[EN-034] A Controller-in-the-Loop Simulation of Ground-Based Automated Separation Assurance in a NextGen Environment

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Abstract: A controller-in-the-loop simulation was conducted in the Airspace Operations Laboratory (AOL) at the NASA Ames Research Center to investigate the functional allocation aspects associated with ground-based automated separation assurance in a far-term NextGen environment. In this concept, ground-based automation handled the detection and resolution of strategic and tactical conflicts and alerted the controller to deferred situations. The controller was responsible for monitoring the automation and managing situations by exception. This was done in conditions both with and without arrival time constraints across two levels of traffic density. Results showed that although workload increased with an increase in traffic density, it was still manageable in most situations. The number of conflicts increased similarly with a related increase in the issuance of resolution clearances. Although over 99% of conflicts were resolved, operational errors did occur but were tied to local sector complexities. Feedback from the participants revealed that they thought they maintained reasonable situation awareness in this environment, felt that operations were highly acceptable at the lower traffic density level but were less so as it increased, and felt overall that the concept as it was introduced here was a positive step forward to accommodating the more complex environment envisioned as part of NextGen.

Keywords: controller-in-the-loop, AOL, NASA, NextGen, ground-based automation, separation assurance

1. INTRODUCTION

In the United States' National Airspace System (NAS) of today, air traffic controllers manage operations within their sector of responsibility through active involvement with each aircraft that enters and exits. This allows the controller to incorporate each aircraft into their overall operational picture and has facilitated the current levels of safety. However, the airspace envisioned for the Next Generation Air Transportation System (NextGen) is expected to be both higher in traffic density and complexity relative to what is experienced today (Fig. 1 presents an example of how such an environment would be displayed without changes to the current system) [1]. The transition to this future system will certainly require changes in a number of areas, without which operations within the NAS would likely become unviable.

Given that the primary responsibility of air traffic controllers is to maintain safe separation between aircraft, the area of separation assurance (SA) has been identified as one requiring a concerted and focused research effort with advances in this domain serving as enablers for the transition to NextGen. Within this framework, the thrust of some of the recent research has been on addressing the impact of higher levels of traffic density and complexity on

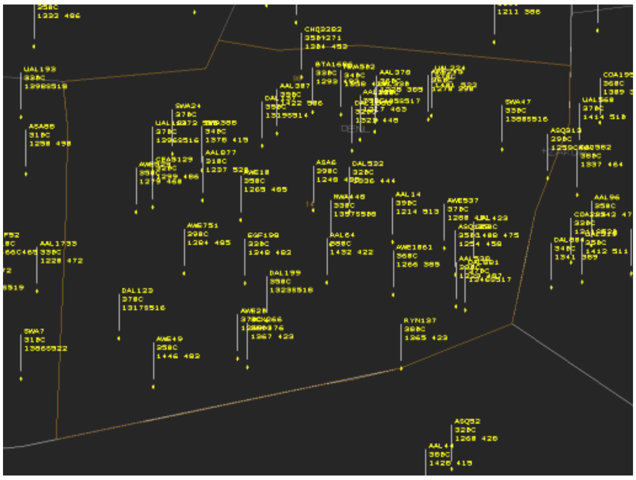

Figure 1 Current day controller display with traffic density reaching levels nearly threefold what is experienced today

the workload of air traffic controllers –a potential barrier to NextGen realization- and exploring the proper levels of automated support necessary for the accommodation of increased traffic and complexity without creating excessive workload and compromising safety.

This paper will first outline the concept of operations that some of the research has been predicated upon followed by brief descriptions of previous SA research conducted in the Airspace Operations Laboratory (AOL) [2] at the NASA Ames Research Center. This will then be followed by the presentation of the most recent research effort with accompanying results and will conclude with a discussion of those results.

2. GROUND-BASED AUTOMATED SEPARATION ASSURANCE

In today's environment, separation assurance is maintained through a largely manual process where the air traffic controller scans and identifies potential separation risks, develops a conflict avoidance resolution based on their understanding of the current operational picture, and issues a verbal clearance to the appropriate aircraft. While this process has been and is carried out very effectively, it will become an increasingly difficult task if and when traffic demand in the United States reaches the increased levels forecast by the Federal Aviation Administration [3].

One of the changes that would provide for the ability to accommodate such levels of traffic is the introduction of greater levels of automation in support of the separation assurance function. Assuming an environment where trajectory based operations (TBO) are being conducted, such automation would perform the duties of conflict detection and develop resolutions for nominal conflict situations and uplink conflict-free trajectories to the appropriate aircraft via data communication channels. Tactical conflict situations with an imminent loss of separation would be handled by an additional layer of automation where tactical vectors and/or altitude changes would be sent to the appropriate aircraft via a separate communications channel dedicated to such transmissions.

Such changes to the task of separation assurance and the involvement of such levels of automation would signal a shift away from an individual air traffic controller having the sole responsibility for maintaining safe separation to one in which the responsibility rests with the service provider- a term used to refer to the collaborative team composed of the air traffic controller and supporting automation. This shift would not only allow for increased airspace capacity, but would also allow for the air traffic controller to provide additional services while managing the airspace by exception.

3. PREVIOUS SA RESEARCH IN THE AOL

The components of the larger concept of ground-based automated separation assurance as well as the concept itself have previously been detailed and presented as part of the Advanced Airspace Concept (AAC) [4-5]. Early simulations and analyses in this particular area were conducted through fast-time simulations and modeling, but investigations into the operational and human factors issues surrounding such changes as envisioned in the concept as well as the environment in which it would be realized were limited.

To date there have been three controller-in-the-loop simulations conducted in the AOL specifically related to separation assurance. Each of these has built upon the research and results of the previous study and has served to inform the next while incrementally introducing greater levels of automation. For simplicity these studies are referred to as SA1, SA2, and SA3 according to their temporal order.

