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Atlantic City International Airport, NJ 08405

Human-in-the-Loop Simulation Experiment of Integrated Arrival/Departure Control Services

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16. Abstract

Objective: In the Human-in-the-Loop (HITL) experiment of Integrated Arrival/Departure Control Services (IADCS), we investigated the effects of changes in airspace, routes, and sector roles on Terminal Radar Approach Control (TRACON) and Air Route Traffic Control Center (ARTCC) controllers. **Background**: Airlines and the National Airspace System (NAS) suffer from a reduction in airport throughput or even closure when weather or traffic volume constrains arrival or departure gates to and from the TRACON. Airlines may experience increases in delays, distance flown, and fuel burn. The IADCS concept provides ways to sustain airport throughput at a higher level for a longer period. The IADCS procedures will reduce the distance flown by and fuel consumption of aircraft arriving at an airport. **Method**: We conducted a HITL experiment that used Atlanta TRACON (A80) and Atlanta ARTCC (ZTL) airspace. Derived from the air traffic forecasts for the year 2020, we developed traffic samples for the airspace and created changes to airspace and routes to support the IADCS concept. The procedures included a *Baseline*—no changes to airspace or routes; a *Lateral Airspace Shift procedure*—a sector gaining a section of airspace; a *Laterally Separated, Bidirectional procedure*—lateral separation between departure and arrival routes; and two *Vertically Separated, Bidirectional procedures*—one with arrivals at higher altitude and departures at lower altitude, and another with arrival and departure aircraft reversed. We used subjective, physiological, and system data to quantify differences between the effect of IADCS conditions. **Results**: Aircraft travel time was shorter when they flew in the IADCS procedures than in the Baseline procedure. Subjective ratings showed that participant controllers preferred the lateral airspace shift and the laterally separated route procedures. They gave substantially negative ratings for one of the vertically separating procedures in which they controlled arrival aircraft at the high altitude and departure aircraft at the low altitude. Our statistical tests of both frequencies and durations of communications between controllers and pilots showed that controllers talked more often with pilots and spent more time with them when they were in the vertically bidirectional procedures. In addition, controllers committed more deviations in those two procedures than in the other procedures. **Applications**: Results from this research are applicable to high-density airports and metroplex airspace.

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Acknowledgments

To prepare and conduct a complex experiment like this involves many people from diverse backgrounds and organizations. Thank you to everyone involved in the success of this experiment.

The participating controllers made this experiment possible. Twelve controllers from several Air Traffic Route Control Centers within the continental United States traveled to our facilities, worked diligently on high-traffic simulation scenarios, answered all our questions, and volunteered to wear equipment to measure eye movements and brain activities. We appreciate their participation very much.

For this complex simulation, we had excellent engineering support from the laboratory personnel. Albert Macias not only managed the Research Development and Human Factors Laboratory, but also wrote the software that integrated eye-tracking data with the other data collected during the experiment. Gary Mueller (co-author) was the lead for the laboratory programming and developing group. Matthew KuKurlo of ANG helped us as a subject matter expert (SME).

Matt Bruckner, Adam Granich, Joel Grochowski, Laura Hamann, Vince Locasale, Chris Parratto, Nicole Smith, Valentina Strogonova, Yev Tabekman, and Matt Zeits programmed many of the new features in Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE). Several DESIREE team members also organized data into a form that we could use in our analyses. Robert Bortu, Wallace Daczkowski, John Dilks, Ed Little, and Otto Smith kept all of our systems going during the experiment as software and hardware engineers. As SMEs of air traffic control, John DiRico, Jim McGhee, and Richard Ridgway (TASC, Inc.), prepared traffic scenarios.

During the shakedown period when we checked hardware and software thoroughly before the experiment, many people in the laboratory helped us as simulation pilots. Even though they were not proficient and certified pilots, they could communicate with controllers and maneuver aircraft well enough for us to test the hardware and software. We want to acknowledge their contributions. In alphabetical order, they were: Rob Bastholm (co-author) of Spectrum Software Technology, Inc., Henry Dorsey, Matt Dworsky (co-author), Kevin Hallman (co-author), Erin Higgins, Ken Schulz (co-author) of TASC, Inc.; and Scott Terrace of BSA.

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Our simulated aircraft do not fly without the support of the Target Generation Facility (TGF) group. Samantha Fullerton, Dana Whicker, Rhoma Gordillo, and others ensured smooth operations of the TGF and simulation pilot workstations during the experiment.

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We appreciate our technical editor, April Jackman (TASC, Inc.), who edited this report to make it more readable. We also appreciate Jennifer Librizzi for her caring secretarial support during the experiment.

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Executive Summary

The Integrated Arrival/Departure Control Services (IADCS) is a Next Generation Air Transportation System (NextGen) operational improvement which is slated for initial operational capability in 2017–2020 that aims to improve capacity at high-density airports (FAA, 2012a, 2012b). Challenges specific to metroplex areas include the increase of air traffic volume and support for multiple airports and unpredictable weather patterns that could close arrival/departure routes or gates.

IADCS proposes to extend terminal separations and procedures to the adjacent Air Route Traffic Control Center (ARTCC) sectors for more flexible traffic during severe weather and other traffic flow disruptions. It proposes the use of resectorization, bidirectional gates, bidirectional routes, and Air Traffic Control (ATC)-assigned routes. It will maximize throughput, improve efficiency, reduce flight duration and distance, reduce noise, and reduce fuel burn and engine emissions.

In this simulation experiment, we compared four IADCS procedures with the Baseline condition that controllers currently use in the weather condition: 1) resectorization to provide the arrival sectors extra airspace; 2) a laterally separated/bidirectional gate to absorb the extra arrival demand; and 3–4) two vertically separated/bidirectional gates—one with arrival aircraft at higher altitudes and departure aircraft at lower altitudes, and another with arrival and departure aircraft in the reverse way.

The time flown by aircraft was shorter when they flew in the IADCS procedures than in the Baseline procedure. Our statistical tests of both communication frequencies and durations between controllers and pilots showed that controllers talked more often and longer with pilots when they used the vertically separated/bidirectional gate procedures. In addition, controllers committed more deviations in those procedures than in the other procedures.

The subjective ratings showed that controllers preferred the lateral airspace shift and the laterally separated route procedures. In general, vertically separated/bidirectional gate procedures were the least preferred procedures. We found three statistically significant results in workload ratings. All three were between vertically separated/bidirectional gate procedures and the Baseline procedure.

Thus, our results clearly showed that vertically separated/bidirectional gate procedures were not as effective as the other procedures and were least preferred by participant controllers.

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1. INTRODUCTION

1.1 Background

The Integrated Arrival/Departure Control Services (IADCS) is a Next Generation Air Transportation System (NextGen) operational improvement (OI) slated for initial operational capability (IOC) in 2017–2020 that aims to improve capacity at high-density airports[1] (FAA 2012a, 2012b). Challenges specific to metroplex areas include: 1) increasing traffic volume forecasts (FAA, 2011); 2) supporting multiple airports; and 3) weather patterns forcing the closure of routes or arrival/departure gates.

IADCS proposes to extend terminal separation and procedures to the entire metropolitan airspace, such as adjacent Air Route Traffic Control Centers (ARTCC) or En Route sectors, and provide greater flexibility in rerouting traffic during severe weather and other disruptions to traffic flow. IADCS also proposes the use of resectorization, bidirectional gates, bidirectional routes, and Air Traffic Control (ATC) assigned routes. The goals of IADCS are to:

1. maximize throughput,
2. improve efficiency,
3. reduce flight duration and distance,
4. reduce noise, and
5. reduce fuel burn and engine emissions.

1.2 Related Empirical Studies

Previously, two human-in-the-loop (HITL) studies (Truitt, McAnulty, & Willems, 2004; Zingale, Truitt, & McAnulty, 2008) evaluated improvements similar to some of those proposed in IADCS. Truitt et al. (2004) investigated whether the proposed New York Integrated Control Complex (NYICC), informally known as "Big Airspace," would lead to operational improvements and benefits. Truitt et al. (2004) tested two components of NYICC: 1) the colocation (physical integration) of the New York ARTCC and the New York Terminal Radar Control (TRACON), and 2) the extension of the terminal lateral 3-nautical mile (NM) separation threshold within a larger portion of the airspace (i.e., in the En Route sectors). The results of the simulation provided general support for the Big Airspace concept.

Zingale et al. (2008) verified that the benefits observed by Truitt et al. (2004) in the New York airspace are applicable to other congested areas. They conducted a HITL simulation that evaluated the potential benefits of Terminal and En Route colocation, resectorization (Hadley, Sollenberger, D'Arcy, & Bassett, 2000; Stein, Della Rocco, & Sollenberger, 2006), and diverging course procedures using a modification of the central Florida airspace. Flights moved more efficiently and controllers made fewer ground-ground transmissions in the Big Airspace conditions than in the Baseline condition. Controller ratings showed that their workload went down after resectorization.

[1] The Integrated Arrival/Departure Airspace Management is operational improvement number 104122 in the NAS Enterprise Architecture portfolio (FAA, 2012a).

1.3 IADCS Procedures

The IADCS program identified a set of procedures for optimizing traffic control operations. The procedures can be applied in, but are not limited to, metroplex environments. In the next section, we discuss the concepts on expanded 3-NM separation, resectorization, bidirectional routes vertically, bidirectional gates, and ATC assigned routes.

1.3.1 Expanded 3-Nautical Mile Separation

This procedure expands the TRACON lateral 3-NM separation requirement to adjacent En Route sectors. In Figure 1, the 170/90 means that the sector controls airspace of altitudes from 9,000–17,000 ft, and the 250/90 means that the sector controls airspace of altitudes from 9,000–25,000 ft. The lateral separation requirement in En Route sectors is 5 NM, but it is typical for controllers to maintain a 7- to 10-NM separation to ensure that they will meet the 5-NM requirement. With a 3-NM separation requirement, controllers will generally keep flights separated from 5- to 6-NM. In the current experiment, we did not address expanded NM separation because other studies (Truitt et al., 2004; Zingale et al., 2008) have already shown its benefit.

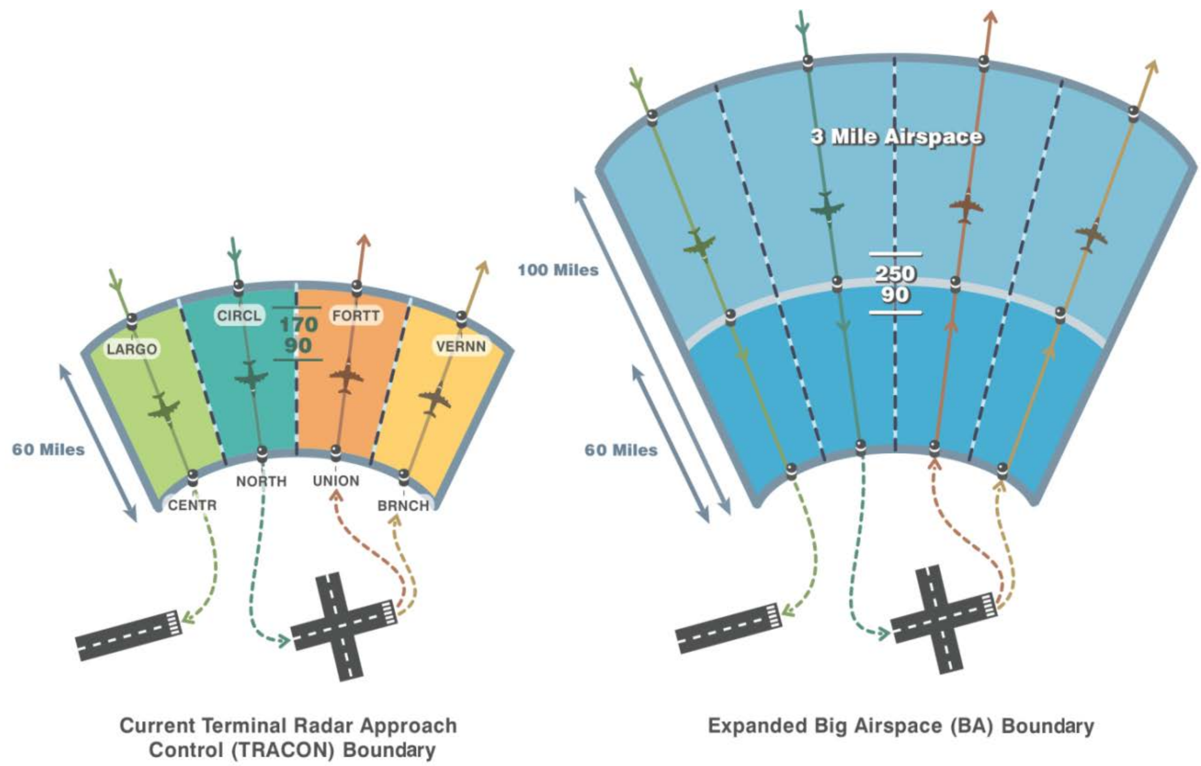
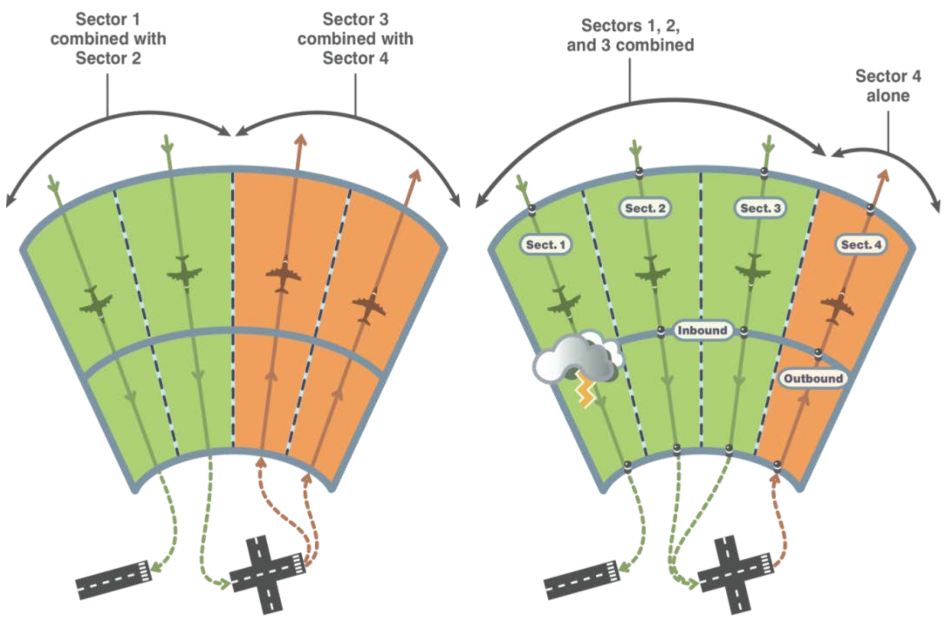


Figure 1. Example of current and expanded airspace (Booz Allen Hamilton, 2014).

1.3.2 Resectorization

Figure 2 shows how a portion of an outbound sector becomes part of an adjacent inbound sector. In this example, the inbound sector controllers would use the new airspace to move flights along a new inbound route. In the other form of resectorization, traffic would fly on a new route in a different direction from the existing route. For example, as shown in Figure 2 (b), an outbound route might be added to a sector that had only inbound routes.



(a) (b)

Figure 2. Example of resectorization (Booz Allen Hamilton, 2014).

1.3.3 Bidirectional Routes Vertically

Figure 3 shows an example of a full-length bidirectional route in Sector 1 (green area). In this example, controllers maintain separation on directional routes by directing departure flights under arrival flights. In this experiment, we call this *High-Play*. Another possibility would be to direct arrivals under the departures. We call this *Low-Play*. Figure 4 shows an example in which flights are cleared on both directions on a segment of a route.

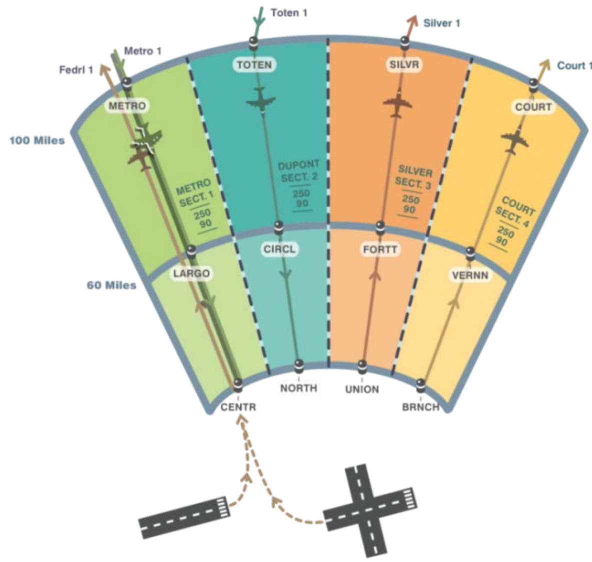


Figure 3. Example of full-length bidirectional route (Booz Allen Hamilton, 2014).

In the procedure shown in Figure 4, a fix normally used for a one-directional flow of traffic (such as an arrival fix) gets split vertically, resulting into a fix for use for both arrivals and departures. For instance, at fix TKOMA, ATC can use the higher altitudes for arrivals and use the lower altitudes for departures. This could result in increasing the capacity of that single fix (i.e., TKOMA). This may be useful during periods of inclement weather or during high volumes of traffic, as many routes and fixes such as SILVER become blocked and unusable.

