possible, but the procedures were optional and at the discretion of the controllers. Although each scenario presented opportunities to use reduced separation, the controllers may have been reluctant to accept the risk in complex situations where so many different variable separation procedures were required. For the most part, the controllers maintained the 5-mile separation standard that they use every day at their facilities. The controllers may have been more willing to use reduced separation in situations that benefited themselves in terms of reduced workload, decreased communications, or fewer control instructions. These kinds of opportunities for reduced separation, however, may have been limited in the sector airspace and traffic scenarios that we used in the simulation.

The proposed set of support tools did not help the participants to use the reduced separation procedures more effectively in the Tools condition compared to the Reduced condition. The results indicated that there were no improvements in sector capacity or efficiency and no differences in controller workload between the experimental conditions. However, almost every participant told us that they needed more practice time to become proficient with the support tools and to become more experienced with the variable separation procedures. During the three days of simulation, each participant received 4 hours of practice in the R-side position and 4 hours of practice in the D-side position. In future research, we should plan another week, or more, for training participants because of the complexity of the separation procedures and the number of tools available for controllers to use.

In contrast, the participants' ratings of effectiveness were positive for most of the support tools. The shading for the single sensor radar area was a simple idea. However, the controllers thought that it was an important tool to identify the boundary where 3-mile separation was allowed for arrivals and where 5-mile separation was required for departures. The controllers also liked the variable brightness setting for the shading and most used a low intensity level that made it easy to read aircraft datablocks in the area. The controllers thought that wake alerts and wake tails were very good tools to help them avoid wake turbulence violations. The wake turbulence separation procedures were the most complex, and these tools helped the controllers to remember the required separation distances. However, the participants were unaccustomed to applying wake tails and thought that automation to display wake tails would improve their effectiveness.

The participants did not use the route amendment graphic tool very often. However, they thought the tool was important and effective for making route amendments and represented a savings compared to the usual keyboard method of data entry. The route amendment graphic tool was a little awkward to use with a trackball and required two hands. The participants thought that they may have used the tool more often with more practice and more applicable scenario situations, such as routing around weather. The tool is probably most effective when used with digital communications technology in which controllers can uplink route amendment control instructions directly to pilots without requiring voice communications.

The participants' ratings for the RNAV conformance monitor were neutral in effectiveness. The RNAV conformance monitor was intended as an alert for the rare instances when pilots accidentally deviate from RNAV routes. In the simulation, we did not plan any pilot deviations and the alerts occurred when controllers vectored aircraft off their filed RNAV routes. Most of the participants reported that they ignored the RNAV alerts in these situations. The controllers also commented that they did not always notice the other datablock features (i.e., interim altitude box and double down arrow). However, they thought that it was important to have indicators to identify aircraft that were filed and established on an RNAV route.

The participants did not use the conflict probed flyout menus and Conflict Identification & Route Display tools very often. In the simulation, the conflict probed flyout menus were limited in their effectiveness because the menus did not always show color. The participants advised us that many experienced controllers do not make full use of URET conflict identification and trial planning features at their facilities. They do not use the conflict route display feature often because they know that URET identifies long-term conflicts that are not a priority. The experienced controllers are more confident that they are able to identify short-term conflicts themselves. However, the participants reported that less experienced developmental controllers use URET automation more frequently and may value conflict probe data shown directly on their R-side display. Therefore, we should recruit controllers who frequently use URET to evaluate these tools in future simulation research.

The participants advised us that improved aircraft halos will be an important tool for future aircraft separation requirements. They thought that larger halos for aircraft with increased separation requirements will be necessary. The controllers reported that it was important to identify aircraft with different separation requirements, and they thought our 3/5-mile halo idea was acceptable. However, they suggested another idea that would allow controllers to manually select their preferred size and apply a single aircraft halo. The disadvantage of this idea is that controllers would need to remember the required separation distance and use more keystrokes to specify the appropriate halo size. Aircraft halos are a key support tool for separation management, and we should consider various alternatives for using automation effectively.