3.1 SA1

The first in this series, referred to as SA1, was conducted in 2007 and evaluated the differences in performance between participants resolving conflicts in a manual and interactive mode as well as a fully automated mode [6-7]. This was done at current day (1x), twice (2x), and three times (3x) that level of traffic. At the heart of the interactive and fully automated modes lay the autoresolver algorithm outlined as part of the Advanced Airspace Concept. Workload impact and acceptability of the algorithm's resolutions were also investigated. Results suggested that the automation provided significant benefits in terms of safety and efficiency particularly at higher levels of traffic. There was also a significant reduction in workload. The resolutions provided by the automation were also rated as being generally acceptable.

3.2 SA2

The second study, SA2, was conducted in 2008 and tested air/ground operations in an environment where ground-based automation was responsible for safely managing aircraft trajectories [8]. Controller participants were responsible for handling pilot requests that were deferred by the automation and also handled scripted off-nominal events and tactical conflict situations both with and without Tactical Separation Assurance Flight Environment (TSAFE) support [9]. Operations were conducted at 2x and 3x levels of traffic. Results showed that the strategic conflict resolution automation was able to resolve 98% of conflicts, 95% of uplinked trajectories were rated as acceptable to the flight crew participants, and workload was generally low. Of the tactical conflicts, 75% were resolved, which served as a springboard for discussion of the issues related to such automation and how they could be addressed in future research [10].

3.3 Current Study (SA3)

The third study in this series, SA3, was conducted in part to begin addressing the concerns expressed by the Joint Planning and Development Office (JPDO) regarding the "lack of clarity" surrounding the functional allocation of new functions and responsibilities between the ground-based air traffic control systems and the flight deck- based systems [11]. To that end, two separate but collaborative studies were conducted with respect to the functional allocation of separation assurance with scheduling constraints between the ground and the air, with the ground-based focus residing at the NASA Ames Research Center and the flight deck-based focus residing at the NASA Langley Research Center. Results and discussions of the collaborative aspect of this overall study have been published previously [12]. This paper will focus specifically on the ground-based portion of the study with a further examination of the allocation of separation assurance functions between the ground-based automation and the human air traffic controller.

4. METHOD

This study was conducted over the course of eight days in February and March of 2010 in the AOL at the NASA Ames Research Center. Training and familiarization was performed for the first three days with the remaining five days being devoted to data collection.

This section will begin with an overview of the experiment design and operational environment as it was presented in the study, followed by a description of the apparatus, participants, airspace, and the procedures used during the data collection phase of the study.

4.1 Design

The overall ground-based study included three different components. The first consisted of short length (S), 15-minute runs that involved three different types of scheduling constraints (see Fig. 2). The second consisted of medium length (M), 30-minute runs that involved scheduling or no scheduling across two different traffic densities referred to as NextGen Levels A and B (see Fig. 3). NextGen Level A was roughly equivalent to 1.5 times current day traffic levels and NextGen Level B was roughly equivalent to 2.0 times. The S and M runs were used to satisfy the collaborative requirements of the larger functional allocation study. The third component of the study was an independent aspect used in a more exploratory context that involved long, three hour runs with scheduling and weather constraints and traffic density levels that fluctuated to the higher extremes. The procedures and results presented in this paper will focus mainly on the medium length runs.

Timing of Arrival Time changes		
	Basic (STA)	S1
	Dispersed (one every minute)	S2
	Synchronous (all at 6 or 8 minutes)	S3

Figure 2 Design matrix for the short duration runs

Arrival Time Constraints		A	B
	No (Baseline)	M1	M2
	Yes (STA)	M4	M3
		NextGen (Traffic) Level	

Figure 3 Design matrix for the medium duration runs

4.2 Operational Environment

For this study, the operational environment was aligned with what is envisioned for NextGen where there is an integration of the flight environment and avionics, ground-based automation, and the controller workstation.

Flight Environment

The flight environment assumed full air-ground data communication and Automatic Dependent Surveillance-Broadcast (ADS-B) equipage for all aircraft transiting the airspace. Trajectory Based Operations were being conducted where it was assumed that all flights were on their user-preferred, 4-D trajectories and were cleared for their departure and arrival transitioning phases of flight.

Ground-Based Automation

The instantiation of ground-based automated separation assurance for this study involved a number of related components working in sequence. The first provided the detection and reporting of conflicts with a 12 minute look-ahead time, followed by the development of conflict resolutions that were calculated to minimize delay, and finally the uplinking of trajectories to the appropriate aircraft without the need for controller involvement in nominal situations. Successful completion of this sequence relied upon accurate speed and position information. However, trajectory uncertainties and inaccuracies did exist as they do today and most likely will in the future. Conformance monitoring of flight trajectories detected when an aircraft had deviated from its path outside of acceptable tolerances, at which point the particular flight was alerted to the controller through an enlarged target symbol and a tactical, dead reckoning conflict probe was activated with a five minute look ahead. In cases where a conflict was detected late, i.e., with less than three minutes to loss of separation, a tactical vector was computed for one or both aircraft in the conflict pair and uplinked when the time to loss of separation fell below two minutes. This resulted in aircraft receiving the uplink to vector according to the uplinked trajectory, which resulted in the aircraft becoming off-track. It was then the controllers' responsibility to put the off-track aircraft back onto their preferred trajectory in a safe manner.

Controller Workstation

The workstations and displays used for the sector controllers and supervisors incorporated advances in the display of information and access to functionality deemed necessary for control operations in a NextGen environment.

Fig. 4 presents a screenshot of an R-side's display as it was implemented in the study where it can be seen that it differed significantly from what one would find today and as shown in Fig. 1.