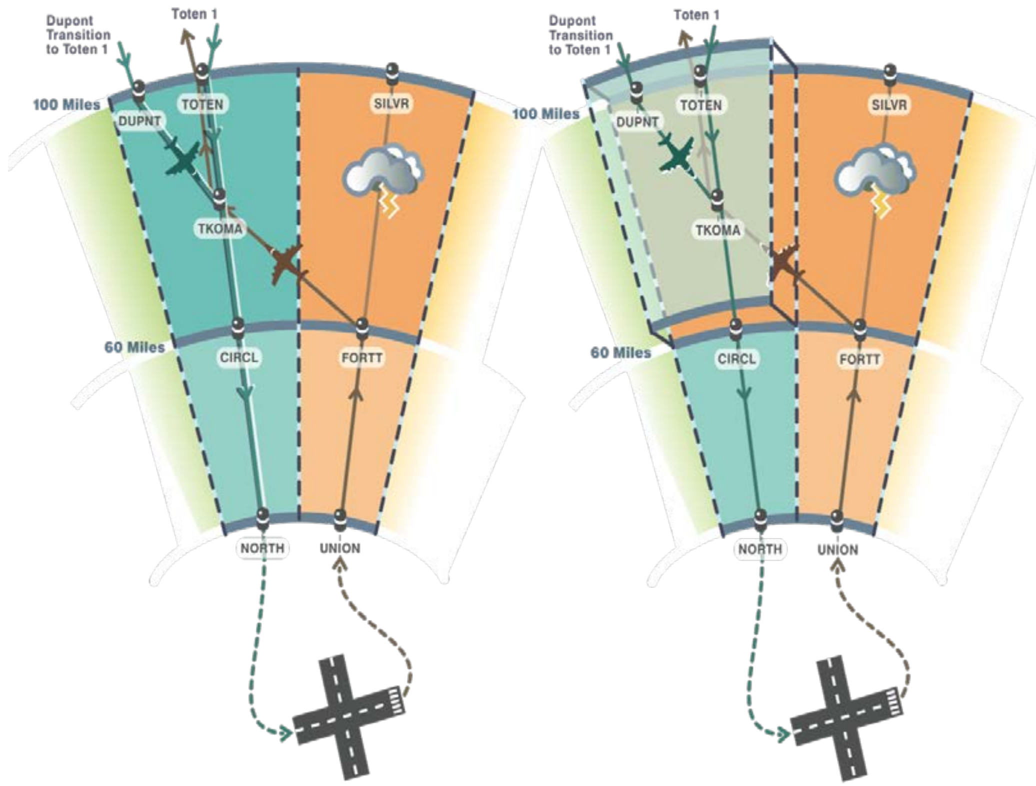


Figure 4. Bidirectional routes segmented horizontally in a sector. Note that both figures show the same concept, except the figure on the right shows the 3D effect visually (with the segment in blue as a higher altitude than the segment in orange) (Booz Allen Hamilton, 2014).

1.3.4 ATC Assigned Routes

ATC assigned routes are temporary and as needed using existing fixes. They can be implemented in lieu of or in addition to existing routes to accommodate for adverse conditions, such as inclement weather. Figure 5 shows an example of an ATC-assigned route using a new fix called NEWFX, in the figure on the right.

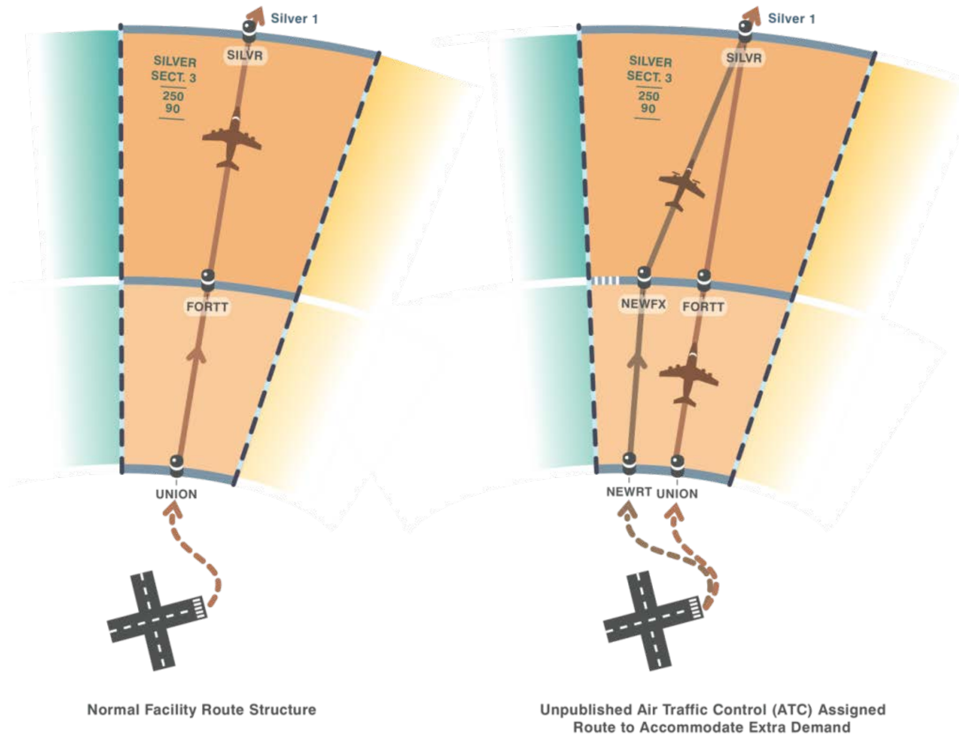


Figure 5. ATC assigned route (Booz Allen Hamilton, 2014).

1.3.5 Optimized Profile Descents and Climbs

Optimized Profile Descents (OPDs) are a NextGen OI that aim to increase flexibility in the terminal environment by allowing airplanes to remain at higher altitudes on arrival to airports and use lower power settings during descent. It is not clear if the current implementation of the User Request Evaluation Tool (URET) will adequately support OPD operations (Johnson, 2009). This may also be the case for Optimized Profile Climb (OPC) operations. URET does not currently support the trajectory modeling of OPD and OPC operation. Both procedures are intended to help airplanes save fuel.

1.4 Purpose

We conducted a HITL simulation to evaluate the effects of the IADCS concept on controller performance and behavior, and system safety and efficiency. This study gave controllers the opportunity to use IADCS procedures and evaluate their usability, suitability, and acceptability.

1.5 Scope

We studied the benefits of IADCS operations in the Atlanta TRACON (A80) and the Atlanta ARTCC (ZTL) when weather affected the northeast quadrant of the Atlanta metroplex area. The experimental design measured the potential benefits of bidirectional routes and limited resectorization. We assumed the level of automation and ATC equipment for the period of 2017–2020. Controllers used the emulations of the En Route Automation Modernization (ERAM) system in the En Route sectors and the Standard Terminal Automation Replacement System (STARS) in terminal sectors. Although Data Communication (Data Comm) may become available during the simulated timeframe and may provide a benefit to the IADCS concept, we did not use it in the simulation because we assumed the benefit of Data Comm would affect the different IADCS procedures in a similar way.

2. METHOD

2.1 Participants

Eight air traffic controllers voluntarily participated in the simulation. We recruited eight ARTCC Certified Professional Controllers (CPCs) from ARTCCs within the continental United States and two recently retired controllers from the Atlanta TRACON (A80). En Route controllers held a current medical certificate.

2.2 Research Personnel

Two engineering research psychologists served as the principal investigators (PIs) and conducted the study. Human Factors specialists supported the PIs by preparing the briefing and experimental material and by collecting, analyzing, and interpreting the data.

Retired air traffic controllers served as subject matter experts (SMEs) during the simulation. They prepared the experimental scenarios to ensure the scenarios were realistic. They used the Over-the-Shoulder Rating Form (see Appendix E) to evaluate participant performance during the simulation.

Other SMEs acted as confederate controllers and assumed control of the En Route arrival sectors adjacent to the departure sectors that participants controlled. The SMEs acted as participating controllers during the technical shakedown.

Simulation pilots operated the Target Generation Facility (TGF) pilot workstations to maneuver flights according to controller clearances and communicated with the controllers using proper terminology.

Hardware and software engineers prepared the simulation and were on standby during the simulations to assist as needed.

2.3 Facilities

We conducted the study at the FAA William J. Hughes Technical Center Research Development and Human Factors Laboratory (RDHFL). The RDHFL houses a high-fidelity ATC simulation environment to conduct realistic experiments.

2.4 Hardware and Software

In the following sections, we briefly describe the hardware and software that we used during the experiment. In the next section, we describe the ATC simulation environment. In section 2.4.2, we describe the workload and physiological equipment.

2.4.1 Air Traffic Control Simulation

We used the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) and the TGF to emulate the air traffic environment. DESIREE emulated both the En Route and the TRACON environments. It received input from TGF to display aircraft targets and flight data on controller workstations. DESIREE also acted as ghost controllers to handoff aircraft to sectors where confederate controllers controlled and sectors where participants controlled traffic.

The TGF is a dynamic, real-time air traffic simulation capability designed to generate realistic aircraft targets for HITL simulations. The TGF simulated aircraft uses models based on the EUROCONTROL Base of Aircraft Data (BADA) to provide realistic aircraft dynamics and characteristics for an aircraft. The TGF maneuvers aircraft based on flight plans and simulation pilot commands. The TGF also provides an interface for simulation pilots to maneuver assigned aircraft.

2.4.1.1 ARTCC Workstations

The ARTCC workstation in this experiment emulated the ERAM system (see Figure 6). The ERAM system replaces the legacy Host Computer System, the Display System Replacement (DSR) system, URET, and several other En Route automation infrastructure elements. URET provides controllers with a conflict probe (CP) and a trial planning (TP) function on the Radar Associate position. The CP probes for aircraft-to-aircraft conflicts up to 20 minutes into the future and for aircraft to Special Activity Airspace up to 40 minutes into the future. The URET platform's main function is CP and TP. However, since its early introduction as a prototype at Indianapolis Center (ZID), it has acquired functions beyond the CP and TP. These functions include templates for flight plan creation and amendments; easier input formats for fix, time, and route amendments; graphical route modification; wind and temperature views; easier input and access to hold information; and reminders for overdue aircraft, HOST Erroneous Route Text, Bad Route Elements (i.e., XXX), and ATC Preferred Routes.

The experimental workstations consisted of the following hardware and software:

- **Radar Controller (R-side) position**
  - the R-side position consisted of a high-resolution (2,048 x 2,048 pixels) 29-inch liquid crystal display (LCD) depicting an emulation of the ERAM R-side display, including a toolbar for display and view controls, and Message Composition Area (MCA) and Response Area (RA) views,
  - R-side DSR keyboard,
  - Voice Switching and Control System (VSCS) emulation, and
  - Keypad Selection Device (KSD) and mouse.
- **Data-side (D-side) position**
  - Situation view,
  - Aircraft List view,
  - Conflict detection and trial planning,
  - Voice Switching and Control System (VSCS) emulation,
  - MCA and RA views,
  - R-side position (RPOS) style toolbar, and
  - Keypad Selection Device (KSD) and mouse.

Figure 6. En Route simulation room.

2.4.1.2 TRACON Workstations

The TRACON Radar position consisted of the following (see Figure *7*):

- **STARS, including**
  - Toolbar for display settings and list control,
  - Digital knobs and buttons for display settings and list control,
  - Communication equipment, and
  - ABC keyboard and trackball (see Figure 8).

Figure 7. TRACON simulation room.

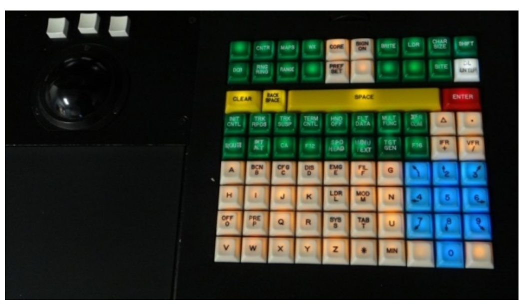


Figure 8. TRACON keyboard.

2.4.1.3 Communication System

The communication system enabled controllers and pilots to communicate in a similar manner as in the field. All controllers could communicate with controllers at other sectors and experimenters.

2.4.1.4 Simulation Pilot Workstations

We used 12 simulation pilot workstations, three per sector: six stations for ARTCC sectors and six stations for TRACON sectors. Each simulation pilot workstation consisted of a computer, keyboard, monitor, and communication equipment. The workstation display showed the traffic on their frequency and a list of assigned aircraft. The simulation pilots had information regarding the current state and flight plan data for each aircraft that they operated. They were able to create macros for frequently used command sequences. We presented weather cells at simulation pilot workstations, which enabled pilots to request deviations due to weather.

2.4.1.5 Experimental Control Workstation

The experimental control workstation consisted of several keyboards and monitors to start up the TGF software, load the simulation pilot configurations, and start the DESIREE software. The experimenters also had displays to monitor the traffic, the health of the simulation software components, and the activities in the controller room. They used a panel to access the voice communication system to address pilots, controllers, and over-the-shoulder raters.

2.4.2 Workload and Physiological Recording Systems

We collected controller workload data using a subjective rating questionnaire. In addition, we used two physiological measures: functional near-infrared spectroscopy (fNIRS) and heart rate variability (HRV). Even though we collected the physiological data, we did not analyze it in this report.

2.4.2.1 Workload Assessment Keypad

To collect instantaneously perceived workload, we used a workload assessment keypad (WAK) (see Figure 9). The WAK technique is an adaptation of the Air Traffic Workload Input Technique (ATWIT) (Stein, 1985) that uses a 10-point scale.

Figure 9. Workload assessment keypad.

2.5 Material

2.5.1 Informed Consent Form

The informed consent form (see Appendix A) described the study in plain language and explained to participants that their participation was strictly voluntary, that their personal information would be protected, and that they did not waive any of their rights if they signed the form. The local FAA Institutional Review Board (IRB) approved the informed consent form before data collection began. Prior to enrolling in the study, participants signed the informed consent form to confirm they fully understood the study and their commitment. After signing the informed consent form, participants were still free to change their mind and leave the study if they desired.

2.5.2 Biographical Questionnaire

We used the Biographical Questionnaire (see Appendix B) to collect information about the participants, such as age, gender, and experience as air traffic controllers.

2.5.3 Post-Scenario Questionnaires

The Post-Scenario Questionnaire (PSQ) (see Appendix C) included questions about the procedure they used during the previous experimental run, and validity and realism of the simulation. The PSQ also asked controllers to rate their performance, situational awareness, and workload. The questionnaire offered participants the opportunity to provide open-ended comments.

2.5.4 Exit Questionnaire

After controllers completed the experiment, they filled out an Exit Questionnaire (see Appendix D) that covered their experiences during the experiment. We asked them to compare the experimental conditions and asked them for feedback on the feasibility of the IADCS concepts.

2.5.5 Exit Interview

After we finished the experiment, we debriefed the controllers and discussed the feasibility of the IADCS concepts. The discussions included topics such as the required training time, the best time to use IADCS, and improvements that we could make.

2.5.6 Over-The-Shoulder Rating Forms

The SMEs used Over-the-Shoulder Rating forms during the experiment to evaluate the performance of the participants (see Appendix E).

2.6 Airspace, Traffic, and Weather

The airspace used in the simulation consisted of the Atlanta Metroplex area, managed by the Atlanta TRACON (A80) and the Atlanta ARTCC (ZTL).

2.6.1 ARTCC Airspace

The ZTL covers the Atlanta Metroplex airspace, Hartsfield-Jackson International Airport and major and minor satellite airports (see Table 1). It is surrounded by five En Route centers: Washington, D.C. (ZDC), Houston (ZHU), Indianapolis (ZID), Jacksonville (ZJX), and Memphis (ZME).

Table 1. Major and Minor Airports

KCLT	- Charlotte Douglas International Airport
KAGS	- Augusta Regional Airport
KAVL	- Asheville Regional Airport
KBHM	- Birmingham International
KCHA	- Chattanooga Lovell Field
KGSO	- Piedmont Triad International Airport
KGSP	- Greenville Spartanburg International Airport
KMGM	- Montgomery International Airport
KTYS	- Knoxville-McGhee-Tyson Airport
FYY	- Fulton County
PDK	- DeKalb Peachtree Airport
RYY	- Cobb County Airport–McCollum Field

The ARTCC controllers staffed the east departure Sector 16 and Sector 32 during the HITL simulation. The SME controlled Sector 49, Logen.

2.6.2 Terminal Airspace

The terminal airspace used in the experiment consisted of two sectors. One sector controlled departures from Atlanta Hartsfield International Airport and gave handoffs to Sector 16. The other sector controlled arrivals to Hartsfield International Airport and accepted handoffs from Sector 49 in the Baseline and Lateral Airspace Shift conditions, or from Sector 16 in the other conditions involving a bidirectional gate.

2.6.3 Routes

The ZTL and A80 airspace contains Victor airways, jet airways, coded routes, Standard Terminal Arrival Routes (STARs), and Standard Instrument Departures (SIDs). The focus of this study was on the use of STARs and SIDs.

2.6.3.1 Standard Terminal Arrival Routes

A confederate ARTCC controller worked the North-East arrival sectors (i.e., Sectors 49 and 50) that contained the FLCON and the PECHY STARs (see Figure 10). The STARs changes the name, depending on the number of the revision. For example, the formal name of the FLCON STARs may be FLCON SEVEN ARRIVAL (FLCON7) for its seventh revision. The revision numbers rotate from 1 through 9—that is, after revision 9, the next revision number would be 1.