The participants identified two additional human factors issues during the simulation. The first was that the RNAV route we designed for this sector was not an efficient airway. The potential benefits of RNAV routes are that pilots can fly these routes with precision using GPS navigation and their onboard Flight Management System. Once established on the RNAV route, pilots should not need control instructions, and controllers monitor the aircraft through the sector. Our RNAV route was more complex because there was a mix of aircraft in the area. Some aircraft were able to fly the RNAV route without control instructions as intended. Some aircraft were filed for the RNAV route, but had to be vectored off the route for spacing. Other aircraft were not equipped to fly the RNAV route, but the controllers instructed the aircraft to fly the same navigation fixes through the sector. In these situations, it was difficult for controllers to identify the aircraft that were RNAV equipped, established on the route, and qualified for reduced separation with other qualified aircraft. In our simulation, we used an RNAV conformance monitor, datablock indicators, and phraseology for pilots and controllers to identify RNAV aircraft. The participants thought our tools helped, but the pilots and controllers did not always remember to use the correct phraseology and there was still some confusion in these situations.

The last human factors issue involved our design for the synchronization of the R-side and D-side displays in the Tools condition of the simulation. The participants reported that in some cases the synchronization was effective for sharing information between the displays. For example, the D-side controller often used halos and wake tails to support the R-side controller. However, the participants noted that sometimes the synchronization was annoying when information sharing was not intended. For example, the D-side controller may use the display for strategic planning and change the R-side display in ways that would interfere with immediate aircraft separation. We need to further develop our R-side and D-side display synchronization concept to enable and disable information sharing at the discretion of controllers.

Finally, HITL simulations are an excellent technique to identify human factors issues using future separation management concepts and advanced air traffic tools. Simulations provide an environment for controllers to try new ideas and evaluate their effectiveness under realistic air traffic conditions. Researchers collect a high quality of information from simulation participants that would not be possible without a "hands on" experience. The challenges for simulations are to provide participants with sufficient training to use the new concepts and tools. The participants need to become highly proficient to maximize the potential for researchers to collect objective and subjective data that will demonstrate benefits in a limited amount of simulation time. Obviously, the more time that can be devoted to training and data collection, the better the quality of results.

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## Acronyms

| | |
|---|---|
| ADS-B | Automatic Dependent Surveillance-Broadcast |
| ARTCC | Air Route Traffic Control Center |
| ATC | Air Traffic Control |
| ATWIT | Air Traffic Workload Input Technique |
| DESIREE | Distributed Environment for Simulation, Rapid Engineering, and Experimentation |
| D-side | Data-side |
| ERAM | En Route Automation Modernization |
| ERP | Engineering Research Psychologist |
| FAA | Federal Aviation Administration |
| FL | Flight Level |
| GENERA | Generic TRACON airspace |
| GPS | Global Positioning System |
| HFTAC | Human Factors Team–Atlantic City |
| HITL | Human-In-The-Loop |
| JPDO | Joint Planning and Development Office |
| NAS | National Airspace System |
| NextGen | Next Generation Air Transportation System |
| PBN | Performance-Based Navigation |
| PTT | Push-To-Talk |
| RDHFL | Research Development and Human Factors Laboratory |
| RNAV | Area Navigation |
| RNP | Required Navigation Performance |
| R-side | Radar-side |
| SME | Subject Matter Expert |
| TGF | Target Generation Facility |
| UAS | Unmanned Aircraft Systems |
| URET | User Request Evaluation Tool |
| VLJ | Very Light Jet |
| 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 "A Human-in-the-Loop Investigation of Automation Requirements for Separation Management" is sponsored by the Federal Aviation Administration (FAA) and is being directed by Dr. Randy Sollenberger.

**Nature and Purpose:**

I have been recruited to volunteer as a participant in this project. The purpose of the study is to evaluate support automation for future separation management in a high-fidelity, human-in-the-loop simulation. The researchers will use the results of this study to recommend automation requirements for future builds of the En Route Automation Modernization (ERAM) system.

**Experimental Procedures:**

A group of four controllers will arrive at the Research, Development, and Human Factors Laboratory (RDHFL) each week to participate in the study. The controllers will travel to the FAA William J. Hughes Technical Center (WJHTC) on Monday and depart on Friday. On Tuesday, Wednesday, and Thursday, the controllers will participate in the experiment 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 traffic scenarios. On the first day of the study, we will brief the participants about the project goals and what to expect as participants in this simulation. On the last day of the study, we will conduct an exit briefing to gather feedback from participants about the entire experiment.