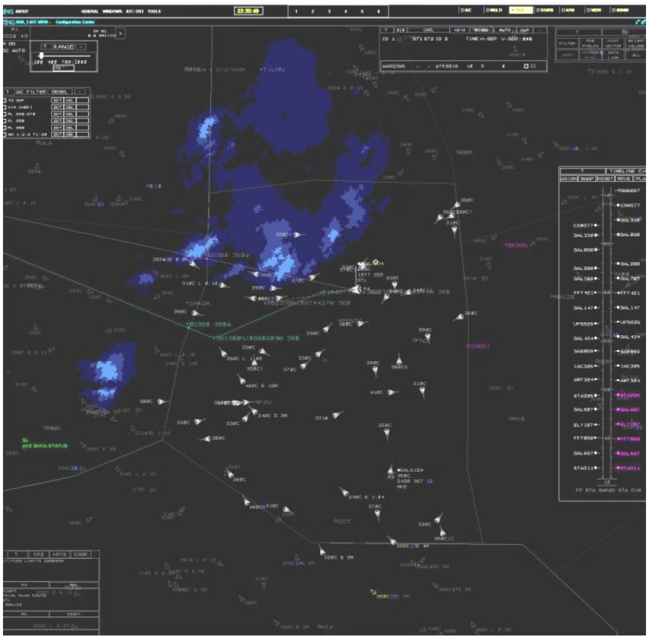

Figure 4 Advanced controller display at high levels of traffic density where scheduling and weather avoidance tasks were being performed

The first difference one may notice in Fig. 4 is that the target symbols were chevrons with an associated limited data block, which displayed the current altitude. This is a necessary departure from today's display due to the problem of data block clutter and overlap once aircraft counts in a sector reach levels predicted for NextGen. In this example, there are nearly 50 aircraft in the sector. This would result in a controller using today's display to spend most, if not all, of their time simply managing data block positions. What enables this reduction in displayed information is the shift described earlier away from active control of each aircraft as it is done today, to one in which the automation manages the traffic and separation functions while the controller monitors and manages the automation. In this case, the information available through a data block is accessed on an as-needed basis rather than having the requirement of being displayed constantly while the aircraft is within the sector's boundaries or under the sector's control.

Additional information and interactive functionality were integrated into the workstation to assist in the performance and monitoring of certain tasks. For example, on the right hand side of Fig. 4 one can see a timeline displayed that controllers used to manage the scheduling constraints in effect for area airports. This timeline featured the scheduled time of arrival on one side and the estimated time of arrival for aircraft scheduled to a particular airport or fix on the other. This served as an indication of how well the scheduling was being adhered to. In the event that an aircraft began falling out of conformance, the timeline provided an interactive function that allowed the controller to call upon an automated algorithm that would attempt to find the optimal, conflict-free solution through speeds and/or vectors to meet the scheduling constraint.

Another item in the display that assisted in the monitoring and management task of the controller was the conflict list seen near the upper right hand corner of Fig. 4. While the ground-based automation handled the nominal conflict detection and resolution tasks independent of the controller in this study, conflicts relevant to the sector were displayed in this list with additional information regarding the vertical profiles of the involved aircraft, predicted time to loss of separation, closest point of approach, as well as the automation's status and progress in resolving the conflict. Constraints on the automation were put in place that prevented heading changes of more than 31 degrees or altitude changes of more than 670 m (2200 ft) from being sent directly to aircraft without controller involvement. In such cases, the resolution of the conflict was alerted to the controller through the conflict list, at which point they would develop a resolution either on their own or by reactivating the conflict resolution algorithm.

In both the scheduling and conflict resolution cases, the controller had access through the workstation and display to data communication capabilities. Once an acceptable solution to a given situation was arrived at, the controller had the option to type an uplink command into the computer readout device (CRD) or access a fly-out menu either through the aircraft's data block or the callsigns in the respective lists where the uplink command could be activated. This then sent the modified trajectory directly to the aircraft. Similar to this functionality was one that was used for cases that required coordination rather than direct contact. In these cases, rather than selecting the uplink command, the controller selected the coordinate clearance command. This sent a proposed trajectory to the sector that had control of the relevant aircraft for their approval. If the proposal was acceptable, the receiving controller could then uplink the clearance directly to the aircraft.

4.3 Apparatus

The operational environment just described was simulated using the Multi Aircraft Control System (MACS) software package [13]. This is a Java based simulation platform developed and maintained by the AOL software team. MACS is a scalable platform used for the prototyping of displays and concepts that range from current day to the exploratory far term timeframe.

MACS was the common thread shared between all of the stations and positions used throughout the simulation. This included radar controller workstations (see Fig. 5) which were composed of standard PCs with 75cm Barco monitors and Display System Replacement (DSR) keyboards and trackballs as input devices. These workstations were also equipped with tablet PCs which were used for voice communications similar to the Voice Communications System (VCS) used currently. Area supervisors had access to two separate stations, each one with a different purpose. One station projected a Traffic Situation Display of the test airspace with accompanying traffic load statuses and predictions for the test sectors. The other station was similar to the radar controller station but was configured differently to enable the performance of strategic planning functions. Four confederate “Ghost” controller stations were used for the control of air traffic outside of the test airspace, which consisted of standard PC setups with 76cm monitors. Ten pseudopilot stations with standard PC setups were also used for the management of individual flights in the problems. Two simulation manager stations were also used for the initiation and termination of each training and data collection run.

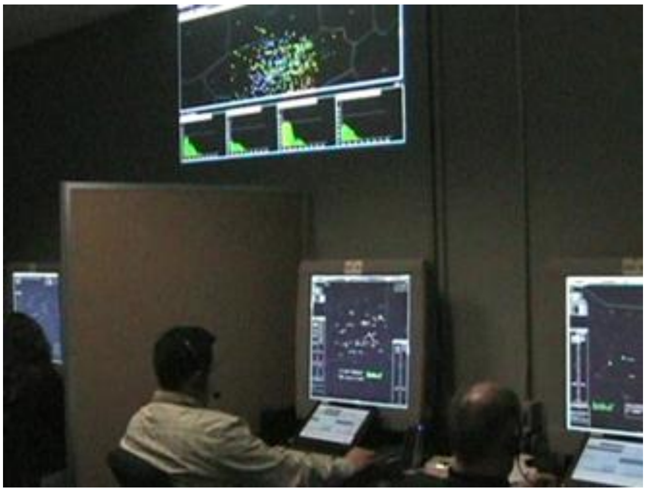

Figure 5 Radar controller workstations with TSD and test sector load predictions projected onto the wall above

4.4 Participants

Six current FAA front line managers, each from different enroute centers and current on radar, served as test participants for this study. Each rotated through radar and area supervisor positions in order to operate and evaluate the concept from the two different perspectives. Four recently retired controllers worked the remaining test positions. Four additional retired controllers acted as confederate “Ghost” controllers that managed the air traffic outside of the test area. Ten general aviation pilots acted as pseudopilots and were assigned to each of the test sectors and the surrounding areas.