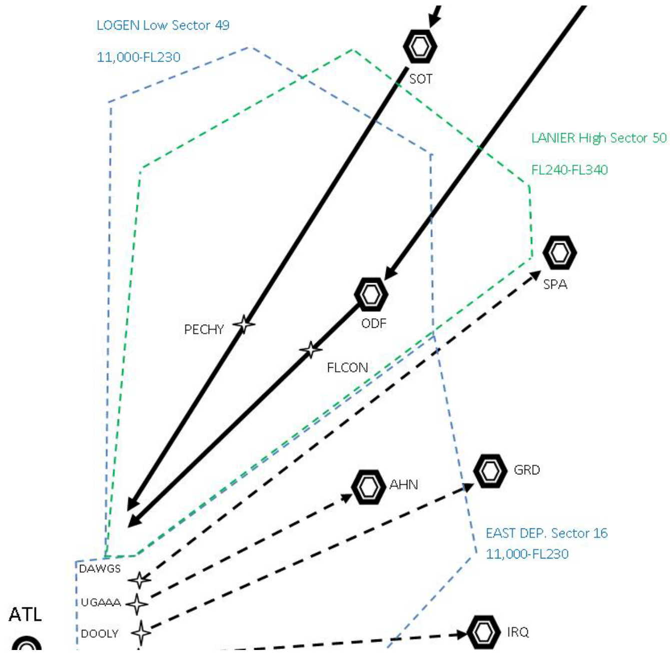


Figure 10. Arrival routes at Atlanta Hartsfield International Airport (ATL) (Booz Allen Hamilton, 2014).

2.6.3.2 Standard Instrument Departures

The controllers worked the east departure En Route sectors (i.e., Sectors 16 and 32) that contained the DAWGS, UGAA, MUNSN, and the DOOLY SIDs. The SIDs changed names in a similar manner as the STARs (see Figure 11).

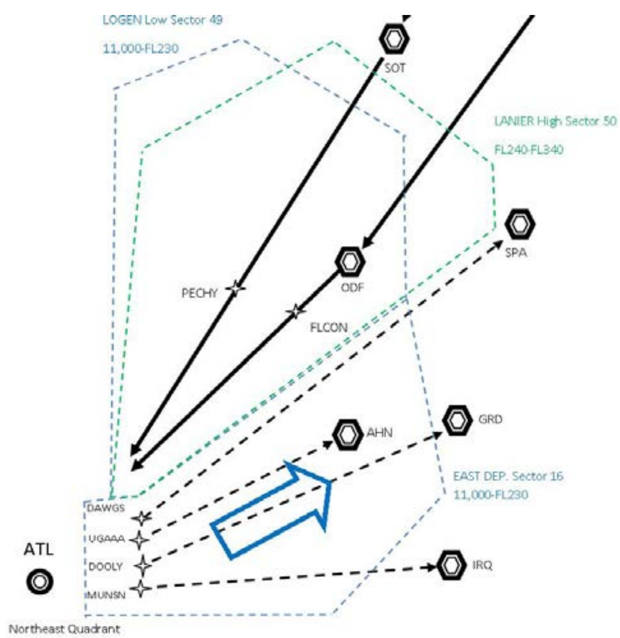


Figure 11. Departure routes at Atlanta Hartsfield International Airport (ATL) (Booz Allen Hamilton, 2014).

2.6.3.3 ATC Assigned Routes

The controllers had two types of ATC Assigned Routes available. For this experiment, we created ATC assignable STARs and SIDs that were available when the arrival sectors became saturated either by weather or by volume. In this experiment, we simulated the weather case.

2.6.4 Standard Operating Procedures and Letters of Agreement

The participants adhered to the standard operating procedures (SOPs) that were currently in place in their respective facility and adhered to the letters of agreement (LOAs) between the respective facilities. Separation minima did not change from current practices during the simulation (i.e., 3 NM in the TRACON sectors and 5 NM in the En Route sectors).

2.6.5 Traffic Samples

We derived the traffic scenarios from live traffic and extrapolated the traffic level projected for 2020. The training scenarios consisted of traffic that was different from the test scenarios. For the test conditions, we counterbalanced several traffic samples for different experimental conditions.

2.6.6 Traffic Volume and Mix

We based traffic on a combination of Performance Data Analysis and Reporting System (PDARS) traffic data (collected on July 21, 2011) and the schedule projected by the Air Traffic Organization (ATO) Management Services for 2020 (based on the same traffic sample).

We developed several 30-minute traffic samples for training. For the experimental runs, we used other scenarios that were 60-minute long. All the scenarios were counterbalanced across conditions. Because participants saw the scenarios derived from the same traffic several times during experimental runs, we changed the call signs to create scenarios that prevent participants from realizing that we derived them from the same underlying traffic samples.

2.6.7 Aircraft Equipage

We built scenarios based on the traffic samples from July 21, 2011. Thus, aircraft in the current experiment had the same equipment as the aircraft would have in the National Airspace System.

2.6.8 Weather

All scenarios included convective weather moving eastward toward the FLCON fix in ZTL49 and ZTL50 sectors, which impeded traffic flow over this fix in the Baseline environment and forced the ZTL49 and ZTL50 sector controllers to divert some flights to the ZTL19 and ZTL20 sectors. As the weather approached the FLCON fix, pilots approaching this fix requested controllers to deviate around the weather. In the scenarios that made alternatives to diverting FLCON traffic to SINCA, the Logen (Sector 49) controller either received additional airspace or handed aircraft off to the departure sectors. Because DESIREE can import data from Weather and Radar Processor (WARP) recordings, we used WARP for an area around ATL. The display of the WARP data conformed to its current format—that is, three levels of weather: low, mild, and high intensity. We manipulated the weather levels that initially affected the North-East arrival sectors followed by closing Sectors 49 and 50.

2.7 Procedure

We briefly describe the schedule, the introductory briefing, and the simulation and interview procedures in the following sections.

2.7.1 Schedule

We held an initial technical shakedown without simulation pilots prior to the simulation followed by a final shakedown with simulation pilots. Each group of air traffic controllers participated in the HITL simulation over the course of 10 consecutive workdays. Table 2 shows that both teams traveled on Day 1 and Day 10. Day 2 included the required briefings and training sessions. Days 3–8 included at least 30 data collection runs, whereas Day 9 included additional data collection runs and the interview.

Table 2. Data Collection Schedule for the Two-Participant Teams (G1 and G2)

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Group 1	Travel	Briefing & Training	Data Collection	Data Collection	Data Collection	
	Data Collection	Data Collection	Data Collection	Data Collection & Interview	Return Travel	
Group 2	Travel	Briefing & Training	Data Collection	Data Collection	Data Collection	
	Data Collection	Data Collection	Data Collection	Data Collection & Interview	Return Travel	

Table 3 shows the six R- and D-teams of En Route controllers that we created out of four controllers. Each number is the identification number of a controller. So, the controller with the identification number 1 was at the R-side of Sector 16 first, and then the D-side of Sector 32 next. By rotating controllers within teams and across sectors, we were able to create three unique teams. We did not consider teams that consisted of an R-side and a D-side controller in one configuration and the same controllers in reversed roles in another configuration. Instead, we considered them as a unique R and D team and used them at different sectors. Each team of controllers completed an experimental simulation in each of five experimental conditions. Table 4 shows the data collection daily schedule.

Table 3. Seating Positions of a Group of En Route Controllers

ZTL 16		*ZTL 32*	
R	**D**	**R**	**D**
1	2	3	4
2	3	4	1
3	1	4	2
3	4	1	2
4	1	2	3
4	2	3	1

Table 4. Data Collection Daily Schedule

Time	**Day**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0800-0930	**Travel**	**Briefing + Training**	Run #1 Forms Break	Run #6 Forms Break	Run #11 Forms Break	Run #16 Forms Break	Run #21 Forms Break	Run #26 Forms Break	Backup Run #1 Forms Break	**Travel**
0930-1100			Run #2 Forms Break	Run #7 Forms Break	Run #12 Forms Break	Run #17 Forms Break	Run #22 Forms Break	Run #27 Forms Break	Backup Run #2 Forms Break	
1100-1230			Run #3 Forms Break	Run #8 Forms Break	Run #13 Forms Break	Run #18 Forms Break	Run #23 Forms Break	Run #28 Forms Break	Backup Run #3 Forms Break	
1230-1330		Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	
1330-1500		**Training**	Run #4 Forms Break	Run #9 Forms Break	Run #14 Forms Break	Run #19 Forms Break	Run #24 Forms Break	Run #29 Forms Break	Backup Run #4 Forms Break	
1500-1630			Run #5 Forms	Run #10 Forms	Run #15 Forms	Run #20 Forms	Run #25 Forms Break	Run #30 Forms	Final Debrief	
1630-1700			Debrief	Debrief	Debrief	Debrief	Debrief	Debrief		

Table 5 shows the changing seating positions of En Route and TRACON controllers during the experiment for Group 1. We had 30 runs from R #1 to R #30. In each cell representing a run, the top line just below a day is En Route ZTL16 and ZTL32 sectors. Under them, A and D are TRACON arrival (A) and departure (D) sectors.

For example, in the first cell (Run #1), R: 4 and D: 1 means Controller 4 positioned at the R-side and Controller 1 positioned at the D-side of ZTL16, respectively. Controller 6 and Controller 5 were positioned at the arrival and departure sectors of TRACON, respectively. We had the same TRACON participants in both Group 1 and Group 2 sessions, but they changed their seating positions depending on the seating schedule. Controller 5 became Controller 6, and Controller 6 became Controller 5 in the second session.

As Table 5 shows, the En Route sector teams switched sector assignment during the experiment, which ensured that participants who worked the R- and D-sides as a team on Sector 16 also worked as a team with the same respective position on Sector 32. This reduced the effect of the sector difference on controllers' performance.

Table 5. Group 1, Week 1 – ARTCC and TRACON Participant Control Position

Day 3			Day 4			Day 5		
ARTCC TRACON	ZTL16 A	ZTL32 D	ARTCC TRACON	ZTL16 A	ZTL32 D	ARTCC TRACON	ZTL16 A	ZTL32 D
R #1	R: 4 D: 1 6	R: 2 D: 3 5	R #5	R: 1 D: 2 5	R: 3 D: 4 6	R #10	R: 1 D: 2 5	R: 3 D: 4 6
R #2	R: 4 D: 1 6	R: 2 D: 3 5	R #6	R: 3 D: 1 6	R: 4 D: 2 5	R #11	R: 3 D: 4 6	R: 1 D: 2 5
R #3	R: 3 D: 4 6	R: 1 D: 2 5	R #7	R: 2 D: 3 5	R: 4 D: 1 6	R #12	R: 2 D: 3 5	R: 4 D: 1 6
R #4	R: 4 D: 2 6	R: 3 D: 1 5	R #8	R: 1 D: 2 5	R: 3 D: 4 6	R #13	R: 2 D: 3 5	R: 4 D: 1 6
			R #9	R: 4 D: 2 6	R: 3 D: 1 5	R #14	R: 3 D: 4 6	R: 1 D: 2 5

Day 6			Day 7			Day 8		
ARTCC TRACON	ZTL16 A	ZTL32 D	ARTCC TRACON	ZTL16 A	ZTL32 D	ARTCC TRACON	ZTL16 A	ZTL32 D
R #15	R: 3 D: 1 5	R: 4 D: 2 6	R #20	R: 1 D: 2 5	R: 3 D: 4 6	R #25	R: 1 D: 2 5	R: 3 D: 4 6
R #16	R: 2 D: 3 5	R: 4 D: 1 6	R #21	R: 3 D: 1 5	R: 4 D: 2 6	R #26	R: 4 D: 1 6	R: 2 D: 3 5
R #17	R: 4 D: 2 6	R: 3 D: 1 5	R #22	R: 4 D: 2 6	R: 3 D: 1 5	R #27	R: 4 D: 1 6	R: 2 D: 3 5
R #18	R: 3 D: 4 6	R: 1 D: 2 5	R #23	R: 4 D: 1 6	R: 2 D: 3 5	R #28	R: 4 D: 2 6	R: 3 D: 1 5
R #19	R: 2 D: 3 5	R: 4 D: 1 6	R #24	R: 3 D: 1 5	R: 4 D: 2 6	R #29	R: 3 D: 4 6	R: 1 D: 2 5

Day 9		
ARTCC TRACON	ZTL16 A	ZTL32 D
R #30	R: 3 D: 1 5	R: 4 D: 2 6

We had five sets of five scenarios corresponding to five experimental conditions. The five experimental conditions (C1 to C5) were: Baseline (Condition 1), Lateral Airspace Shift (Condition 2), Bidirectional Routes–Laterally Separated (Condition 3), Bidirectional Routes–Vertically Separated–High-Altitude Arrivals (Condition 4), and Bidirectional Routes–Vertically Separated–Low-Altitude Arrivals (Condition 5). Each set was created from a different traffic sample. We randomized the presentation order (see Table 6). The last column entry in the table shows the scenario identification. For example, Set1S1 means the scenario came from the Set 1 sample and met the characteristics of the Baseline condition, S1.

Table 6. Experimental Condition and Scenario Assignments

Day 3			Day 4			Day 5		
R #1	C1	Set2S1	R #6	C5	Set3S5	R #11	C1	Set1S1
R #2	C2	Set2S2	R #7	C2	Set2S2	R #12	C4	Set2S4
R #3	C5	Set1S5	R #8	C1	Set1S1	R #13	C5	Set2S5
R #4	C4	Set3S4	R #9	C3	Set3S3	R #14	C3	Set1S3
R #5	C3	Set1S3	R #10	C4	Set1S4	R #15	C2	Set3S2
Day 6			**Day 7**			**Day 8**		
R #16	C1	Set2S1	R #21	C3	Set3S3	R #26	C4	Set2S4
R #17	C2	Set3S2	R #22	C1	Set3S1	R #27	C3	Set2S3
R #18	C4	Set1S4	R #23	C5	Set2S5	R #28	C5	Set3S5
R #19	C3	Set2S3	R #24	C4	Set3S4	R #29	C2	Set1S2
R #20	C5	Set1S5	R #25	C2	Set1S2	R #30	C1	Set3S1

2.7.2 Initial Briefing

Experimenters welcomed the participants and briefed them on the purpose of the experiment, schedule, experimental conditions and procedures, and their rights as described in the Informed Consent Form (see Appendix A). Each participant read and signed an Informed Consent Form before beginning the experiment. The participating controllers expressed their understanding and willingness to participate voluntarily in the study by signing the Informed Consent Form at that time. After this, the controllers completed the Background Questionnaire (see Appendix B).

During the second part of the initial briefing, SMEs introduced the airspace, LOAs, SOPs, and the simulation equipment.

After the initial briefing, controllers sat at their assigned controller positions and completed the practice scenarios. Each practice scenario took approximately 30 minutes. Controllers adjusted the workstations according to their preferences during the practice scenarios.

The SMEs provided participants with the position relief briefings before each of the experimental runs. All scenarios lasted approximately 50 minutes. After each test run, participants filled out the PSQ about their experience during the run (see Appendix C). When they completed all the scenarios, the participants filled out the Exit Questionnaire (see Appendix D), then experimenters, participants, and SMEs held the exit briefing.

The participants spent eight days at the RDHFL. They had one day of training to become familiar with the airspace, systems, and procedures. We developed three sets of practice scenarios. The participants worked with low-traffic level scenarios first, which started with 5 to 8 aircraft in the sector, built up to approximately 15 aircraft by 15 minutes, and then remained at that level for the remainder of the scenario. The participants had at least eight practice scenarios on the day of their arrival.

In the field, the Monitor Alert Parameter (MAP) value is a threshold set for each sector as the maximum number of aircraft that can be in a sector before Traffic Management will start diverting traffic around that sector to reduce controller workload. In some training scenarios, participants had a peak instantaneous aircraft count (PIAC) of the MAP.

2.8 Experimental Design

We used a two-way (2x5) repeated-measures experimental design (i.e., two sectors and five procedures). The following sections describe each experimental condition. We describe independent and dependent variables, respectively.

2.8.1 Independent Variables

As presented in section 1.3, we used four IADCS procedures in addition to the Baseline. The design of the study included the following independent variables:

- **Procedure –** This variable had five levels:
    1. one *baseline* level using current airspace and procedures;
    2. one level using *resectorization* (i.e., the Big Airspace approach) to provide the arrival sectors an extra piece of airspace that included an ATC assignable STAR. We called this *Lateral Airspace Shift* in this experiment;
    3. one level using *laterally separated routes* (i.e., using regular SIDs, but one of the SIDs was replaced by a STAR); and
    4. two levels using *bidirectional routes*:
        a. one for East operations (departing to the East) of the Atlanta Hartsfield Airport.
        b. one for West operations (departing to the West) of the Atlanta Hartsfield Airport.
- **Sector Type –** This variable had two levels:
    1. High Sector (ZTL32)
    2. Low Sector (ZTL16)

2.8.1.1 Integrated Arrival/Departure Control Services Conditions

2.8.1.1.1 Baseline (BA)–East Operations

Controllers did not use the IADCS procedures in the Baseline condition. Controllers needed to divert traffic due to weather during the current-day operations. Figure 12 shows the adjoining sectors and participant-controlled Sector 16 and Sector 32. Sector 16 is the low-altitude departure sector abutted to Sector 32. Sector 49 and Sector 50 are the low- and high-arrival sectors, respectively, which became saturated because of approaching weather.