On Tuesday after the project briefing, we will assign the four participants to two R-side/D-side teams, and the controllers will perform four practice scenarios to become familiar with the simulation equipment, generic airspace, and experimental conditions of the study. On Wednesday, the controllers will perform two practice scenarios and then begin the three test scenarios. On Thursday, the controllers will switch R-side and D-side positions with their team members and perform two more practice scenarios and three more test scenarios. In the three experimental conditions, we will manipulate the separation procedures and support tools that will be available for controllers to use.

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. Each R-side controller will be asked to wear an oculometer to record eye movements. 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 oculometer that is used to record eye movements may cause some discomfort. The skin area under the headband that supports the oculometer may show some redness after wearing the device for the duration of the scenario.

**Confidentiality:**

My participation is strictly confidential, and no individual names or identities will be recorded or released in any reports.

**Benefits:**

I understand that the only benefit to me is that I will be able to provide the researchers with valuable feedback and insight into the automation required to support future separation management. My data will help the FAA to identify the human factors issues in the future separation management concept and develop automation support for controllers.

**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.

**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 understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed.

I have not given up any of my legal rights or released any individual or institution from liability for negligence.

Dr. Sollenberger has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Dr. Sollenberger or another member of the research team will be available to answer any questions concerning procedures throughout this study.

If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Dr. Sollenberger at (609) 485-7169.

**Compensation and Injury:**

I agree to immediately report any injury or suspected adverse effect to Dr. Randy Sollenberger at (609) 485-7169. 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 **actively controlled traffic** in the en route environment? | _____ years _____ months |
| 6. How long have you **actively controlled traffic** in the terminal environment? | _____ years _____ months |
| 7. How many of the **past 12 months** have you actively controlled traffic? | _____ months |

| | | | |
|---|---|---|---|
| 8. Rate your current **skill as a CPC**. | Not Skilled | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Skilled |
| 9. Rate your **level of motivation** to participate in this study. | Not Motivated | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Motivated |

# Appendix C

# Post-Scenario Questionnaire

Post-Scenario Questionnaire

Instructions:

Please answer the following questions based upon your experience in the scenario just completed. Your identity will remain anonymous.

## Performance

| | | | |
|---|---|---|---|
| 1. Rate your **overall level of ATC performance** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 2. Rate your **performance** for **identifying aircraft conflicts** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 3. Rate your **performance** for **separating aircraft efficiently** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 4. Rate your **performance** for **meeting in-trail spacing requirements** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |
| 5. Rate your **performance** for **identifying RNAV nonconformance** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |

## Workload

| | | | |
|---|---|---|---|
| 6. Rate your **overall workload** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |
| 7. Rate your **workload** due to **scanning for aircraft conflicts** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |
| 8. Rate your **workload** due to **variable aircraft separation requirements** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |
| 9. Rate your **workload** due to **in trail spacing requirements** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |
| 10. Rate your **workload** due to **monitoring for RNAV nonconformance** during this scenario. | Extremely Low | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely High |

## Situation Awareness

| | | | |
|---|---|---|---|
| 11. Rate your **overall level of situation awareness** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |

| | | | |
|---|---|---|---|
| 12. Rate your **situation awareness** for **detecting aircraft conflicts** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |

| | | | |
|---|---|---|---|
| 13. Rate your **situation awareness** for the required **lateral separation** between aircraft during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |

| | | | |
|---|---|---|---|
| 14. Rate your **situation awareness** for the required **wake turbulence separation** between aircraft during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |

| | | | |
|---|---|---|---|
| 15. Rate your **situation awareness** for **detecting RNAV nonconformance** during this scenario. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |

## Simulation Pilots and Scenario Difficulty

| | | | |
|---|---|---|---|
| 16. Rate the **performance of the simulation pilots** in terms of their responding to control instructions and providing readbacks. | Extremely Poor | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Good |

| | | | |
|---|---|---|---|
| 17. Rate the **difficulty** of this scenario. | Extremely Easy | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Difficult |