4.5 Airspace

The airspace used in this study consisted of test sectors from the eastern portion of Kansas City Center (ZKC) and the western portion of Indianapolis Center (ZID) in the central region of the United States. This was high altitude enroute airspace with the floors of the sectors set at flight level (FL) 290. For the medium length runs, four test sectors were used: ZKC 90, ZKC98, ZID81, and ZID80. As seen in Fig. 6, the design of each sector is slightly different and the traffic flows and characteristics produced differences in density and complexity between them. Arrivals and departures from local area airports contributed to this complexity for some of the sectors with transitioning aircraft interacting with the level flights transiting the airspace. Confederate controllers handled the traffic outside of the four test sectors as well as the aircraft below FL290.

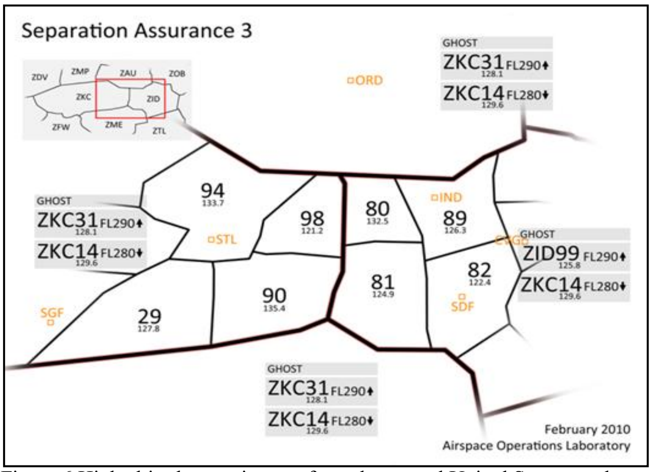

Figure 6 High altitude test airspace from the central United States used during the study

4.6 Procedure

The first three days of the simulation were dedicated to training the participants on the tools, airspace, and concepts that they would be presented during the data collection phase. This was done through a combination of briefing discussions, overviews and presentations in the laboratory, and hands-on interaction with the workstations and software. The hands-on portion of the training was conducted by using traffic scenarios of varying levels of traffic density ranging from very light to the full scale densities that they would experience during the formal simulation.

The traffic scenarios used in the short and medium runs were initially developed by the team in the ATOL as were the formulations of the STA assignments that would be issued to aircraft in the appropriate runs. These traffic scenarios were then collaboratively adjusted and modified to ensure proper, uniform characteristics and performance in each laboratory’s respective platforms. In the AOL, it was also necessary to convert the traffic scenarios into the format appropriate for use in MACS. Python scripts were also developed for use in the issuing of STA assignments in the runs involving scheduling constraints. Traffic scenarios as well as convective weather representations were also developed in the AOL for use in the exploratory runs.

The data collection runs were conducted over the five days following initial training. Each day was divided into three different phases with the mornings devoted to the collaborative short and medium runs. The first two runs of the day involved the thirty minute scenarios with various scheduling and traffic density conditions. These were then followed by three, short 15-minute runs with varying STA assignment conditions.

These morning runs were conducted in parallel in two separate but adjoining rooms. Each room was equipped with four radar controller stations-one for each test sector-and two area supervisor stations to be used by a single supervisor. For consistency, each room was running the same problems in the same conditions but was completely isolated from one another. Within each room, the area supervisor could monitor the traffic situation by walking the floor and by assessing the flows and traffic load statuses and predictions for each of the four test sectors via the two supervisor stations. The four radar controllers, however, were separated by partition (see Fig. 5) with the two ZKC test sectors on one side and the two ZID sectors on the other. Inter-center communications and coordination were required to be carried out via voice channels and/or ground-to-ground data comm.

During the runs, the tasks of the control team were different in many respects from what they are today. As this was a functional allocation study of ground-based automated separation assurance, the main departures from today's roles and responsibilities were in this area. Table 1 provides a delineation of the tasks performed by the automation and the human controllers during the data collection runs.

For the medium duration runs, there were four conditions in which participants operated. In the two Baseline conditions, participants managed the automation and traffic situations according to the allocation of functions in Table 1. This was done at two different traffic density levels, which were approximately 1.5 and 2.0 times greater than current day (from here called Level A and B). The two STA conditions involved the participants operating in the same manner as in the Baseline conditions, but with the added responsibility of maintaining the scheduled times of arrivals for aircraft arriving at a number of area airports. Automated support for this task was provided through timelines that were configured and assigned to each radar controller workstation.

Data were collected from a variety of sources throughout the study for later consolidation and analyses. During each run, screen recordings were taken on each of the workstations. Every action performed within the simulation network and the various states and aspects of the traffic were recorded in real-time through the data collection processes within MACS. Questionnaires were taken by participants after each run followed by a post-simulation questionnaire once the final run was complete. A post-simulation debrief discussion was also conducted with the test and confederate participants where a variety of topics regarding the concept and the study as it was run were covered.

5. RESULTS

While data were collected and a number of metrics were analyzed for each of the conditions in this study, the following results section and ensuing discussion will focus on the medium (M) duration runs. This portion of the study was a 2 x 2 within subjects design where Traffic Density (NextGen Level A and B) was varied across Arrival Time Constraints (Baseline and STA). The metrics to be presented here will first be aircraft counts as they were recorded for each sector, followed by reported workload by the test participants, number of conflicts and conflict resolution data, separation violations, and finally subjective feedback from the participants.