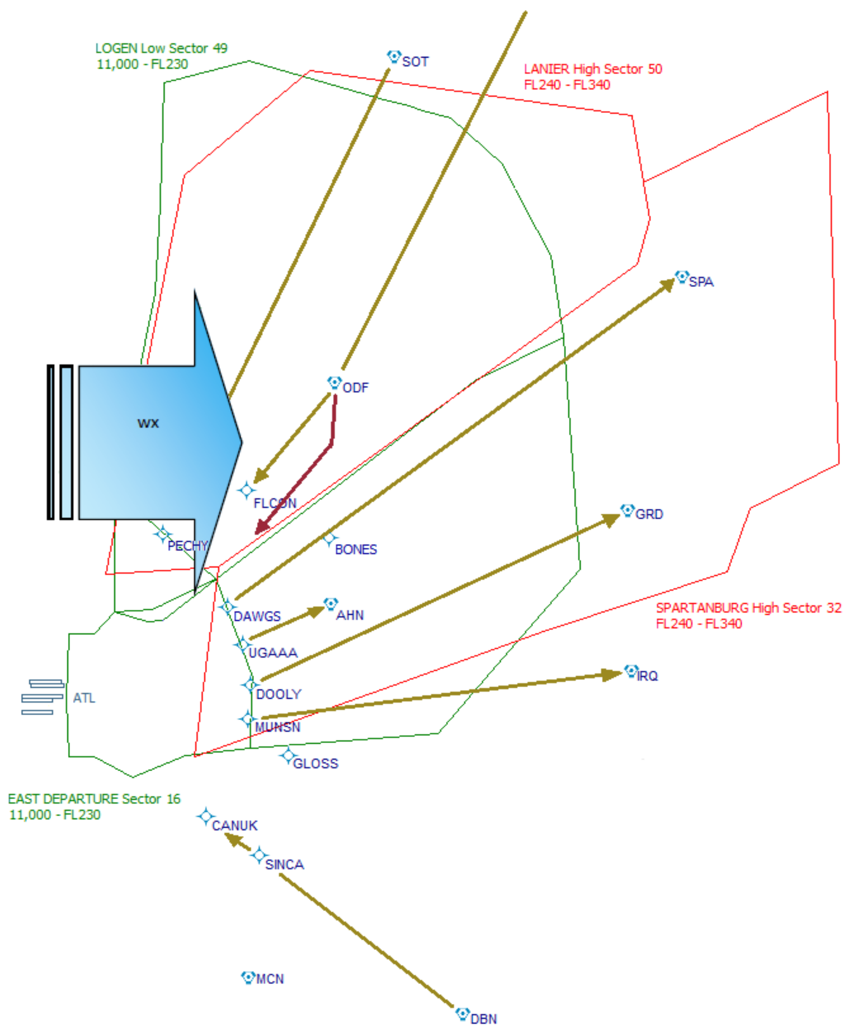


Figure 12. Airspace used in the Baseline condition (Booz Allen Hamilton, 2014).

Weather affected the inbound traffic that began to deviate to south along the boundary with Sector 16 requiring point-outs. The FLCON arrivals continued until point-outs were no longer approved. The FLCON arrivals were held at ODF (see Figure 13). In addition, all FLCON arrivals abeam SPA and north were rerouted to SINCA via the DBN transition. TMU rerouted the traffic held at ODF to ATL via IRQ DBN SINCA (see Figure 14).

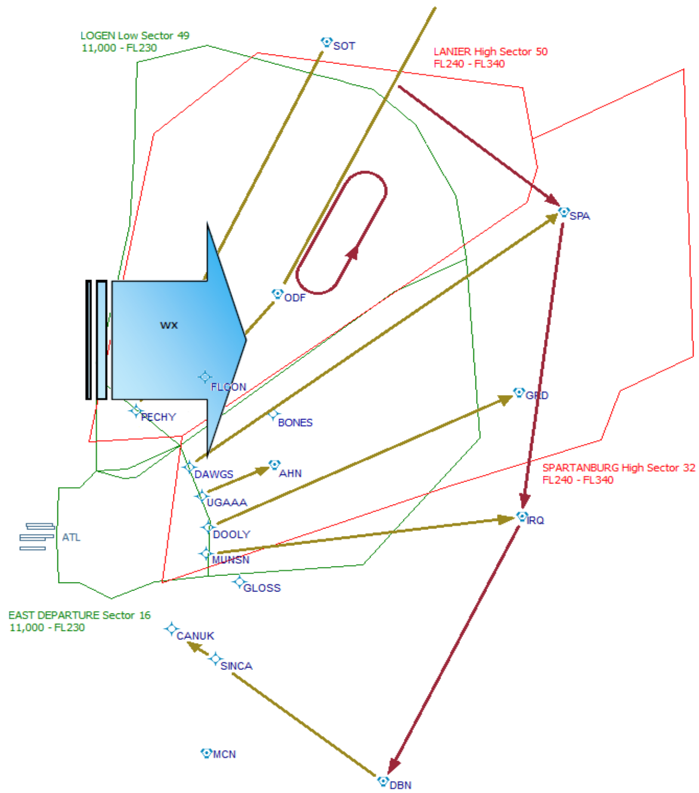


Figure 13. Hold occurred due to the weather (Booz Allen Hamilton, 2014).

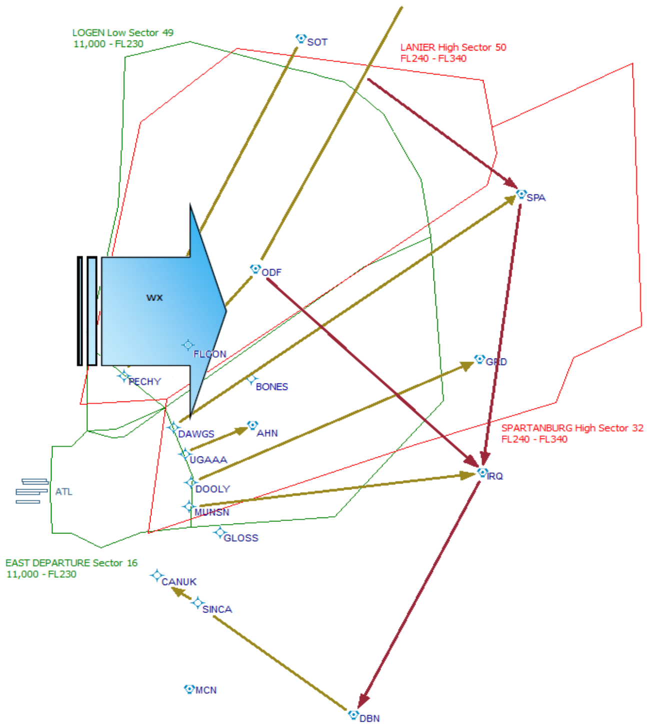


Figure 14. Traffic held at ODF released to IRQ (Booz Allen Hamilton, 2014).

2.8.1.1.2 Lateral Airspace Shift (AS)–East Operations

The Lateral Airspace condition resulted in rotating the east departure airspace clockwise relative to ATL (see Figure 15). The airspace shift consisted of a section of airspace surrounding the DAWGS departure route in Sector 16 (**A**), which was assigned to Sector 49, and a section of airspace, which was added to the southern boundary of Sector 16, BULDG (B). Once this was established, TMU moved all departures one route south from their original routes, which took place prior to departure. All arrivals continued to run via ODF, BONES, and DAWGS.

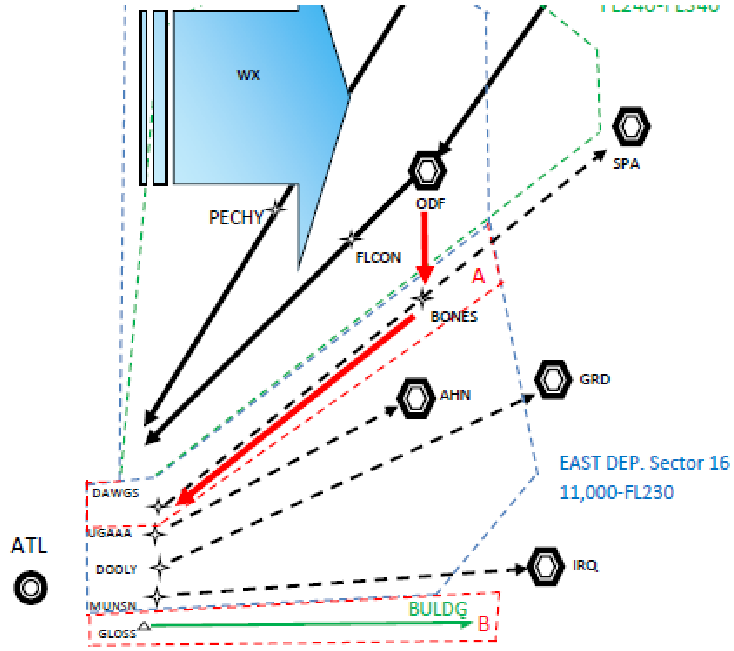


Figure 15. Airspace used in the lateral airspace condition (Booz Allen Hamilton, 2014).

2.8.1.1.3 Laterally Separated Routes (LR)–West Operations

There were no deviations, and traffic flowed normally at first. Then, at 15 minutes, TMU coordinated using GRD AHN UGAAA to absorb excess arrival demand (see Figure 16). Any departures that were already airborne used UGAAA; all others used DAWGS. The GRD AHN UGAAA arrival serviced flights from ORF, CLT, RIC, RDU, and CHS (illustrated with a red arrow in Figure 16).

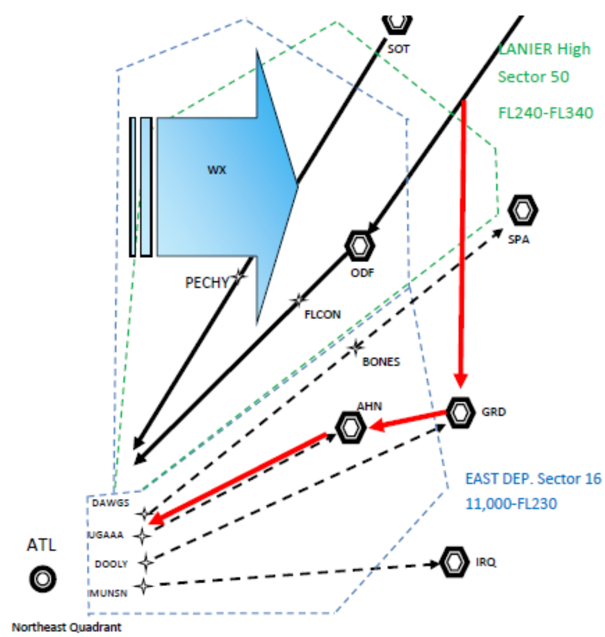


Figure 16. Laterally separated routes (Booz Allen Hamilton, 2014).

2.8.1.1.4 Bidirectional Routes–Vertically Separated

We included two vertically bidirectional conditions: Vertically Separated–High-Altitude Arrivals and Vertically Separated–Low-Altitude Arrivals. In both conditions, the departure sectors received an ATC assignable STAR route while keeping the SID route, but the departure and arrival streams of traffic were separated vertically (see Figure 17).

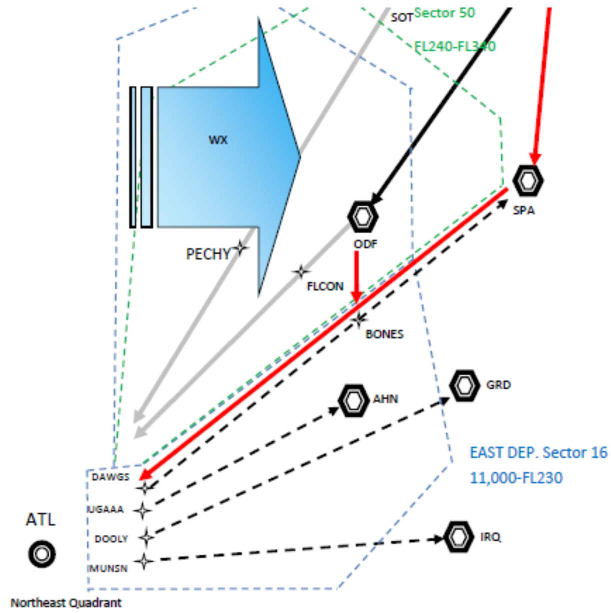


Figure 17. Bidirectional and vertical routes (Booz Allen Hamilton, 2014).

2.8.1.1.4.1 <u>Vertically Separated: High-Altitude Arrivals (or DAWGS High Play) (HP) East Operations</u>

We configured the airport for east operations. Because the departures were at a low altitude, the east departure sector controllers used a special bidirectional route to handle the diverted traffic from the FLCON STAR. Arrival flights followed the BONES1 STAR located above the DAWGS SID. TMU advised that the DAWGS High playbook was in effect. This meant that A80 handed off DAWGS departures to ZTL at 11,000 ft and accepted arrival over DAWGS at 14,000 ft. This was needed because FLCON was closed. All aircraft north of MOL were routed to ATL via MOL SPA DAWGS. Sector 32 continued to hand off ATL arrivals to Sector 16 descending to FL240. Sector 16 descended those aircraft to cross DAWGS at FL140.

2.8.1.1.4.2 <u>Vertically Separated: Low-Altitude Arrival (or DAWGS Low Play)(LP) –West Operations</u>

We configured the airport for west operations. As in the High-Altitude Arrivals condition, the east departure sector controllers used a bidirectional route to handle the diverted traffic from the FLCON STAR. Because the airport ran west operations, the departing aircraft had a chance to climb to altitude, and the SID was above the STAR.

TMU advised that the DAWGS Low playbook was in effect. It meant that A80 handed off DAWGS departures to ZTL (at or above 13,000 ft) 10 miles west of DAWGS. DAWGS arrivals coming from ODF to BONES crossed BONES at FL170 and were expected to cross DAWGS at FL110. Sector 32 delivered the rerouted DAWGS arrivals to Sector 16 at FL240. This was necessary because FLCON was closed. All aircraft north of MOL were routed to ATL via MOL SPA DAWGS without altitude restrictions.

2.8.2 Dependent Variables

2.8.2.1 System Variables and Voice Communications

The TGF, DESIREE, and communications systems provided a large number of variables that we used as dependent variables for this study.

Table 7 captures many of these variables, including the type and unit of observation, name, measurement units, and data sources.

Table 7. System Variable Types, Variables, Units, and Data Sources

Variable Type and Unit of Observation	Variable	Source
Distance	Within a sector	TGF, DESIREE, HF-DRAT
- **per aircraft**	On the frequency	,,
- **average**	Under control	,,
	Under responsibility	,,
	Total	,,
Time	Within a sector	TGF, DESIREE, HF-DRAT
- **per aircraft**	On the frequency	,,
- **average**	Under control	,,
	Under responsibility	,,
Number of Aircraft	Within a sector	TGF, DESIREE, HF-DRAT,
- **interval**	On the frequency	,,
- **scenario**	Under control	,,
- **instantaneous**	Under responsibility	,,
	Landed	,,
	Departed	,,
Number of Holds and Delays	Holds	DESIREE, HF-DRAT
- **interval**	Ground delays	,,
- **scenario**	In own sector	,,
- **instantaneous**	Outside of own sector	,,
Number of Controller Entries per	Altitude	TGF, DESIREE, HF-DRAT
- **sector**	Speed	,,
- **controller**	Heading	,,
- **aircraft**	Direct to fix	,,
	Route	,,
	Handoff acceptance	,,
	Handoff initiation	,,
	Macros (and content)	,,
	Total	,,
Duration of Controller Entries	Altitude	DESIREE , HF-DRAT
(average) per	Speed	,,
- **sector**	Heading	,,
- **controller**	Direct to fix	,,
- **aircraft**	Route	,,
	Handoff acceptance	,,
	Handoff initiation	,,

Variable Type and Unit of Observation	Variable	Source
	Macros (and content)	,,
	Total	,,
Number of Voice Clearances (push-to-talk) per - **sector** - **controller** - **aircraft**	Altitude	DESIREE-PTT, HF-DRAT
	Speed	,,
	Heading	,,
	Direct to fix	,,
	Route	,,
	Handoff acceptance	,,
	Handoff initiation	,,
	Complex clearances	,,
	Total	,,
Duration of Voice Clearances (push-to-talk) per - **sector** - **controller** - **aircraft**	Altitude	DESIREE-PTT, HF-DRAT
	Speed	,,
	Heading	,,
	Direct to fix	,,
	Route	,,
	Handoff acceptance	,,
	Handoff initiation	,,
	Complex clearances	,,
	Total	,,
Number of Potential Conflicts - **sector** - **aircraft**	Lateral separation violation	DESIREE, HF-DRAT
	Conflict alerts	,,
	Conflict probe alerts	,,
	Wake separation violation	,,
Duration of Potential Conflicts	Lateral separation violation	DESIREE, HF-DRAT
	Conflict alerts	,,
	Conflict probe alerts	,,
	Wake separation violation	,,

Note. TGF = Target Generation Facility; DESIREE = Distributed Environment for Simulation, Rapid Engineering, Experimentation; HF = Human Factor; DRAT = Data Reduction and Analysis Tool; PTT = Push-To-Talk.

2.8.2.2 Workload Measures

To assess workload, we included subjective and objective measures. The workload measures included an instantaneous workload rating, overall scenario workload ratings addressed in the PSQ and Exit Questionnaire, and physiological measures.

2.8.2.2.1 Air Traffic Workload Input Technique

During each scenario, the participants used a version of the Air Traffic Workload Input Technique (ATWIT) implemented as the WAK to provide workload ratings (Stein, 1985). The participants received instructions to indicate their instantaneous workload level by pressing one among 10 buttons numbered from 1 to 10.