## Support Tools

### Shading for 3-mile Separation Area

| | | | |
|---|---|---|---|
| 18. What effect, if any, did the **3-mile area shading** have on your ability to **separate aircraft effectively**? | Negative Effect | ①②③④ ⑤ ⑥⑦⑧⑨<br>None (⑤) | Positive Effect |

19. Explain how the **3-mile shading area** affected your ability to separate aircraft, if at all?

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### Wake Turbulence Distance Indicator

| | | | |
|---|---|---|---|
| 20. What effect, if any, did the **wake distance indicator** have on your ability to **separate aircraft effectively**? | Negative Effect | ①②③④ ⑤ ⑥⑦⑧⑨<br>None (⑤) | Positive Effect |

21. Explain how the **wake distance indicator** affected your ability to separate aircraft, if at all?

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## Wake Turbulence Alert

| | | | |
|---|---|---|---|
| 22. What effect, if any, did the **wake turbulence alert** have on your ability to **separate aircraft effectively**? | Negative Effect | ①②③④ ⑤ ⑥⑦⑧⑨<br>\|<br>None | Positive Effect |

23. Explain how the **wake turbulence alert** affected your ability to separate aircraft, if at all?

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## Performance-Based Navigation Conformance Monitor

| | | | |
|---|---|---|---|
| 24. What effect, if any, did the **RNAV conformance monitor** have on your ability to **separate aircraft effectively**? | Negative Effect | ①②③④ ⑤ ⑥⑦⑧⑨<br>\|<br>None | Positive Effect |

25. Explain how the **RNAV conformance monitor** affected your ability to separate aircraft, if at all?

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## Route Amendment Graphic Tool

| | | | |
|---|---|---|---|
| 26. What effect, if any, did the **route amendment tool** have on your ability to **separate aircraft effectively**? | Negative Effect | ①②③④ ⑤ ⑥⑦⑧⑨<br>None | Positive Effect |

27. Explain how the **route amendment tool** affected your ability to separate aircraft, if at all?

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## Conflict Probed Menus

| | | | |
|---|---|---|---|
| 28. What effect, if any, did the **probed menus** have on your ability to **separate aircraft effectively**? | Negative Effect | ①②③④ ⑤ ⑥⑦⑧⑨<br>None | Positive Effect |

29. Explain how the **conflict probed menus** affected your ability to separate aircraft, if at all?

______________________________________________________________________

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## Conflict Identification on Radar Display

| | | | |
|---|---|---|---|
| 30. What effect, if any, did the **conflict identification data** have on your ability to **separate aircraft effectively**? | Negative Effect | ①②③④ ⑤ ⑥⑦⑧⑨<br>None (⑤) | Positive Effect |

31. Explain how the **conflict identification data** affected your ability to separate aircraft, if at all?

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32. Do you have any additional comments or clarifications about your experience in this scenario?

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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 | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |

| | | | |
|---|---|---|---|
| 2. Rate the **realism of the simulation hardware** compared to actual equipment. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |

| | | | |
|---|---|---|---|
| 3. Rate the **realism of the simulation software** compared to actual functionality. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |

| | | | |
|---|---|---|---|
| 4. Rate the **realism of the simulation generic airspace** compared to actual NAS airspace. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |

| | | | |
|---|---|---|---|
| 5. Rate the **realism of the simulation traffic scenarios** compared to actual NAS traffic. | Extremely Unrealistic | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Realistic |

| | | | |
|---|---|---|---|
| 6. To what extent did the **oculometer interfere** with your ATC performance? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

| | | | |
|---|---|---|---|
| 7. To what extent did the **WAK online workload rating technique interfere** with your ATC performance? | None At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

8. Do you have any comments or suggestions for improvement about our simulation capability?

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## Support Tools

### Shading for 3-mile Separation Area

| | | | |
|---|---|---|---|
| 1. How effective was the **3-mile shading area** to display separation boundary information? | Extremely Ineffective | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Effective |

| | | | |
|---|---|---|---|
| 2. How easy was it to use the **3-mile shading area** to display separation boundary information? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |

| | | | |
|---|---|---|---|
| 3. Regardless of the specific way we did it, how important is it to display **separation boundary information**? | Not At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