Table 1 Allocation of functions between the automation and controller

Automation	Controller
Detect Separation Conflicts	Supervise the automation
Resolve trajectory-based conflicts (if within tolerances)	Resolve trajectory conflicts flagged by the automation
Resolve all time-critical traffic conflicts	Monitor and maintain schedule compliance
Alert controller to urgent problems	Place aircraft back on trajectory following automated tactical maneuvers
Provide trajectory planning assistance	
Use datalink to communicate	

5.1 Aircraft Count

Data for aircraft count are shown as a means of providing the context for the remainder of the results. Fig. 7 shows the average aircraft count in each of the four test sectors plotted over time for the NextGen Level A and B traffic densities.

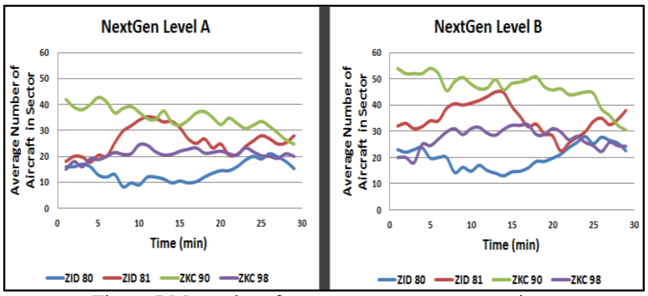

Figure 7 Mean aircraft count per test sector over time

For aircraft count in NextGen Level A, the lower of the two densities, mean aircraft count in ZKC90 for the entire run was 34.69 aircraft in sector (*SD* = 4.51), followed by ZID81 with a mean number of 25.94 aircraft (*SD* = 5.29) in sector. Sector ZKC 98 had a mean number of 20.86 aircraft (*SD* = 2.20), followed by ZID80, which had the lowest mean aircraft count with a mean number of 13.91 aircraft (*SD* = 3.71). Sectors ZKC90 and ZID81 were the largest in terms of airspace volume of the four.

The NextGen Level B traffic density, found on the right hand side of Fig. 7, had higher mean levels of aircraft count in each of the sectors relative to that experienced in Level A. While the actual counts differed between the conditions, the order of sectors in terms of aircraft count held constant across the Level B conditions with ZKC90 clearly having the highest mean aircraft counts with 45.76 aircraft over time (*SD* = 5.90), followed by ZID81 with a mean of 34.66 aircraft (*SD* = 5.62), ZKC98 with a mean of 28.00 aircraft, (*SD* = 4.10), and ZID80 with a mean of 20.34 aircraft (*SD* = 4.75).

5.2 Workload

Throughout each run, workload prompts were displayed to the participants at three minute intervals through a workload keypad integrated into their display. The prompts consisted of the keypad highlighting at the appropriate time accompanied by an audible tone. The ratings were on an interval scale from one to six, with one translating to the lowest level of workload and six the highest. The analysis of workload was performed across Traffic Density Levels (A and B) and Arrival Time Constraints (Baseline and STA). Fig. 8 presents the mean workload ratings for each of these conditions.

The descriptive statistics show that for Baseline-Level A, the mean reported workload was 1.78 (*SD* = 0.64) and the corresponding STA-Level A was slightly higher at 1.83

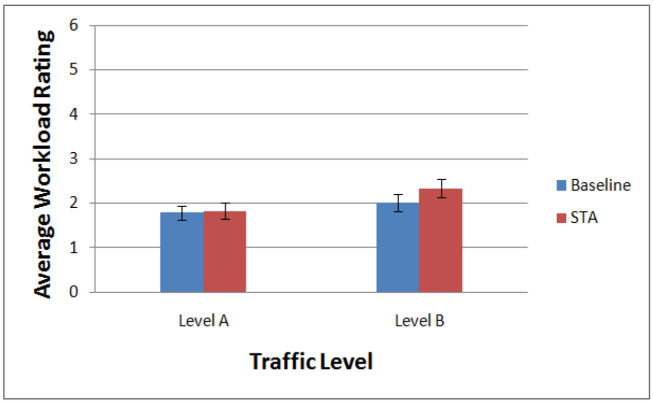

Figure 8 Mean reported workload per condition (+/- 1 standard error)

(*SD* = 0.74). For Traffic Density NextGen Level B, the Baseline-Level B condition had a mean reported workload rating of 2.01 (*SD* = 0.79) and the STA-Level B had a more noticeable increase in mean reported workload rating with 2.34 (*SD* = 0.79).

To investigate the differences in mean reported workload ratings, a one-way, repeated measures Analysis of Variance (ANOVA) test was conducted first to test the difference between the Baseline and STA Arrival Time Constraints conditions. While Fig. 8 and the descriptive statistics showed the STA conditions being reported as generally higher in workload than the Baseline conditions, results from this test did not reveal any significant difference ($F(1, 31)= 2.60$, $p> .05$). An additional test was performed to examine the differences between the two Traffic Density levels in mean workload ratings. This test did yield significant differences where mean workload reported in Traffic Density Level B was significantly higher than in Level A ($F(1, 31)= 14.85$, $p< .01$).

Also of interest in the analysis of reported workload was how it may have differed between sectors considering that the traffic complexities and characteristics differed between them. Fig. 9 shows how the overall workload differed between the sectors with ZKC 90 having the highest mean workload at 2.56 (*SD* = 0.50) followed by ZKC 98 at 2.09 (*SD* = 0.49), ZID 81 at 1.80 (*SD* = 0.33), and ZID 80 showing the lowest mean workload at 1.49 (*SD* = 0.49). To investigate these differences further, a one way ANOVA was conducted where a significant difference in mean reported workload between the sectors was found ($F(3, 60)= 7.65$, $p< .01$). As a follow-up, Tukey's Honestly Significant Difference (HSD) tests were conducted where it was found that ZKC90 had significantly higher workload than ZID81 ($p< .01$) and ZID80 ($p< .01$). The only sector that ZKC90 did not significantly differ from was ZKC98.