The WAK is an adaptation of the ATWIT (Stein, 1985) to assess instantaneous subjective workload during simulations. It uses a 10-point anchored scale. In our simulation, it emitted a tone and illuminated the keys at 2-minute intervals to prompt the participants for a workload rating ranging from 1 (very low) to 10 (very high). The low end of the scale (1–2) reflects low workload—i.e., participants can accomplish all their tasks easily and have spare time remaining. At levels 3–5 of the workload scale, controllers experience increasing levels of moderate workload. They can still finish all tasks, but the chance of an error steadily increases, and less time is available. At levels 6–8 of the workload scale, controllers experience high workload, have no spare time available, can barely finish all essential tasks, and leave some unessential tasks unfinished. At levels 9–10 of the workload scale, participants experience extremely high workload. It is likely that participants leave essential tasks unfinished and most likely only focus on keeping aircraft separated. We configured the WAK device to prompt participants for input every 2 minutes with 20 seconds to respond. If the device did not receive a response within 20 seconds, it recorded a code for missing data.

2.8.2.3 Post-Scenario Questionnaires (PSQ)

The PSQ included items to assess the workload that controllers experienced during the simulation scenario they just completed (see Appendix C). Controllers also had the opportunity to comment on the reasons why they experienced the workload at that level.

The PSQ contained several items for controller ratings of situational awareness for aircraft positions, altitude, and handoff state. The PSQ also contained items assessing controller situational awareness of potential losses of separation (conflicts). Finally, the PSQ contained items that assessed controller situational awareness of required spacing while sequencing aircraft.

We also included several questions to evaluate the impact of the condition experienced during the run that controllers just completed. We asked them to respond based on their experience on the four phases of the previous run:

- **Phase 1:** Initial Base Period—The initial 10 minutes before the weather affected the traffic flow.
- **Phase 2:** Transition—The interval during which traffic changes from the Base Period to a situation in which weather is starting to affect the traffic flow. For example, in the Baseline conditions, controllers experienced point-outs and aircraft diverting into their airspace. Under the IADCS conditions, controllers experienced

a transition to a new airspace configuration or started to receive arrival traffic in addition to their departure traffic.

- **Phase 3:** New Normal—The time after the transition during which the new traffic pattern stabilized.
- **Phase 4:** End Run—The last period between Phase 3 and the end of the run.

2.8.2.4 Exit Questionnaires

The exit questionnaire provided controllers an opportunity to compare the different conditions that they experienced during the experiment and contained several items that specifically addressed each of the IADCS configurations.

The exit questionnaire included items that assessed differences in workload between experimental conditions. Controllers had the opportunity to comment on the reasons why they experienced the workload at that level for each of the conditions. The questionnaire also asked the participants about their overall experience with the IADCS.

3. RESULTS AND DISCUSSION

In the following section, we present and discuss the results of various dependent variables. Then, we present the general discussion and conclusion of the overall results.

3.1 Traffic Samples

In Traffic Sample 1, traffic of ARTCC sectors increased until 22 minutes to approximately 15 or 16 aircraft for Sector ZTL32 and approximately 11 or 12 aircraft for Sector ZTL16. Traffic in the TRACON Departure sector was nearly constant at six aircraft. For the Arrival sector, traffic increased continuously during the experimental run to a maximum of 11 aircraft.

In Traffic Sample 2, traffic of ARTCC Sector ZTL32 increased sharply to approximately 19 aircraft by 24 minutes after the start of the experimental run, and then it declined slowly to approximately 14 aircraft. Traffic in Sector ZTL16 was variable at first, but after 16 minutes it increased until the end of the run to a maximum of approximately 12 aircraft. Traffic in the TRACON Departure sector varied little at approximately three to four aircraft, and the Arrival sector had a continuous increase in traffic during the run (50 minutes) to a maximum of 11 aircraft.

In Traffic Sample 3, traffic of ARTCC Sector ZTL32 increased to approximately 17 aircraft at 24 minutes, and then it declined to 14–15 aircraft for the remaining time. Traffic in Sector ZTL16 increased to approximately 13 aircraft at 38 minutes, and then remained at approximately 12 aircraft to the end of the run. Traffic in the TRACON Departure sector varied little at three to four aircraft, and the Arrival sector had a continuous increase in traffic during the run to a maximum of 12 aircraft.

3.2 Workload Ratings

Table 8 shows the distributions of workload ratings across participants. There were two individuals who gave "10" ratings more often than others. Their ratings of 10 occurred 47 times. There were a total of 53 ratings of 10 (see Table 8). In addition to issues already mentioned (e.g., skewness, missed responses), there was a missing session (due to software error) that unbalanced the data set. Some participants performed particular sector/position roles more often than other roles, partially confounding the Participants factor with certain interactions of the factors of interest. Removing this confounding factor would have required many more days of data collection than were practical to run. Thus, we did not try objective statistical analyses.

Table 8. Rating Values Used by ARTCC Controller Participants

	Rating									
Participant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	559	87	5					1		1
2	444	155	23	11	3	5	2	3	2	18
3	233	142	25	16	3	1	2	2		29
4	319	118	134	72	9	2	1	2		
5	570	91	6		1			1		1
6	354	214	19	5	1					1
7	249	395	60	7	3				1	1
8	462	207	28			1				1
9	424	215	62	7	4					
10	273	380	48	2						
11	560	152	3							
12	197	401	33		1	1		1		1

The WAK ratings of 10 were mostly from two participants (Participants 2 and 3). Table 9 shows the frequency of WAK ratings of 10 for these two participants. It appears that even though WAK 10 ratings were mainly from two participants, their rating distributions did not give a clear pattern, except that there were more 10 ratings in Baseline and High Play conditions (see Figures 18 and 19).

Table 9. Ratings of 10 by Participants 2 and 3

Participant	Sector	Position	Condition	Traffic	Run number	Run number	Frequency
3	16	R	BA	3	30	25	10
3	32	R	HP	3	4	26	8
3	16	R	AS	1	29	24	8
3	32	D	LR	2	27	22	2
3	16	D	AS	2	7	6	1
2	32	D	BA	3	30	25	5
2	16	D	HP	3	4	26	4
2	32	D	AS	1	29	24	3
2	16	D	LR	3	9	28	2
2	32	D	LR	1	14	12	1
2	32	D	HP	1	18	14	1
2	16	D	AS	1	25	29	1
2	32	R	LR	2	27	22	1
1	16	D	BA	3	30	25	1
7	16	R	LP	1	20	20	1
8	32	D	BA	3	30	30	1

Note. BA = Baseline; AS = Airspace Shift; LR = Laterally Separate Routes; HP = High Play; LP = Low Play.

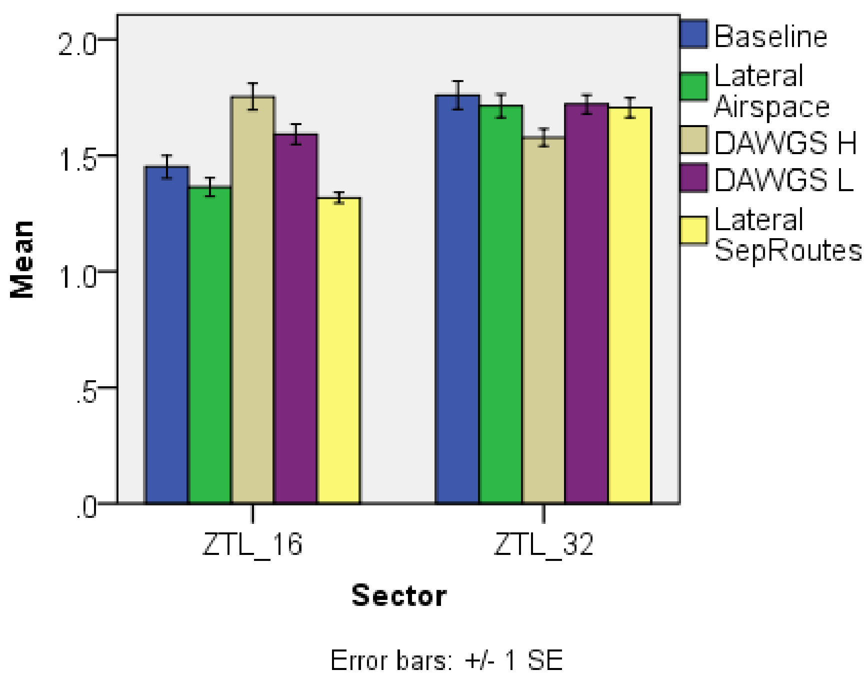


Figure 18. Average WAK ratings including Participants 2 and 3.

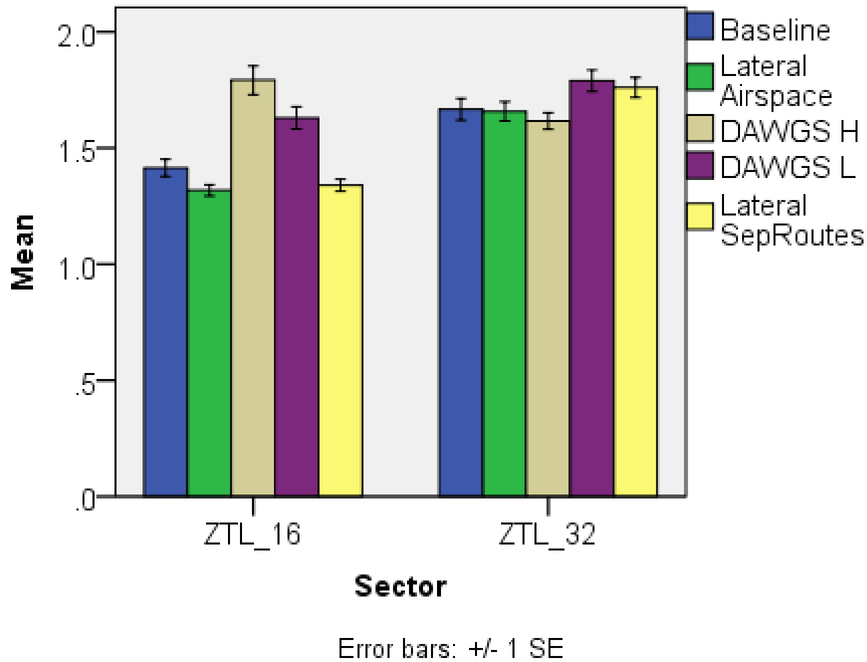


Figure 19. Average WAK ratings without Participants 2 and 3.

3.3 Clearances

In all scenarios, there were KATL arrival and departure aircraft affected by the weather and rerouted as determined by the experimental condition. This subset of aircraft received different clearances from the ARTCC controllers, by necessity, because they were flying different ground tracks.

Most other aircraft (transiting flights) flew the same routes on the same schedule across all conditions. A few were time-shifted slightly, as necessary, to avoid unrealistic conflicts. This subset might show small differences in clearances issued to maintain tactical separation from the deviated or rerouted flights. If there were systematic differences across conditions, some plays had given more workload to controllers and created more potential for conflict than other plays.

We want to compare the frequency and kinds of clearances given to transiting aircraft by controllers to see if the various traffic plays had differing impacts on ARTCC sector operations. For this purpose, we analyzed all clearances that had affected the four-dimensional trajectory of an aircraft such as altitude, speed, heading, and route clearances.

Table 10 shows the total number of clearances issued to the flights in Sectors 16 and 32. There were too few speed clearances to analyze statistically. We used a chi-square test of association among other categories: Altitude, Heading, and Route clearances. Although there were more Altitude clearances in the vertically bidirectional traffic plays (High Play and Low Play), this difference was not statistically significant. There were no statistically significant differences between experimental conditions in terms of number of clearances issued by ARTCC controllers to transiting aircraft.

Table 10. Clearances by Type and Traffic Play

Clearance Type	BA	HP	LP	AS	LR
Altitude	83	97	101	79	86
Heading	14	17	20	21	13
Route	39	30	34	29	41
Speed	3	3	2	1	1

Note. BA = Baseline; HP = High Play; LP = Low Play; AS = Airspace Shift; LR = Laterally Separate Routes.

3.3.1 Discussion

Controllers used more altitude clearances in the vertically bidirectional plays even though we ensured procedural separation of the bidirectional traffic flows. This reflects a more cautionary approach by the controllers when handling traffic transitioning vertically in opposite directions, resulting in step climbs and descents.

3.4 Deviations and Loss of Separation

3.4.1 Deviations

In our analysis, we differentiated basic deviations that applied to all IADCS conditions from the other types of deviations that applied to DAWGS High and DAWGS Low procedures only. There were also deviations due to pilot errors, which we did not include in our analysis. We categorized deviations into three types: basic deviations, deviations specific to DAWGS High procedure, and deviations specific to DAWGS Low procedure. The basic deviations were as follows:

- Controllers did not transfer radio communication to the receiving sector controllers prior to the aircraft crossing the sector boundary, unless otherwise coordinated ahead.
- Controllers did not point out an aircraft to the next sector controller prior to that aircraft reaching 2.5 NM from the next sector boundary, unless otherwise coordinated.

The deviations specific to the DAWGS High condition:

- Any A80 departures that do not cross DAWGS level at 11,000 ft is a deviation by A80.
- Any ATL arrivals that do not cross DAWGS level at 14,000 ft is a deviation by Sector 16.

The deviations specific to the DAWGS Low condition:

- Any A80 departures that do not cross DAWGS level at 13,000 ft is a deviation by A80.
- Any ATL arrivals that do not cross DAWGS level at 11,000 ft is a deviation by Sector 16.

We verified each deviation by using a display tool called SimViewer, which replayed each participant's activities and communications. If a deviation occurred because a simulation pilot neglected or entered a controller clearance into the system significantly late, we did not use it for the analysis. If a deviation occurred due to a system malfunction, we also did not include it in our data analysis. We only used deviations caused by controllers. The deviation frequency of DAWGS High was the highest (see Figure 20).

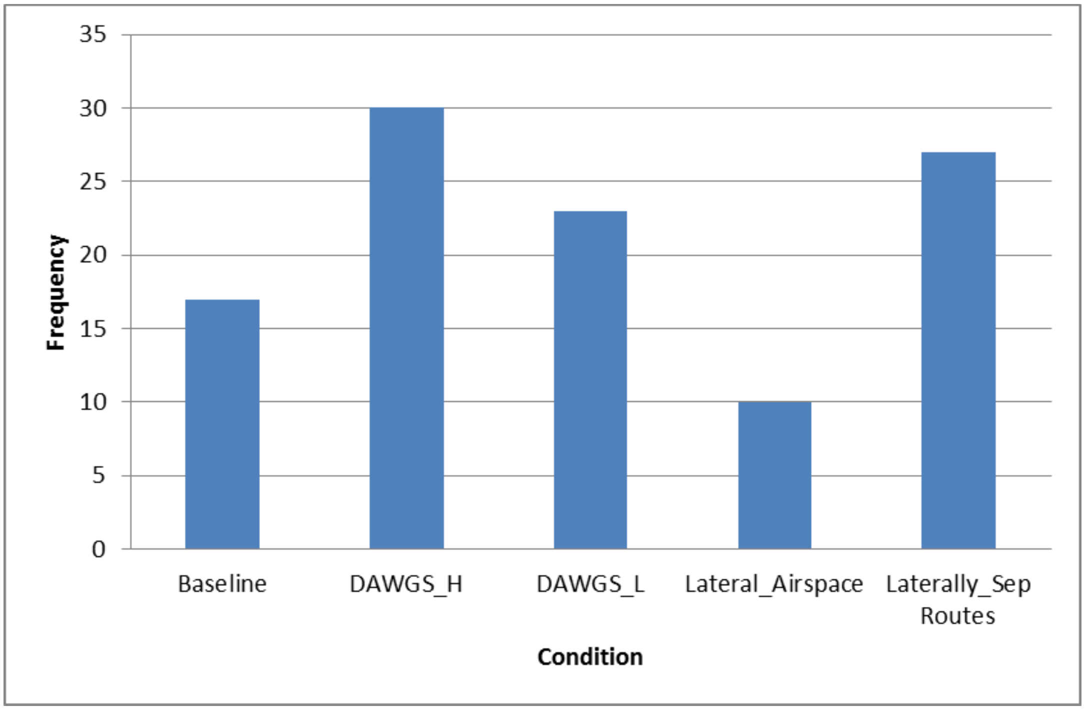


Figure 20. Total deviation frequency by experimental condition.

We evaluated frequencies of deviations in four 12-minute bins (see Figure 21). Specifically, from 2–14 minutes, from 14–26 minutes, from 26–38 minutes, and from 38–50 minutes. We excluded deviations that occurred before 2 minutes and after 50 minutes. As the effect of weather increased, there were more deviations.

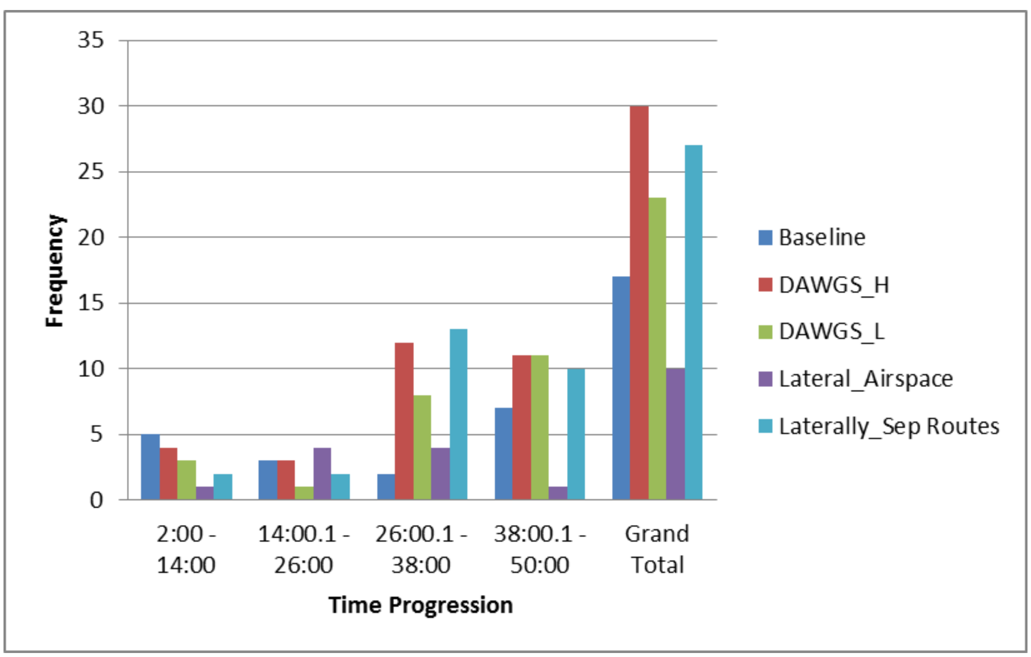


Figure 21. Total deviation frequency by time in a scenario run.