4. Do you have any comments or suggestions to improve the **3-mile shading area** idea?

__________________________________________________________________

__________________________________________________________________

__________________________________________________________________

### Wake Turbulence Distance Indicator

| | | | |
|---|---|---|---|
| 5. How effective was the **wake distance indicator** to display wake turbulence separation requirements? | Extremely Ineffective | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Effective |

| | | | |
|---|---|---|---|
| 6. How easy was it to use the **wake distance indicator** to display wake turbulence separation requirements? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |

| | | | |
|---|---|---|---|
| 7. Regardless of the specific way we did it, how important is it to display **wake turbulence separation requirements**? | Not At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

8. Do you have any comments or suggestions to improve the **wake distance indicator** idea?

__________________________________________________________________

__________________________________________________________________

__________________________________________________________________

## Wake Turbulence Alert

| | | | |
|---|---|---|---|
| 9. How effective was the **wake turbulence alert** to display potential wake violations? | Extremely Ineffective | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Effective |

| | | | |
|---|---|---|---|
| 10. How easy was it to use the **wake turbulence alert** to display potential wake violations? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |

| | | | |
|---|---|---|---|
| 11. Regardless of the specific way we did it, how important is it to display **potential wake violations**? | Not At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

12. Do you have any comments or suggestions to improve the **wake turbulence alert** idea?

______________________________________________

______________________________________________

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______________________________________________

## Performance-Based Navigation Conformance Monitor

| | | | |
|---|---|---|---|
| 13. How effective was the **RNAV conformance monitor** to display **pilot deviations**? | Extremely Ineffective | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Effective |

| | | | |
|---|---|---|---|
| 14. How easy was it to use the **RNAV conformance monitor** to display **pilot deviations**? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |

| | | | |
|---|---|---|---|
| 15. Regardless of the specific way we did it, how important is it to display **pilot deviations on RNAV routes**? | Not At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

16. Do you have any comments or suggestions to improve the **RNAV conformance monitor** idea?

______________________________________________

______________________________________________

______________________________________________

______________________________________________

## Route Amendment Graphic Tools

| | | | |
|---|---|---|---|
| 17. How effective was the **route amendment tool** to display proposed route changes and make amendments? | Extremely Ineffective | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Effective |
| 18. How easy was it to use the **route amendment tool** to display proposed route changes and make amendments? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |
| 19. Regardless of the specific way we did it, how important is it to display **proposed route changes and make amendments**? | Not At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

20. Do you have any comments or suggestions to improve the **route amendment tool** idea?

______________________________________________

______________________________________________

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## Conflict Probed Menus

| | | | |
|---|---|---|---|
| 21. How effective were the **probed menus** to display conflicted trial plans? | Extremely Ineffective | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Effective |
| 22. How easy was it to use the **probed menus** to display conflicted trial plans? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |
| 23. Regardless of the specific way we did it, how important is it to display **conflicted trial plans**? | Not At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

24. Do you have any comments or suggestions to improve the **conflict probed menus** idea?

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## Conflict Identification on Radar Display

| | | | |
|---|---|---|---|
| 25. How effective was the **conflict identification data** to display aircraft conflicts and trajectories? | Extremely Ineffective | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Effective |

| | | | |
|---|---|---|---|
| 26. How easy was it to use the **conflict identification data** to display aircraft conflicts and trajectories? | Extremely Difficult | ①②③④⑤⑥⑦⑧⑨⑩ | Extremely Easy |

| | | | |
|---|---|---|---|
| 27. Regardless of the specific way we did it, how important is it to display **aircraft conflicts and trajectories**? | Not At All | ①②③④⑤⑥⑦⑧⑨⑩ | A Great Deal |

28. Do you have any comments or suggestions to improve the **conflict identification data** idea?

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

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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.