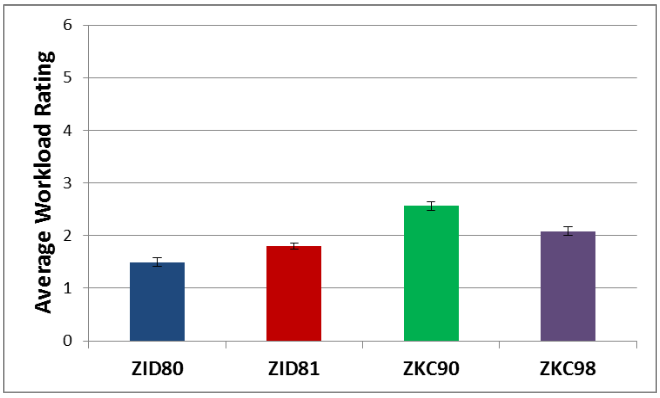

Figure 9 Mean overall workload per sector (+/- 1 standard error)

5.3 Conflict Data

To better understand the environment and operations as they played out in this study, the number of conflicts was a point of interest for analysis particularly as it lies at the heart of separation assurance.

5.3.1 Number of conflicts

Fig. 10 shows the mean number of conflicts recorded that were predicted to lose separation within any of the four test sectors. From this figure one can see two visible trends: The STA conditions resulted in fewer conflicts in the test area regardless of traffic density, and overall the Level B density had a greater number of conflicts than Level A. Descriptive statistics show that the mean number of conflicts for Baseline-Level A were 68.75 (SD = 4.19) and lower for STA-Level A with 58.00 (SD = 2.83). Baseline-Level B had a large increase with a mean number of 113.00 conflicts (SD = 3.74). STA-Level B showed a fewer number of conflicts with a mean of 101.75 (SD = 6.99).

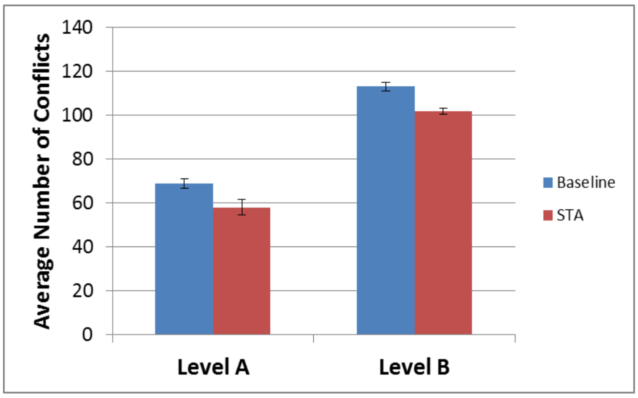

Figure 10 Mean number of conflicts predicted to lose separation within the test area (+/- 1 standard error)

A one-way, repeated measures ANOVA was first run to examine the differences in the mean number of conflicts between the Baseline and STA conditions where it was found that the STA conditions did indeed result in significantly fewer conflicts (F(1,7)= 30.52, p< .01). The differences between traffic density levels were also examined where it was also shown that Traffic Density Level A resulted in significantly fewer numbers of conflicts than in the higher density Level B (F(1,7)= 492.80, p< .01).

5.3.2 Conflict resolutions

In addition to the number of conflicts, an understanding of how the conflicts were resolved or attempted to be resolved was desired. This involved an examination of all of the clearances sent to aircraft in conflict. There were three types of resolutions that could be sent via data comm: strategic automated resolution (Automated Resolution), uplink by controller of resolutions deferred by the automation (ATC Resolution), and the tactical TSAFE maneuvers sent to aircraft with two minutes or less to loss of separation (TSAFE).

Fig. 11 presents these data for each of the conditions where naturally the overall number of resolution clearances sent resembles the conflict numbers shown in Fig. 10.

From Fig. 11 one can see that, as designed, the majority of conflicts were resolved by the strategic conflict resolution automation. Upon further inspection of the strategic resolutions, increases in the contributions of ATC resolutions to the overall number were found as the traffic density level increased. In Baseline-Level A, ATC resolutions accounted for 14% of strategic resolutions. This increased to 21% of strategic resolutions in Level B. This was likewise the case for the STA conditions where at the Level A density ATC resolutions accounted for 20% of strategic resolutions and increased to 25% in Level B.

A similar trend is also observable when accounting for TSAFE resolutions and their contribution to the overall number of clearances. For the Baseline conditions, there is an increase in TSAFE's contribution from 12% to 22% as traffic density increases from Level A to B. This is also the case for the STA condition where there is an increase from 16% to 24% from Level A to B.

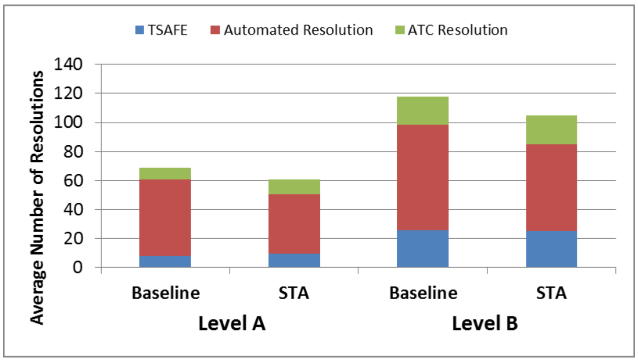

Figure 11 Mean numbers of Automated, ATC, and TSAFE resolutions per condition

To better understand the composition of the clearance numbers in terms of each sector's contribution, the overall number of clearances was separated out accordingly. These mean numbers reflect an overall view of resolutions sent throughout the study, regardless of condition.

Fig. 12 presents the mean number of all conflict resolutions sent per sector. The most striking result from this portion of the analysis is sector ZKC 98's share of conflict resolutions relative to the other sectors. For example, ZKC 98 had a mean number of 111.75 total resolutions sent while ZID 81 sent a mean total of 86.00 resolutions. ZKC98 had required a greater number of resolutions sent despite the fact that it had a lower level of traffic (see Fig. 7). This is due in part to the smaller size of ZKC 98 but, more importantly, also to the complexity of the sector. A more striking example of how the complexity of ZKC 98 affected the composition of clearances sent is a comparison of the mean number of TSAFE resolutions. All things being equal, one might expect each of the four sectors to be responsible for 25% of the total number of TSAFE resolutions sent. However, as shown in Fig. 12, this was not the case. Of the total mean number of TSAFE resolutions sent, ZKC 98 accounted for 55% whereas the other sectors ranged between 12% and 17%. The percentage for ZKC 98 was a direct result of its complexity. The implications this may have had on workload and acceptability will follow in the Discussion section.