As aircraft in the DAWGS conditions did not cross the DAWGS fix until after the 26-minute mark, deviations specific to DAWGS conditions occurred after 26 minutes (see Figure 22). There were more deviations in the DAWGS High condition than in the DAWGS Low condition.

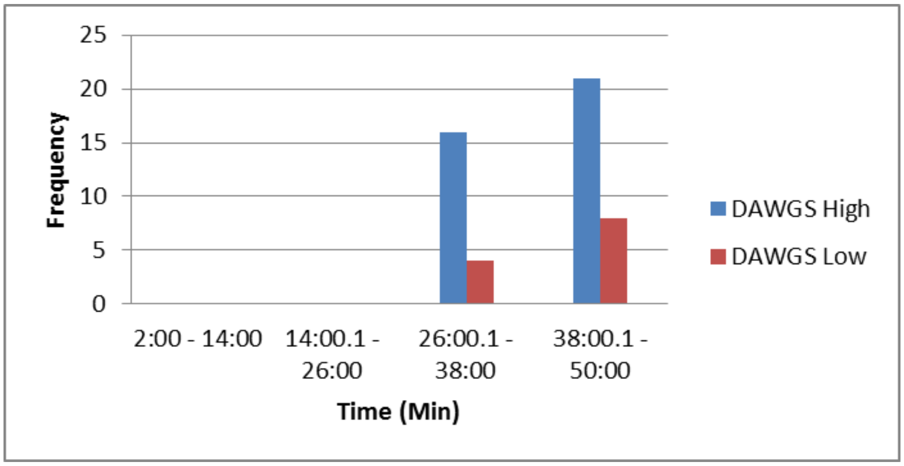


Figure 22. Total frequency of DAWGS-specific deviations.

3.4.2 Loss of Separation

For the loss of separation data, we found that we had some duplicates of the loss of separation aircraft pairs because they moved in and out of losing separation. After removing the duplicates, we categorized the loss of separation instances based on the following four categories:

- **3M (3 NM):** The aircraft were still in 3-NM separation airspace and, therefore, we should not count less than 5 miles as a loss of separation.
- **OE (operation-error potential):** A loss of separation of less than minimum separation, and the controller is implicated.
- **PD (pilot deviation):** A pilot deviation resulting from a pilot doing something other than what the controller instructed, and the deviation resulted in a loss of separation.
- **SE (system error):** A scenario or system error resulted in a loss of separation (e.g., two aircraft getting too close within the first 2 minutes of the scenario).
- **VS (visual situation):** The controller asked if the pilot had an aircraft in sight, and the pilot concurred.

There were 13 losses of separation. The distribution of OEs was similar across all five conditions. We only looked at loss of separation instances that involved one or more aircraft physically inside or under control of Sector 16 or Sector 32 controllers (see Table 11). The results showed there were large separation loss differences between vertical separation procedures (High and Low Plays) and other procedures as shown in bold in Table 12. With the current data, we do not know what caused these large differences. We may be able to know it with more detailed data analyses in the future.

Table 11 Frequency of Separation Loss

Conditions	3M	OE	PD	SE	VS	Total
AS	0	2	0	2	0	4
BA	1	3	0	0	0	4
HP	0	3	3	2	1	**9**
LP	1	2	0	7	0	**10**
LR	2	3	0	0	0	5
Total	**4**	**13**	**3**	**11**	**1**	**32**

Note. BA = Baseline; AS = Airspace Shift; HP = High Play; LP = Low Play; LR = Laterally Separate Routes; 3M = 3 Nautical Miles; OE = Operation Error; PD = Pilot Deviation; SE = Scenario or system error; VS = Visual Situation.

3.4.3 Discussion

As illustrated in Figures 21–22, Laterally Separate Routes, DAWGS High, and DAWGS Low had the most deviations. When the traffic was heavy, the same pattern also appeared. As shown in Figure 21, DAWGS High had more deviations than DAWGS Low. As the bidirectional, vertical procedures had additional procedures, we assume there were more chances of deviations. Overall, DAWGS High and Low procedures produced more deviations than any other procedure when we added up the basic and DAWGS-specific deviations.

3.5 Time and Distance

In the fast-time simulation, Young, Bassett, and Hailston (2013) already showed the advantage of the IADCS procedures over the Baseline in saving time and distance flown by aircraft. In our HITL experiment, we expected the same results. We describe the results below. Unfortunately, the simulation software did not output total-distance-flown-to-last-fix values, but we could obtain total flying time. As there should be a strong correlation between flying time and distance, we believe analyzing time alone would capture the meaningful difference between experimental conditions. The following results are based on the flying time.

We could use the flight distance and time within sector boundaries. However, this does not show the total effect of a traffic control procedure because it ignores the flight outside of the sector (see Figure 23). The route KORG..BAAVI..KDST is shorter than the route KORG..ALBAA..KDST without the paths outside of the sector; with the paths outside of the sector, its overall flight distance and time are longer. To avoid this misrepresentation, we subtracted the starting time of the flight in the flight plan of each flight from the estimate of the time at its last fix and destination. This duration-of-flight measure included flight segments outside the sectors in addition to those inside the sector. For the non-controlled segments outside the sectors, we assumed random variations in time and distance, which would net out across experimental conditions (i.e., procedures).

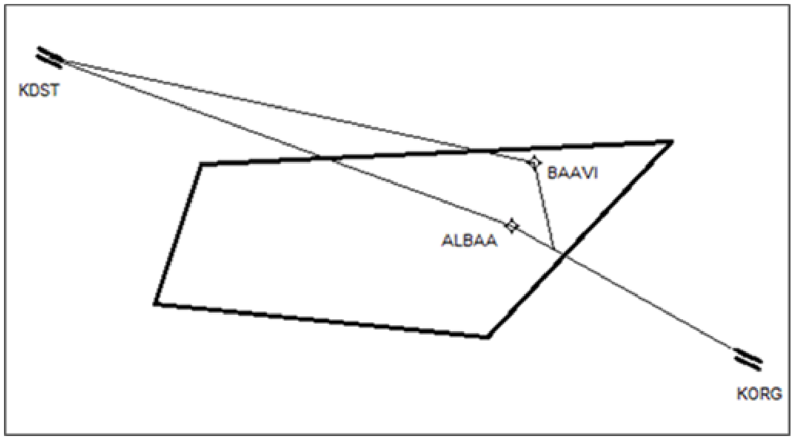


Figure 23. Sector and flight-track geometry artifact (hypothetical).

3.5.1 Time Flown

Within each of the three traffic samples, there was a subset of KATL arrivals. The weather influenced the arrivals that occurred approximately 20 minutes after the start of each experimental run. Controllers rerouted these flights as determined by the experimental condition. For these aircraft, we calculated flying time from the start of the flight to the actual or predicted arrival time at KATL (as mentioned above). The average times in Table 12 reflect the routing specific to the different experimental conditions by the two segments—before and after the weather.

We want to point out that the set of arriving flights (67 aircraft) before the weather event was not the same set of flights (i.e., 142 aircraft) after the weather because some of aircraft might have left and some might have entered into the data sets we used for this analysis. Within each of the "before" and "after" subsets, we used the same set of flights across the different experimental conditions—so our comparisons between them were meaningful. As Table 12 shows, the differences between the Baseline and other conditions were not large before the weather. But after the weather, the differences were significantly larger. The time for the Baseline after the weather is in bold in the table.

Table 12. Average Time of Flight of KATL Arrivals, Before and After Weather Event, by Traffic Play, Minutes

Segments in an Experimental Run		*Traffic Play*				
		Baseline	Lateral Airspace	Laterally Separate Routes	**DAWGS High**	**DAWGS Low**
Before Weather Event (67 flights)	**Average (min)**	49.5	49.8	47.3	50.1	47.1
After Weather Event (144 flights)	**Average (min)**	**70.4**	53.6	53.3	52.5	52.7

We expected that KATL arrivals in the Baseline condition would have a significantly longer flight path after the weather than other procedures, simply based on the geometry of the re-routes. Young et al. (2013) already reported it. We performed an analysis of variance (ANOVA) using Statistica 13; both the main effects of Play ($F[4,1045]=9.05$, $p<0.05$) and Before/After Weather Event

($F[1,1045]=39.34$, $p<0.01$), and their interaction ($F[4,1045]=7.30$, $p<0.01$) were statistically significant. This interaction effect is due to the large difference between the times of the Baseline condition before the weather (49.5 minutes) and after the weather (70.4 minutes). The post-hoc tests between the procedures after the weather showed that the comparisons between the Baseline with any IADCS procedure were significant below $p=.01$. All comparisons between each of the IADCS procedures after the weather were not statistically significant.

3.6 Post-Scenario and Exit Questionnaires

3.6.1 Post-Scenario Questionnaire

After each scenario run, participants rated in the PSQ form how the situation created by the experimental procedure affected their controlling air traffic (see Appendix C). We asked them to rate each of the major ATC tasks proposed by Alexander, Alley, Ammerman, Hostetler, and Jones (1988): Situation Monitoring, Resolving Aircraft Conflicts, Managing Air Traffic Sequences, Routing or Planning Flights, Assessing Weather Impact, and Managing Sector and Position Resources. We instructed them to use the following rating guideline: A rating of -5 represented that the procedure they had used limited or hindered their performance tremendously. A rating of 5 represented the opposite—the procedure helped them in a very positive manner. The rating of 0 represented no effect.

Because of the large individual differences and a small number of participants (four participants in each group), we decided not to run any statistical tests but to examine the data by each individual and discuss the general response patterns. As their ATC tasks were different by their control positions of R- or D-side and by sector, we compared their ratings at these four specific conditions (2 positions x 2 sectors) per condition. We calculated the average ratings for each of the combinations.

In the following figures, we present four graphs of Group 1 data. Each participant had six runs for each experimental condition. The graph represents each participant's average ratings per five experimental conditions on six control tasks: situation monitoring, resolving conflict, managing sequences, route planning, assessing weather situation, and managing resources (see Figures 24–27). In the figures below, we used the range between -2 and +2 to see the difference more clearly instead of using -5 and +5, which was the rating range.

Even with large individual differences in Group 1 participants' ratings, we could see a few clear patterns. Participant 1 preferred all alternative procedures, except DAWGS High, to the Baseline procedure. Participant 2 did not show any clear preferences of the alternative procedures to the Baseline procedure. For Participant 2, DAWS High was the worst procedure as with Participant 1. Participants 3 and 4 did not give any substantially low ratings for DAWGS High. For Participant 4, ratings on DAWGS High and DAWGS Low were lower than ratings on other procedures. Participant 4 preferred the Laterally Separate Route procedure over the other procedures, including the Baseline procedure. For Participant 3, the Baseline procedure was rated as the most preferred procedure.

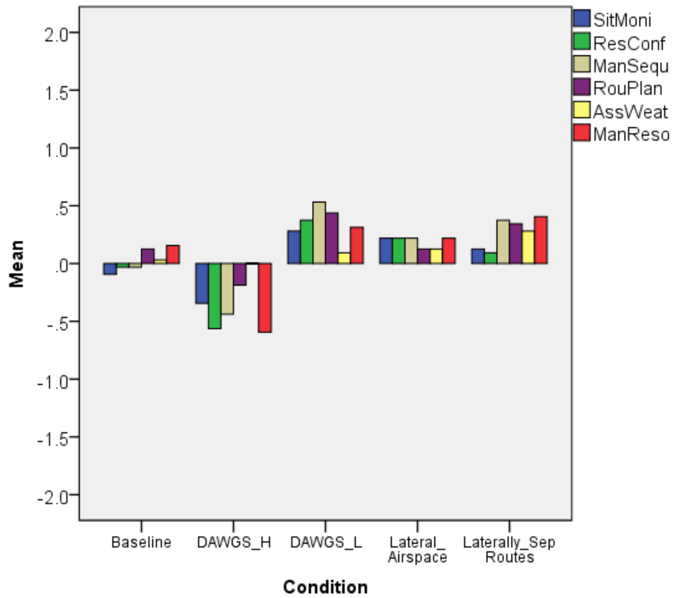


Figure 24. Average ratings of Participant 1 of Group 1.

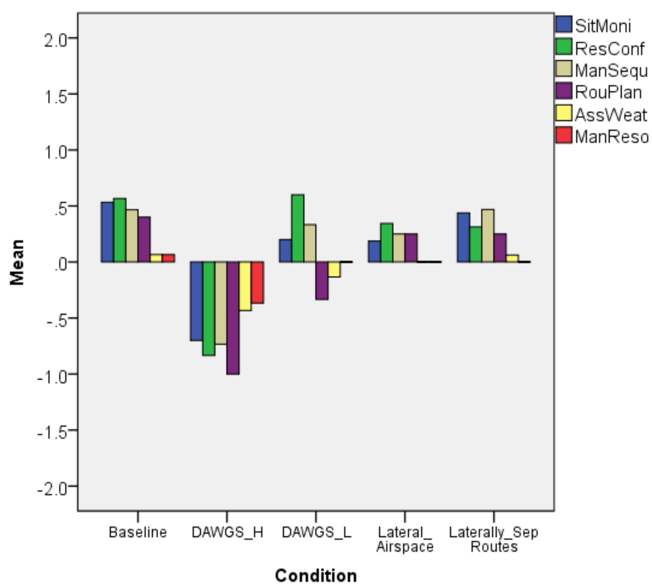


Figure 25. Average ratings of Participant 2 of Group 1.

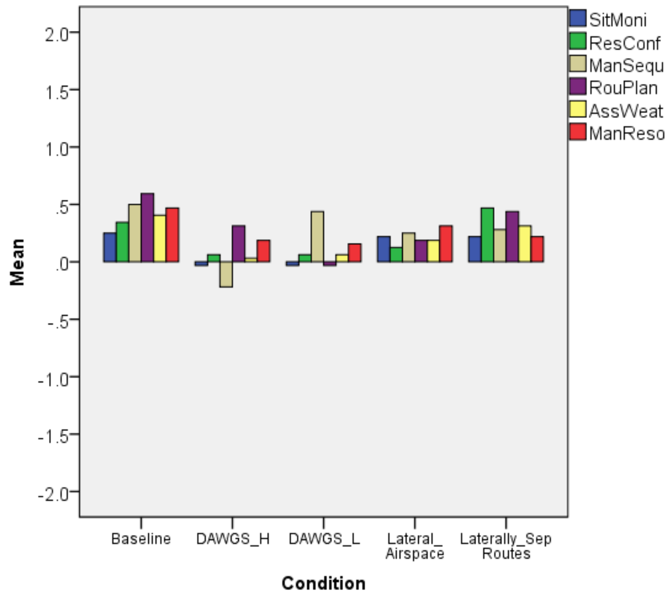


Figure 26. Average ratings of Participant 3 of Group 1.

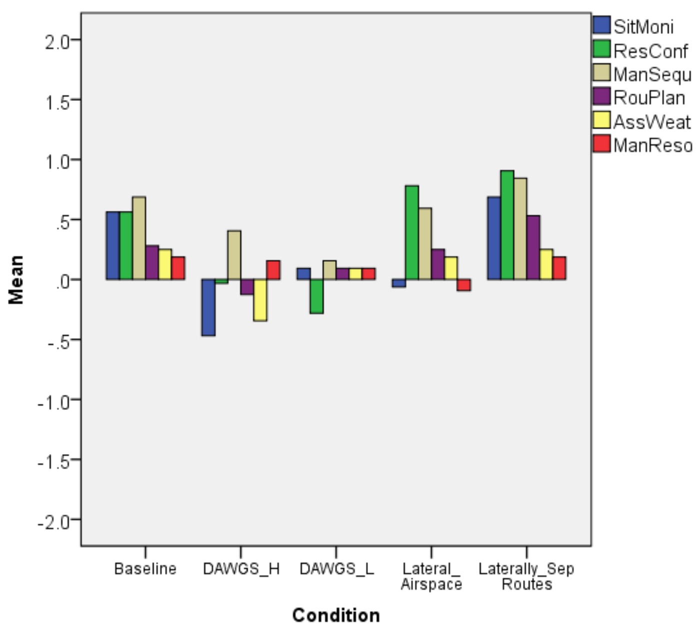


Figure 27. Average ratings of Participant 4 of Group 1.

We observed the same trend in Group 2 data (see Figure 28–31). Participants 1, 2, and 3 rated Baseline and DAWGS High as the least preferred procedures. Participant 4 rated DAWGS High and DAWGS Low as the least preferred procedures.