## Rating Scale Descriptors

***Remove this Page and keep it available while doing ratings***

| Scale | Quality | Supplementary |
|---|---|---|
| 1 | **Least Effective** | Unconfident, Indecisive, Inefficient, Disorganized, Behind the power curve, Rough, Leaves some tasks incomplete, Makes mistakes |
| 2 | **Poor** | May issue conflicting instructions, Doesn't plan completely |
| 3 | **Fair** | Distracted between tasks |
| 4 | **Low Satisfactory** | Postpones routine actions |
| 5 | **High Satisfactory** | Knows the job fairly well |
| 6 | **Good** | Works steadily, Solves most problems |
| 7 | **Very Good** | Knows the job thoroughly, Plans well |
| 8 | **Most Effective** | Confident, Decisive, Efficient, Organized, Ahead of the power curve, Smooth, Completes all necessary tasks, Makes no mistakes |

| **I - MAINTAINING SAFE AND EFFICIENT TRAFFIC FLOW** |
| --- |
| |
| **II - MAINTAINING ATTENTION AND SITUATION AWARENESS** |
| |
| **III – PRIORITIZING** |
| |
| **IV – PROVIDING CONTROL INFORMATION** |
| |
| **V – TECHNICAL KNOWLEDGE** |
| |
| **VI – COMMUNICATING** |
| |

| I - MAINTAINING SAFE AND EFFICIENT TRAFFIC FLOW | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1. Maintaining Separation and Resolving Potential Conflicts ...........<br>• using control instructions that maintain appropriate aircraft and airspace separation<br>• detecting and resolving impending conflicts early<br>• recognizing the need for speed restrictions and wake turbulence separation | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 2. Sequencing Aircraft Efficiently ....................................................<br>• using efficient and orderly spacing techniques for arrival, departure, and en route aircraft<br>• maintaining safe arrival and departure intervals that minimize delays | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 3. Using Control Instructions Effectively/Efficiently ........................<br>• providing accurate navigational assistance to pilots<br>• issuing economical clearances that result in need for few additional instructions to handle aircraft completely<br>• 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 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5. Maintaining Awareness of Aircraft Positions ................................<br>• avoiding fixation on one area of the radar scope when other areas need attention<br>• using scanning patterns that monitor all aircraft on the radar scope | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 6. Giving and Taking Handoffs in a Timely Manner..........................<br>• ensuring that handoffs are initiated in a timely manner<br>• ensuring that handoffs are accepted in a timely manner<br>• ensuring that handoffs are made according to procedures | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 7. Ensuring Positive Control .............................................................<br>• tailoring control actions to situation<br>• 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 ...................<br>• ensuring that pilots follow assigned clearances correctly<br>• correcting pilot deviations in a timely manner | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 9. Correcting Own Errors in a Timely Manner..................................<br>• acting quickly to correct errors<br>• 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 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 11. Taking Actions in an Appropriate Order of Importance<br>• resolving situations that need immediate attention before handling low priority tasks<br>• issuing control instructions in a prioritized, structured, and timely manner | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 12. Preplanning Control Actions<br>• 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<br>• shifting control tasks between several aircraft when necessary<br>• 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 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 15. Providing Essential Air Traffic Control Information<br>• providing mandatory services and advisories to pilots in a timely manner<br>• exchanging essential information | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 16. Providing Additional Air Traffic Control Information<br>• providing additional services when workload permits<br>• exchanging additional information | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 17. Providing Coordination<br>• providing effective and timely coordination<br>• 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 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 19. Showing Knowledge of LOAs and SOPs<br>• controlling traffic as depicted in current LOAs and SOPs<br>• performing handoff procedures correctly | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 20. Showing Knowledge of Aircraft Capabilities and Limitations<br>• using appropriate speed, vectoring, and/or altitude assignments to separate aircraft with varied flight capabilities<br>• issuing clearances that are within aircraft performance parameters | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 21. Showing Effective Use of Equipment<br>• updating data blocks<br>• 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 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 23. Using Proper Phraseology<br>• using words and phrases specified in the 7110.65<br>• using phraseology that is appropriate for the situation<br>• using minimum necessary verbiage | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 24. Communicating Clearly and Efficiently<br>• speaking at the proper volume and rate for pilots to understand<br>• speaking fluently while scanning or performing other tasks<br>• ensuring clearance delivery is complete, correct and timely<br>• speaking with confident, authoritative tone of voice | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| 25. Listening to Pilot Readbacks and Requests<br>• correcting pilot readback errors<br>• acknowledging pilot or other controller requests promptly<br>• 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** |