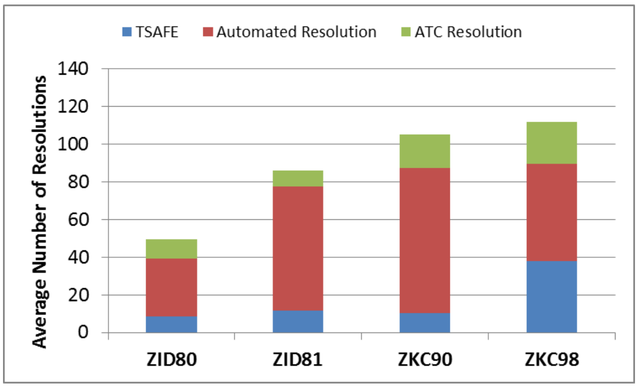

Figure 12 Mean numbers of Automated, ATC, and TSAFE resolutions per test sector

5.4 Losses of Separation

The benchmark for safety in any air traffic environment, excluding mid-air collisions, is loss of separation events. These events can be broken down according to two classifications: Proximity Events (PE) and Operational Errors (OE). The PE classification, the less severe of the two, refers to events where a pair of aircraft has a closest point of approach (CPA) that is between 8.33 km and 9.26 km (4.5 and 5.0 nautical miles (nm) respectively) laterally and 243.84 m (800 ft) vertically. Operational Errors involve aircraft pairs that have a CPA of less than 8.33 km (4.5 nm) laterally and 243.84 m (800 ft) vertically.

For this part of the study, there was a combined total of 20 PEs and OEs. Fig. 13 presents the breakdown of these numbers according to the conditions in which they took place. From this figure one can see that the Level A traffic density resulted in one OE each for the Baseline and STA conditions. This number increased as traffic density increased to Level B where both Baseline and STA conditions resulted in a total of six OEs each with four and two additional PEs respectively.

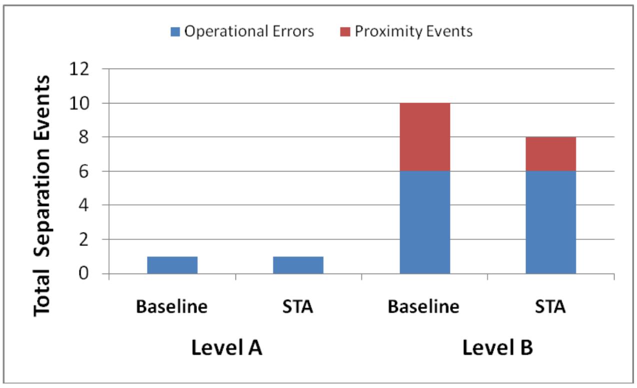

Figure 13 Total numbers of Operational Errors and Proximity Events per condition

As shown in Fig. 14, examining the number of separation events by sector rather than condition revealed that ZKC98 had the highest number of OEs with seven followed by ZKC90 with five and ZID80 with three; ZID81 had none. In terms of PEs, however, ZID80 had the highest number with three while the other sectors each had one.

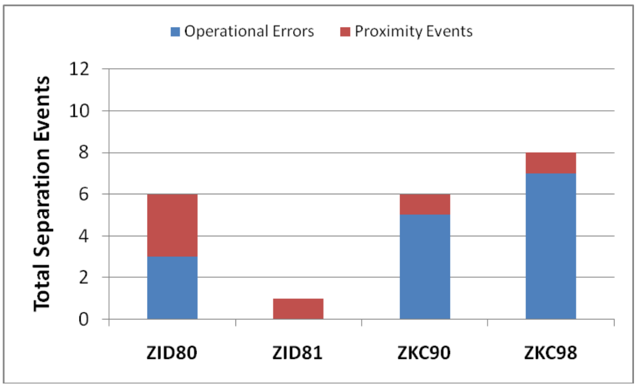

Figure 14 Total numbers of Operational Errors and Proximity Events per test sector

5.5 Subjective Feedback

Following each run and at the conclusion of data collection questionnaires were distributed to the participants in order to elicit their subjective feedback on a range of topics. References [12] and [14] provide additional data from this feedback. This section will focus on a subset of the responses as they relate to situation awareness, acceptability, and overall impressions of the concept.

5.5.1 Situation Awareness

The concept as it was implemented and the environment in which it was introduced was a significant departure from what the participants experience today. Because of that, the impact of operations on their situational awareness was of interest. To gain insight into the impact, the Situation Awareness Rating Scale (SART) [15] was used after each run where participants were asked to give responses to three questions on their understanding of the situation, demand that it placed on them, and their supply of attention capacity during the run. Participants answered the three SART questions on a 7-point scale from 1= "very low" to 7 = "very high". The responses to these questions are then converted into an overall rating of situation awareness.

All three questions were answered using the full range of the scale – from 1 to 7- with a good spread of answers particularly between the sectors. As shown in Fig. 15, answers for the understanding question tended to be at the higher end of the scale with few lower ("poor understanding") responses. Overall, participants felt they had a "very good understanding" of the situation (M=6.33, SD=1.37), an "average" supply of attention capacity (M=4.25, SD = 1.89), and that there was only "a little" demand on their attention (M=2.96, SD = 1.37) (see Fig. 15). These responses combine to indicate that participants felt they had a "reasonable situation awareness" (M=5.08, SD=2.28).