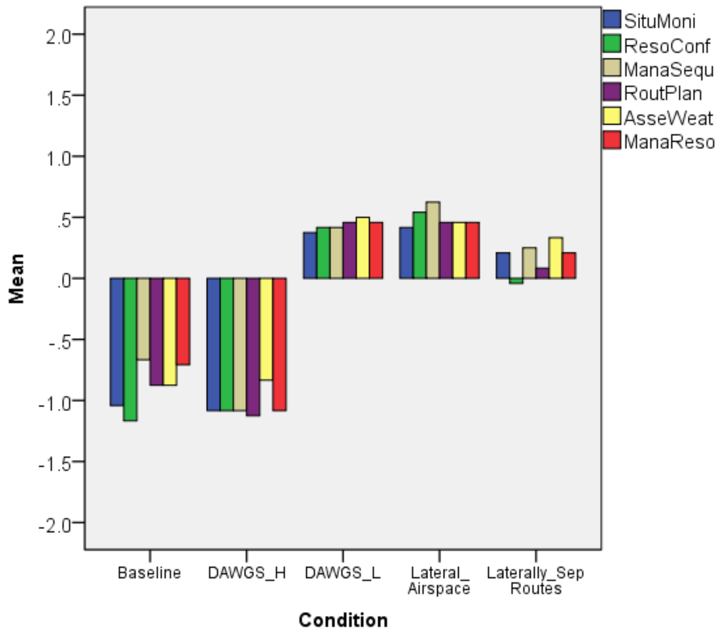


Figure 28. Average ratings of Participant 1 of Group 2.

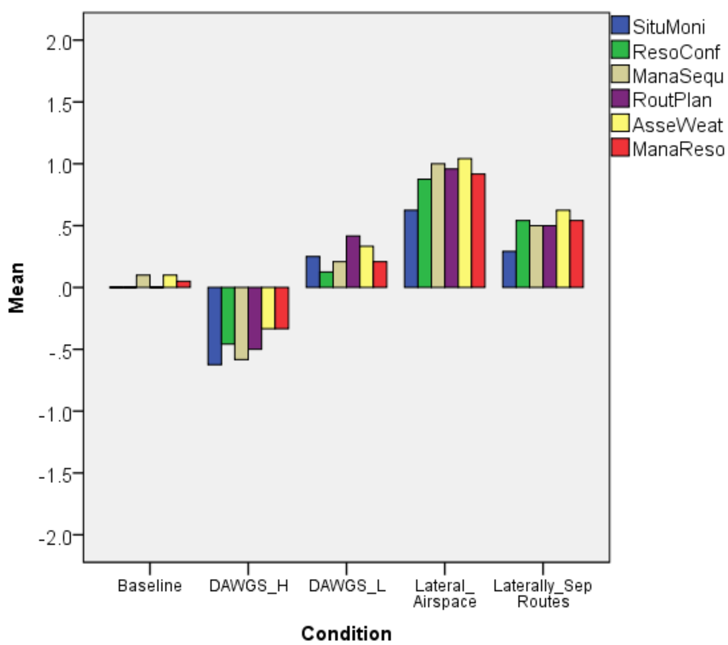


Figure 29. Average ratings of Participant 2 of Group 2.

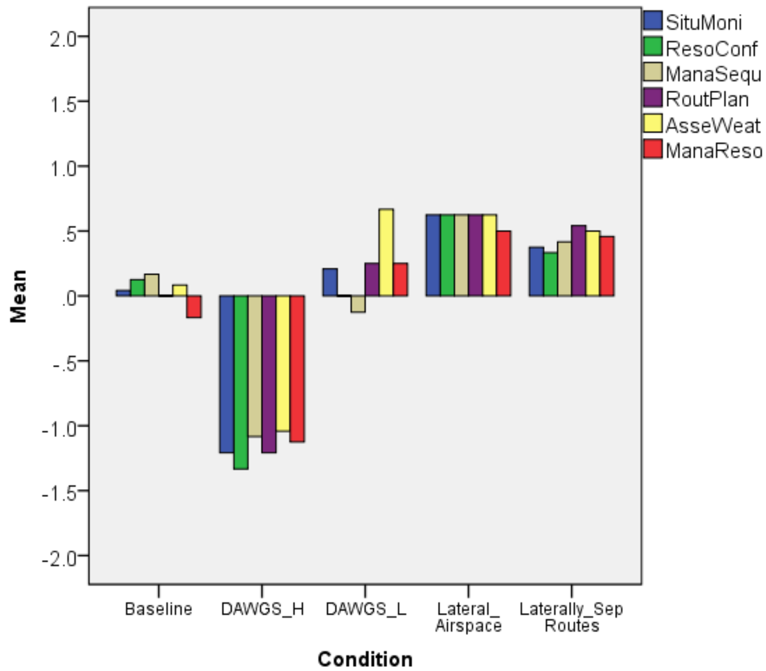


Figure 30. Average ratings of Participant 3 of Group 2.

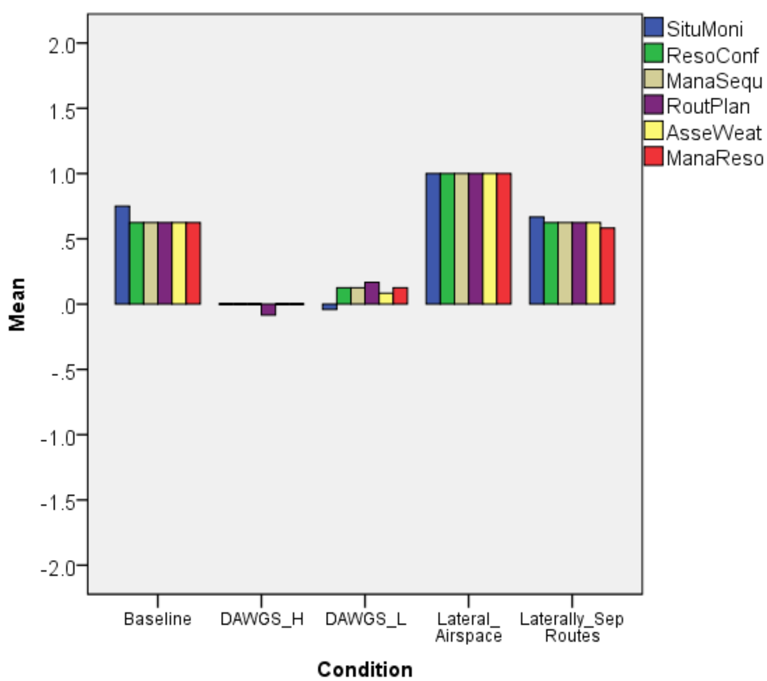


Figure 31. Average ratings of Participant 4 of Group 2.

3.6.2 Exit Questionnaire

We asked participants about the general characteristics of the simulation experiment (see Appendix D, Exit Questionnaire):

1. The overall realism of the simulation experience compared to actual ATC operations.
2. The realism of the simulation hardware compared to actual equipment.
3. The realism of the simulation software compared to actual functionality.
4. The realism of the airspace compared to actual National Airspace System (NAS).
5. The realism of the simulation traffic scenarios compared with actual NAS traffic.
6. The interference of the WAK rating technique with the ATC performance.
7. The interference of the functional near-infrared technique with the ATC performance.
8. The interference of the heart-rate variability technique with the ATC performance.
9. The simulation pilot performance interference with ATC performance.

We asked participants to use the following guideline: A rating of -5 represents being very negative, a rating of 0 represents being neutral, and a rating of 5 represents being very positive. Figure 32 shows the results by each participant. Participants 5 and 6 were TRACON controllers and participated in both simulations repeatedly. In general, participants perceived the simulation experiment variables acceptable except pilot performance.

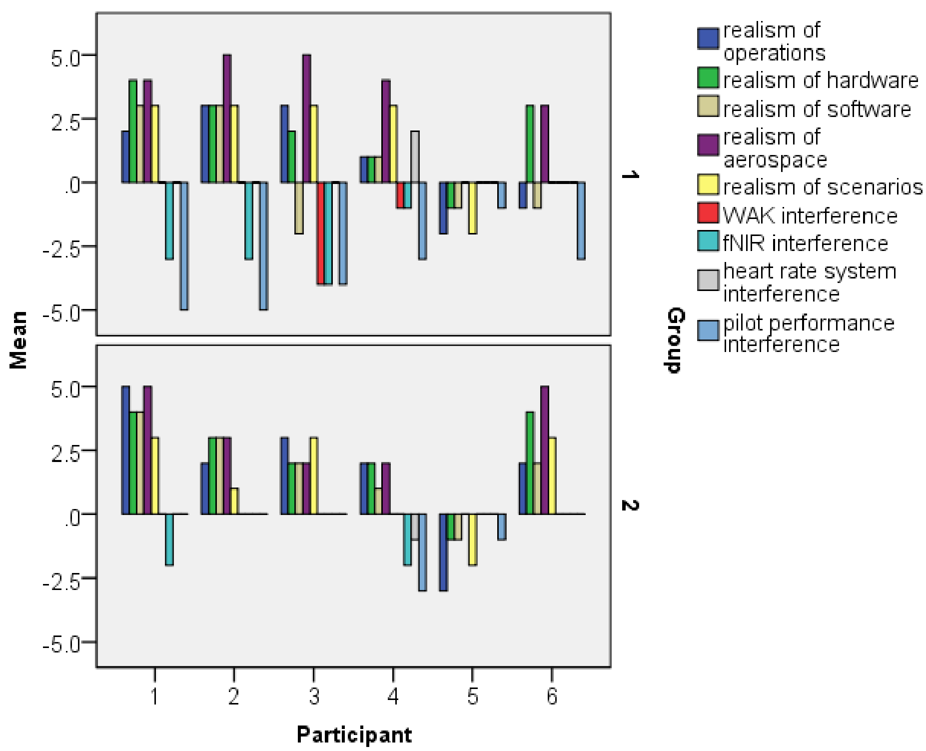


Figure 32. Participants' perception on various aspects of the experiment.

We created a new set of questions after finishing Group 1. We asked Group 2 participants to evaluate each of the procedures directly to the Baseline after they finished the experiment (see Appendix D). We asked them to assign a number between 0 and 100 for each experimental condition. We told them we had given 50 for the Baseline and that they could imagine the number of 100 for the ideal ATC procedure. We told them that a number smaller than 50 meant that the procedure was worse than the Baseline procedure. Figure 33 shows the results. All ARTCC participants rated DAWGS High worse than the Baseline. For the two TRACON controllers, there was no clear pattern in their responses. To show the clear distinction between conditions, we used a line graph instead of a bar graph.

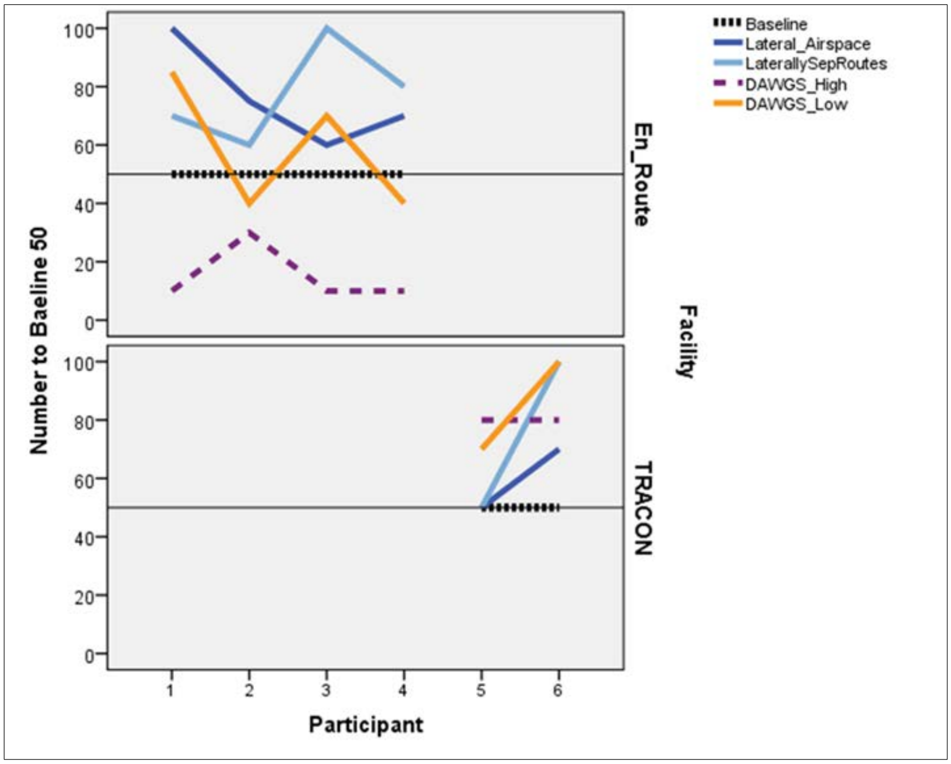


Figure 33. Group 2 controllers' response to the second section of the Exit Questionnaire that compared each procedure to the Baseline procedure.

3.6.3 Exit Interviews

3.6.3.1 ARTCC Participants

In the following, we summarize participants' comments.

- Participants pointed out that using the AHN for arrivals was possible only when the airport operations were in a west configuration. The east configuration was "problematic" because of all the satellite airport traffic. The TRACON participants echoed this as well.

- Participants pointed out that when implementing the IADCS procedures, it "needs a person or device that can call when." Participants also pointed out that "the wheel movement of airways would work as the weather moves in."

- They preferred assigned routes to vectoring. These route options would be useful.
- Formalizing procedures is important, as the procedures help everyone be on the same page when implementing traffic management decisions. Some of the participants did not like the airspace shift.
- Participants felt that airspace shift would create more workload than it is worth.
- Participants felt that airspace shift might not work because the shift would give arrival airspace to departure space and vice versa, and the controller may not have the training to work on those aircraft.
- These new tools may require new forms of training because they are not standard operating procedures.
- Participants felt that using the IADCS procedures would provide benefits.

In the following, we list participant controllers' comments and suggestions (without any particular order).

- "Procedures would make the reroutes work well."
- "Easy workflow using UGGGA. Tunneling would be ok but would use more fuel."
- "DAWGS low is much better than DAWGS high."
- "High sector was not a problem; lots of time to work them."
- "Bidirectional routes ran parallel; not completely over top. Workload issues."
- "We prefer arrivals to be pushed down under departures when both are using the same airspace. It's safer and easier for the controller."
- "I'd like to see some of these tools used now. I think they will make life a lot easier during SWAP days."
- "These procedures will help to alleviate congestion that currently results from gates being closed when weather is in the area."

3.6.3.2 TRACON Participants

IADCS procedures used in ZTL airspace, using the AHN Arrivals, with west operations at Atlanta, works well when aircraft transition to A80. When the airport is in east operations, the transition to A80 is difficult. Their comments were:

- "East operation would be difficult due to all the satellite traffic using the east gates."
- "It could work if you modify the departures out the east gates."
- "Have to make sure that we keep altitude separation at facility boundaries."
- "Bidirectional would not work in the TRACON." (Note: We did not use bidirectional routes in the TRACON airspace in this experiment.)
- "Too many data blocks cluttering the screen in bidirectional."

4. CONCLUSION

As expected, the time flown by aircraft showed a noticeable difference between experimental procedures and the Baseline. The time difference between the experimental procedures (53 minutes on average) and the Baseline (71 minutes) was approximately 18 minutes. The results agreed with the fast-time simulation results by Young et al. (2013). The subjective ratings showed that controllers preferred the Lateral Airspace Shift and the Laterally Separated route procedures. All results were consistent in pointing out that Vertically Separated Bidirectional procedures (High-Altitude Arrivals and Low-Altitude Arrivals) were the least preferred and effective procedures. We found three statistically significant results in subjective workload ratings, and two of them were the higher workload ratings of the High-Altitude Arrival procedure compared with those of the Baseline procedure from R-side controllers at Sector 32 (high-altitude ARTCC sector) and from D-side controllers at Sector 16 (low-altitude ARTCC sector).

Our statistical tests of both frequency and duration of communications between controllers and pilots also showed that controllers talked more often with pilots and spent more time with them when they were in the Vertically Separate Bidirectional procedures. In addition, controllers committed more deviations in the two procedures than in other procedures. Our results clearly showed that Vertically Separated Bidirectional procedures (DAWGS High and DAWGS Low) were not preferred procedures. We conjecture this may be due to the perceptual and cognitive complexity in processing more vertical (i.e., altitude) commands in these two procedures than any other procedures. This conclusion is supported by previous air traffic control research reports that showed more operational errors when one or both aircraft descend or ascend (Grossberg, 1989; Rodgers & Nye, 1993).

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Acronyms

A80	Atlanta Terminal Radar Control Facility
APR	Air Traffic Control Preferred Routes
ARTCC	Air Route Traffic Command Center
ATC	Air Traffic Control
ATL	Atlanta Hartsfield International Airport
ATO	Air Traffic Organization
ATWIT	Air Traffic Workload Input Technique
BADA	EUROCONTROL Base of Aircraft Data
CID	Computer Identification
CONUS	Continental United States
CP	Conflict probe
CPC	Certified Professional Controller
DESIREE	Distributed Environment for Simulation, Rapid Engineering, Experimentation
DRAT	Data Reduction and Analysis Tool
D-side	Data-side
DSR	Display System Replacement
DTS	Direct Transmission System
ECG	Electrocardiography
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
fNIR	Functional Near Infrared
fNIRS	Functional Near-Infrared Spectroscopy
HCS	Host Computer System
HERT	HOST Erroneous Route Text
HITL	Human-in-the-loop
IADCS	Integrated Arrival/Departure Control Services
IOC	Initial operational capability
IRB	Institutional Review Board
KSD	Keypad Selection Device
LCD	Liquid Crystal Display
LOA	Letter of agreement
MCA	Message Composition Area
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NM	Nautical mile
NYICC	New York Integrated Control Complex
OI	Operational Improvement

OPC	Optimized Profile Climb
OPD	Optimized Profile Descent
PDARS	Performance Data Analysis and Reporting System
PI	Principal Investigator
PSQ	Post-Scenario Questionnaire
RA	Response Area
RDHFL	Research Development and Human Factors Laboratory
R-side	Radar-side
SATCS	Supervisory Air Traffic Control Specialist
SID	Standard Instrument Departure
SME	Subject matter expert
SOP	Standard Operating Procedure
STAR	Standard Terminal Arrival Routes
STARS	Standard Terminal Automation Replacement System
TGF	Target Generation Facility
TP	Trial planning
TRACON	Terminal Radar Approach Control
URET	User Request Evaluation Tool
VSCS	Voice Switching and Control System
WAK	Workload Assessment Keypad
WARP	Weather and Radar Processor
WJHTC	William J. Hughes Technical Center
XXX	Bad Route Elements
ZHU	Houston ARTCC
ZID	Indianapolis ARTCC
ZJX	Jacksonville ARTCC
ZME	Memphis ARTCC
ZTL	Atlanta ARTCC

Appendix A: Informed Consent Form

Informed Consent Statement

I, ________________________________, understand that this study entitled, "A Human-in-the-Loop Investigation of Integrated Arrival/Departure Control Services," is sponsored by the Federal Aviation Administration (FAA) and is being directed by Dr. Sehchang Hah and Mr. Ben Willems.

Nature and Purpose:

I have been recruited to volunteer as a participant in this project. The purpose of the study is to evaluate new procedures in high density metroplex airspace to sustain traffic throughput into and out of an airport under adverse conditions including the presence of convective weather and heavy traffic. I will evaluate these new procedures in a high-fidelity, human-in-the-loop simulation. The researchers will use the results of this study to generate requirements for the implementation of the Integrated Arrival/Departure Control Services concept in the National Airspace System.

Experimental Procedures:

A group of six controllers will arrive at the Research, Development, and Human Factors Laboratory (RDHFL) to participate in the study for two weeks. I will travel to the FAA William J. Hughes Technical Center (WJHTC) on Monday and depart on Friday of the following week. From Tuesday until Thursday of the following week, I will participate in the experiment at the RDHFL's ATC simulator. I 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, I will participate in a group discussion about my experiences during the simulations. On the first day of the study, I will be briefed about the project goals and what to expect as a participant in this simulation. On the last day of the study, I will attend an exit briefing to provide feedback about the entire experiment.

On Tuesday after the project briefing, I will receive training to become familiar with the simulation equipment, airspace, and experimental conditions of the study. Each day the research team will assign me to position at a sector.

If I am an En Route participant, I will wear a functional Near-InfraRed Spectroscopy sensor array and a Heart Rate Variability sensor during experimental scenarios. The research team will provide a space for privacy and ask me to place the reference electrode over my sternum and the left and right electrodes below my left and right clavicles. The data are for research purpose only and not for any clinical diagnostic purpose. The researchers are not qualified to diagnose any symptoms based on the data collected.

After each test scenario, I will complete a questionnaire to evaluate how the ATC environment affected me during that test scenario. Subject matter experts will make over-the-shoulder observations during the simulation to evaluate the effects of the experimental conditions on air traffic control. The simulation software will record my interactions with the system as well as aircraft track and status data to produce measures of safety, capacity, efficiency, and communications. The simulation software will also collect audio-visual recording of ATC activities and communications.

Discomfort and Risks:

I understand that I will not be exposed to any foreseeable risks. To apply the small surface electrodes used for the assessment of heart rate variability to the skin, the research team may need to trim some body hair. Medical tape will hold the electrodes in place. The sensor pad that is used for the oxygenation assessment may cause some redness on the forehead, but that should dissipate soon after the pad is removed.

Anonymity and Confidentiality:

The information that I provide as a participant is strictly confidential and I shall remain anonymous. I understand that no Personally Identifiable Information (PII) will be disclosed or released, except as may be required by statute. I understand that situations when PII may be disclosed are discussed in detail in FAA Order 1280.18: *Protecting Personally Identifiable Information (PII).* My participation is strictly confidential, and no individual names or identities will be disclosed in any reports.

Benefits:

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

Participant Responsibilities:

I am aware that to participate in this study I must either be an En Route, certified professional controller (CPC) or a recently retired terminal controller from Atlanta TRACON. En Route CPCs are required to be qualified at an air traffic control facility and hold a current medical certificate. Recently retired Atlanta TRACON controllers are required to have retired within the last 4 years. 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 discontinue 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.

Ben Willems and Sehchang Hah have adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Ben Willems and Sehchang Hah 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 Ben Willems at (609) 485-4191 or Sehchang Hah at (609) 485- 5809.

Compensation and Injury:

I agree to immediately report any injury or suspected adverse effect to Mr. Ben Willems at (609) 485-4191 or Sehchang Hah at (609) 485 5809.

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

Participant # ___________ **Date ___________**

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**?	O Male	O Female
2. What is your **age**?	_____ **years**	
3. How long have you worked as **an Air Traffic Controller (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 a Traffic Management unit?	_____ **years** _____ **months**	
5. How long have you **actively controlled traffic** in an En Route facility?	_____ **years** _____ **months**	
6. How long have you **actively controlled traffic** in a TRACON?	_____ **years** _____ **months**	
7. How long have you **actively controlled traffic** in a Tower?	_____ **years** _____ **months**	
8. How many of the **past 12 months** have you actively controlled traffic?	_____ **months**	

Appendix C: Post-Scenario Questionnaire

Participant # ___________ **Date ___________**

Post-Scenario Questionnaire

1. Air Traffic Control Tasks

Each scenario consists of four phases (see notional figure below):
- A Base, Transition, New Normal, and an End Run phase.

For each of the following major tasks, please rate how well the situation you were in during the preceding scenario for each of the phases helped or hindered your controlling air traffic. A rating of -5 represents that you thought they limited or hindered your performance tremendously. A rating of 5 is the opposite: They helped you in a very positive manner. The rating of 0 means no effect.
We have listed subtasks for your reference. Please consult them. Please circle the number that corresponds to your rating for each task.

A. Situation Monitoring: Checking and evaluating separation, Analyzing initial requests for clearances, Processing departure/en route time information, Housekeeping.

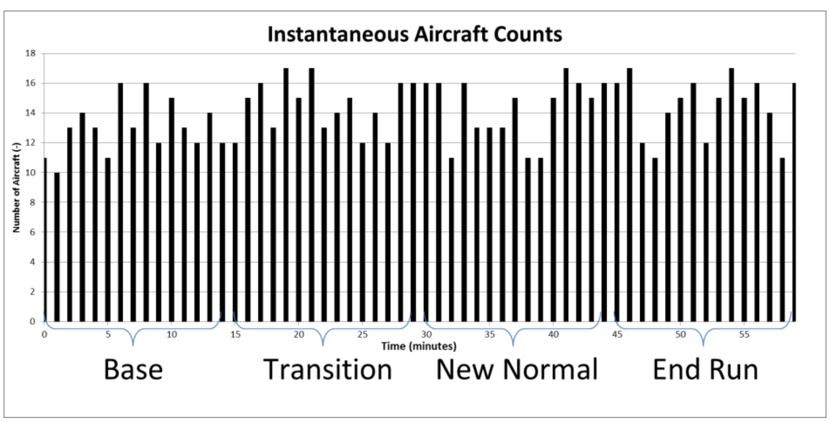
B. Resolving Aircraft Conflicts: Performing aircraft conflict resolution, Performing airspace conflict processing, Suppressing/Restoring alerts.

C. Managing Air Traffic Sequences: Responding to traffic management constraints/flow conflict, Processing deviations, Establishing arrival sequences, Managing departure flows, Monitoring non-controlled objects.

D. Routing or Planning Flights: Planning clearances; Responding to contingencies/emergencies; Responding to special operations; Reviewing flight plans; Processing flight plan amendments; Receiving transfer of control/radar identification; Initiating transfer of control/radar identification; Issuing point-outs; Responding to point-outs; Issuing clearances; Establishing, maintaining, and terminating radio communications; Establishing radar identification.

E. Assessing Weather Impact: Responding to significant weather information,

F. Managing Sector/Position Resources: Assuming position responsibility, Executing backup procedures for communication failures/transient operation, Managing personal workload.



Traffic phases during each of the scenarios

Participant # ___________ **Date** ___________

Base	Hindered Greatly										Helped Greatly
1A. Situation Monitoring	-5	-4	-3	-2	-1	0	1	2	3	4	5
1B. Resolving Aircraft Conflicts	-5	-4	-3	-2	-1	0	1	2	3	4	5
1C. Managing Air Traffic Sequences	-5	-4	-3	-2	-1	0	1	2	3	4	5
1D. Routing or planning flights	-5	-4	-3	-2	-1	0	1	2	3	4	5
1E. Assessing weather impact	-5	-4	-3	-2	-1	0	1	2	3	4	5
1F. Managing sector/position resources	-5	-4	-3	-2	-1	0	1	2	3	4	5

Transition	Hindered Greatly										Helped Greatly
1A. Situation Monitoring	-5	-4	-3	-2	-1	0	1	2	3	4	5
1B. Resolving Aircraft Conflicts	-5	-4	-3	-2	-1	0	1	2	3	4	5
1C. Managing Air Traffic Sequences	-5	-4	-3	-2	-1	0	1	2	3	4	5
1D. Routing or planning flights	-5	-4	-3	-2	-1	0	1	2	3	4	5
1E. Assessing weather impact	-5	-4	-3	-2	-1	0	1	2	3	4	5
1F. Managing sector/position resources	-5	-4	-3	-2	-1	0	1	2	3	4	5

New Normal	Hindered Greatly										Helped Greatly
1A. Situation Monitoring	-5	-4	-3	-2	-1	0	1	2	3	4	5
1B. Resolving Aircraft Conflicts	-5	-4	-3	-2	-1	0	1	2	3	4	5
1C. Managing Air Traffic Sequences	-5	-4	-3	-2	-1	0	1	2	3	4	5
1D. Routing or planning flights	-5	-4	-3	-2	-1	0	1	2	3	4	5
1E. Assessing weather impact	-5	-4	-3	-2	-1	0	1	2	3	4	5
1F. Managing sector/position resources	-5	-4	-3	-2	-1	0	1	2	3	4	5

End Run	Hindered Greatly										Helped Greatly
1A. Situation Monitoring	-5	-4	-3	-2	-1	0	1	2	3	4	5
1B. Resolving Aircraft Conflicts	-5	-4	-3	-2	-1	0	1	2	3	4	5
1C. Managing Air Traffic Sequences	-5	-4	-3	-2	-1	0	1	2	3	4	5
1D. Routing or planning flights	-5	-4	-3	-2	-1	0	1	2	3	4	5
1E. Assessing weather impact	-5	-4	-3	-2	-1	0	1	2	3	4	5
1F. Managing sector/position resources	-5	-4	-3	-2	-1	0	1	2	3	4	5

Participant # ___________ **Date ___________**

2. The effect of the air traffic control environment

We define air traffic control (ATC) environment here as the combination of procedures, airspace, routes, and automation.

In the following questions we will ask you to **compare the ATC environment at your own facility during a busy period to the environment you just worked**.

A rating of 0 represents that you thought the environment did not limit or hinder the topic of the question at all. The rating of -5 represents that it hindered your air traffic control greatly. The rating of 5 represents it helped greatly.

Please note that your rating is **about the environment you worked in during this simulation run**.

Please rate the effect of the environment on	**Hindered Greatly**										**Helped Greatly**
A. **Maintaining traffic flow** during a convective weather event?	-5	-4	-3	-2	-1	0	1	2	3	4	5
B. The **complexity** of the traffic situation	-5	-4	-3	-2	-1	0	1	2	3	4	5
C. **Safety**	-5	-4	-3	-2	-1	0	1	2	3	4	5
D. **Predictability of traffic**	-5	-4	-3	-2	-1	0	1	2	3	4	5
E. Your **workload**	-5	-4	-3	-2	-1	0	1	2	3	4	5
F. Your **ability to detect potential conflicts**	-5	-4	-3	-2	-1	0	1	2	3	4	5
G. Your **ability to plan future actions**	-5	-4	-3	-2	-1	0	1	2	3	4	5
H. Your **confidence** in controlling traffic	-5	-4	-3	-2	-1	0	1	2	3	4	5
I. **Pilot performance**	-5	-4	-3	-2	-1	0	1	2	3	4	5

Participant # ___________ **Date ___________**

If you have any additional comments about the positive or negative aspects of the experimental environment in your previous scenario run, please give us your feedback/opinions.

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Appendix D: Exit Questionnaire

Participant # ___________ Date ___________

Exit Questionnaire

From 1 to 9, please use the following rating guidelines.

A rating of -5 represents being very negative.
A rating of 0 represents being neutral.
A rating of 5 represents being very positive.

Simulation Realism and Research Apparatus Ratings	
Please rate:	**Extremely** **Extremely**
1. The **overall realism of the simulation experience** compared to actual ATC operations.	Unrealistic Realistic -5 -4 -3 -2 -1 0 1 2 3 4 5
2. The **realism** of the simulation hardware compared to actual equipment.	Unrealistic Realistic -5 -4 -3 -2 -1 0 1 2 3 4 5
3. The **realism of the simulation software** compared to actual functionality.	Unrealistic Realistic -5 -4 -3 -2 -1 0 1 2 3 4 5
4. The **realism of the airspace** compared to actual National Airspace (NAS).	Unrealistic Realistic -5 -4 -3 -2 -1 0 1 2 3 4 5
5. The **realism of the simulation traffic scenarios** compared to actual NAS traffic.	Unrealistic Realistic -5 -4 -3 -2 -1 0 1 2 3 4 5
6. If the **WAK online workload rating technique interfered** with your ATC performance?	Interfered Helped -5 -4 -3 -2 -1 0 1 2 3 4 5
7. If the **functional near inbred technique interfered** with your ATC performance?	Interfered Helped -5 -4 -3 -2 -1 0 1 2 3 4 5
8. If the **heart rate variability technique interfered** with your ATC performance?	Interfered Helped -5 -4 -3 -2 -1 0 1 2 3 4 5
9. If the **simulation pilot performance interfered** with your ATC performance?	Interfered Helped -5 -4 -3 -2 -1 0 1 2 3 4 5

Participant # ___________ **Date ___________**

10. Do you have any comments or suggestions for improvement of our simulation?

11. Do you have any comments or suggestions for improvement of the IADCS?

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

13. Comparison between procedures: Ratings and justifications.

In the following, please assign a number to a procedure corresponding to its usefulness in air traffic control. First, let's assign 50 to the Baseline. Please, then, assign any numbers to the other four procedures. You could assign numbers between 0 and 100 that are larger than 50 or smaller than 50. Of course, they can be 50. In essence, we are trying to compare the procedures to the Baseline procedure.

You could imagine the number of 100 for the absolutely ideal procedure you can think of. If you assign a number larger than 50 to a procedure, it means that the procedure was easier and more efficient for you to use than the Baseline procedure. Of course, the difference between that number and 50 signifies the degree of more easiness and efficiency you perceived. It is totally subjective to define the magnitude of the difference. Of course, you can assign a number that is smaller than 50, which means that the procedure was worse than the Baseline procedure.

Below I added short descriptions of the five procedures to help you recall what the procedures were like. After you read the description of each procedure and are sure of the procedure, please assign a number to the procedure. As mentioned above, we already assigned 50 to the Baseline condition.

After assigning a number, we will appreciate it if you could describe your justifications.

1. Baseline: East operations.

--------- The number assigned: 50

(Description of the Baseline: Controllers diverted air traffic due to weather. Aircraft in Sector 49 began deviating into Sectors 16 and 32. Sector 49 began holding aircraft and rerouted them to the south east corner point, SINCA).

2. Lateral Airspace: East Operations.

a. Please assign a number to this procedure: ( )

b. Justification:

(Description of the Lateral Airspace procedure: The scenario started with the same initial deviations as the Baseline. A section of the East departure sectors came under the control of the FLCON arrival sectors. Also, a sector of airspace from the SINCA arrival sectors became available to the East departure sectors. The lateral airspace condition resulted in rotating the East Departure airspace clockwise relative to Hartsfield airport (ATL).

3. Laterally Separated Routes - AHN Arrivals (UGAAA): West Operations.

a. **Please assign a number to this procedure: ( )**

b. **Justification:**

(Description of Laterally Separated Routes: There were no deviations. GRD AHN UGAAA became an arrival fix to absorb excessive arrival demand. All departure aircraft except already air born were rerouted to DAWGS.

4. DAWGS High (arrivals) Bidirectional: East Operations.

a. **Please assign a number to this procedure: ( )**

b. **Justification:**

(Description of the DAWGS High procedure: There were no deviations. All departure aircraft used their normal SIDS. The only change was in their altitude changes. Later in the scenario, A80 handed off DAWGS departures to ZTL at 110 and accept arrivals over DAWGS at 140.

5. DAWGS Low (arrivals) Bidirectional: West Operations.

a. **Please assign a number to this procedure: ( )**

b. **Justification:**

(Description of the DAWGS Low procedure: There were no deviations. All departure aircraft used their normal SIDS. The only change was in their altitude changes. Later in the scenario, DAWGS departure aircraft were cleared to cross 10 miles west of DAWGS at or above FL130. DAWGS arrival aircraft were cleared to cross DAWGS at FL110.

Appendix E: Over-the-Shoulder Rating Form

Over-The-Shoulder 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

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

Over-The-Shoulder Rater Scenario Notes

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

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

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

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

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

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