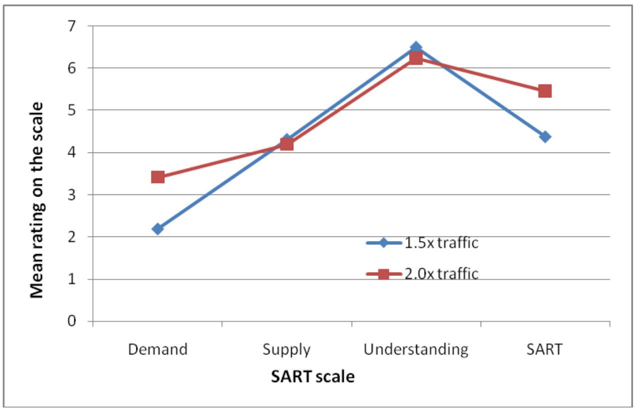

Figure 15 Mean SART ratings compared by the level of traffic density

5.5.2 Acceptability of Operations

Subjective feedback was also sought regarding the acceptability of operations as they were experienced in this concept's environment. This was gained through the presentation of questions closely aligned with the Controller Acceptance Rating Scale (CARS) [16]. Participant answers are compiled on a scale from one to ten where one indicates that the operation is not safe and ten indicates the system is acceptable. Participants rated the separation assurance operation as safe less often under NextGen Traffic Level B (67.5% of the time) than under Level A (90.6% of the time). A general analysis of the comments indicated that it was not the absolute volume of traffic that concerned participants but that the situations became more complex as the traffic increased (and finding a conflict solution with a clear path became less and less easy). For example, one participant commented that, "Traffic level really not that much of a factor. Number of conflictions at any one moment were more of a factor."

5.5.3 Overall Concept Impressions

Following the completion of the data collection phase of the study, a post-simulation debrief and discussion was conducted. This allowed both the researchers and participants to converse openly and freely regarding their ideas and opinions on the concepts presented and how they were carried out in the study. With respect to the concept, participants provided positive feedback with quotes such as, "you're on the right track," and, "it seems fairly natural, why not do it?" However, some concern was expressed regarding some of the more technical aspects of how the concept could be realized. One participant remarked, "…it seemed as if controller and automation fought against each other at times to resolve conflicts." This was mainly in response to the hands-off approach taken in the operation of automated tactical conflict resolutions. Despite these types of concerns, however, the overall mood and assessment of the concept was positive and can best be summed up by one of the participants who said, "It's inevitable, I think the concept is strong, it needs work and testing, I think it's the way we're going to go."

6. DISCUSSION AND CONCLUSIONS

The results presented in this paper were from a larger study that examined the functional allocation of ground-based automated separation assurance, which was also part of an overall study that examined the functional allocation of separation assurance between the flight deck and a ground-based ATC system. These studies were part of a continuing series of investigations into the realm of automated separation assurance and its related issues particularly as they relate to human-systems integration.

The results presented here were based on the medium duration runs of the larger study that were 30 minutes in length and varied Arrival Time Constraints (Baseline and STA) across two levels of Traffic Density (NextGen Level A and B). With the exception of number of conflicts where the STA condition had significantly fewer conflicts than Baseline, comparisons between Baseline and STA did not yield many insightful results. The most noteworthy comparisons were between the Traffic Density levels.

In Fig. 7 the plots of sector counts over time for each of the test sectors showed that NextGen Level B had generally higher sector counts but that the differences ranged between the sectors. These plots provided an important context in which to view the subsequent results because what was witnessed was a shift away from sector count alone being the driving factor for workload and safety to other factors such as local complexities within a sector.

For example, traditionally one might expect workload ratings to be highest for the sectors with the highest sector counts, which were, in decreasing order, ZKC90 and ZID81, the two largest sectors. However, an examination of reported workload revealed that it was ZKC98 that resulted in higher workload than ZID81, despite lower levels of traffic. It should be mentioned that although there were inter-sector differences, even the highest overall mean workload ratings were still relatively low and within an acceptable range.

In this simulation, ZKC98 was at once one of the smallest sectors while also being the most complex. This complexity existed by virtue of heavy arrival and departure corridors within the sector where transitioning aircraft interacted with aircraft at level flight. It was this type of interaction and inherent complexity that allowed for the observation of the equal or greater impact of complexity over that of simple sector count on operations and acceptability.

This was first evident through the examination of conflict data where it was initially found that as traffic density increased from Level A to B, there was a significant increase in the number of conflicts. This naturally resulted in a greater number of conflict resolutions to be issued. Upon further examination of clearances by sector it was found that despite ZKC98 having the third lowest level of traffic count, it had the highest number of resolutions sent. This was particularly the case in terms of tactical resolutions where more than half of all sent were in this sector.

For sectors ZKC98 and ZKC90, the number of operational errors followed the same trend as the number of clearances sent respectively. This was not the case, however, with ZID81, which had the second highest levels of traffic and the third highest number of clearances sent but did not have any resulting operational errors.

ZID81 had the second highest levels of traffic but was managed such that operations and workload were tenable with the least impact on safety with only one proximity event. This speaks to the potential that greater levels of traffic can be safely accommodated but also that particular attention needs to be paid to the complexity of the local environment and the ability to mitigate or manage it effectively.

While the ultimate goal of any system is to eliminate separation violation occurrences, they did occur here and are being investigated. Preliminary results show that late detection and the difficulties related to accurate trajectory predictions for transitioning aircraft played significant roles in the violation of separation minima. Despite the complexities described and the number of operational errors, while attempting to assess the success rate of the conflict resolutions sent it was found that over 99% of conflicts were successfully resolved and avoided an operational error in this portion of the study.

Subjective feedback from the participants provided this research effort with a different perspective on operations apart from the objective data. Situation awareness was rated as being “reasonable” even with the levels of automation in operation but that it was not the same for all sectors. In terms of acceptability, participants rated operations at the lower traffic density quite highly. However, this showed a reversal as the density increased such that there was a 23% decrease in participant ratings. This did not seem to affect their overall assessment of the concept, however, where the general consensus was that the approach taken was a viable way forward.

To conclude, in this study it was found that the increase in traffic density resulted in the greatest impact on operations. However, it was not aircraft count alone but local complexities that affected the observed results. This observation coupled with feedback provided by the participants speaks to the promise that this functional allocation concept of ground-based separation assurance holds for the ability of the NAS to accommodate the environment envisioned as part of NextGen.

7. ACKNOWLEDGMENTS

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