# PILOT AND CONTROLLER WORKLOAD AND SITUATION AWARENESS WITH THREE TRAFFIC MANAGEMENT CONCEPTS

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## Abstract

This paper reports on workload and situation awareness of pilots and controllers participating in a human-in-the-loop simulation using three different distributed air-ground traffic management concepts. Eight experimental pilots started the scenario in an en-route phase of flight and were asked to avoid convective weather while performing spacing and merging tasks along with a continuous descent approach (CDA) into Louisville Standiford Airport (SDF). Two controllers managed the sectors through which the pilots flew, with one managing a sector that included the Top of Descent, and the other managing a sector that included the merge point for arrival into SDF. At 3-minute intervals in the scenario, pilots and controllers were probed on their workload or situation awareness. We employed one of three concepts of operation that distributed separation responsibility across human controllers, pilots, and automation to measure changes in operator situation awareness and workload. We found that when pilots were responsible for separation, they had higher levels of awareness, but not necessarily higher levels of workload. When controllers are responsible and actively engaged, they showed higher workload levels compared to pilots and changes in awareness that were dependent on sector characteristics.

## Introduction

The Next Generation Air Transportation System (NextGen) is intended to modernize and increase the effectiveness of the national air traffic management system in the U.S.A. [1]. By 2025, NextGen is anticipated to accommodate as much as three times (3X) current day air traffic, while increasing its efficiency (e.g., shorter flight routes, shorter time on ground, fewer delays, etc.) and maintaining safety. Many organizations have been working toward NextGen goals by researching and developing advanced technologies such as controller-pilot datalink communications, advanced cockpit displays of traffic, weather, terrain, conflict alerting and resolution tools, and semi-autonomous automated air traffic management agents. New procedures and operational concepts for NextGen, such as trajectory-oriented operations and performance-based navigation procedures, are also being evaluated for use [2]. Because the human operator will still be an integral part of the air traffic management system, NextGen concepts of operation and technologies must be evaluated to determine their influence on human operator performance, workload, and situation awareness.

Situation awareness refers to an operator's understanding of his or her environment [3]. High situation awareness is needed for an operator to function optimally in a complex system such as air traffic management [3, 4]. Many aviation accidents that occur as a result of human error have been attributed to low situation awareness [4]. Thus, new systems and technologies being developed for NextGen must also assist operators in maintaining high situation awareness. Mental workload refers to the relationship between the amount of processing capability that an operator has available and the demand for those resources required by the task [5]. Workload is known to yield a curvilinear relationship with operator performance, with performance being negatively influenced by extremely low or high levels of workload [6]. With regard to separation assurance, workload varies as a function of traffic density [7], with workload increasing drastically after a certain threshold is reached. Thus, new NextGen tools and technologies must be evaluated in terms of their impact on operator workload.

This simulation is one of a series of studies in an on-going line of research aimed at optimizing situation awareness and workload metrics. We used online probes to capture operator situation awareness and workload. Online probe latency has been shown to be more predictive of performance than offline probes [8] and related to performance metrics assumed to depend on situation awareness [9, 10, 11]. Moreover, past simulations we conducted show that the online probes can discriminate between levels of awareness with different degrees of automation and training [12, 13]. Using a pilot conflict resolution task with differing levels of automation, [12] found that probe latencies were significantly longer in a fully automated condition compared with conditions in which pilots had to generate resolutions manually or were allowed to evaluate and modify suggested resolutions. The shorter latencies were indicative of higher situation awareness of the information being probed through active engagement with the conflict resolution task. Vu et al. [13] found longer probe latency for student controllers to questions involving projection into the future compared to questions relating to the present state of events in a simulation environment. Since more situation awareness is needed to accurately project future states, the probe latency appears to be a sensitive metric for capturing different degrees of situation awareness.

We selected three concepts of operation that distributed separation responsibility across pilots, controllers, and automation. It is worth noting that these concepts of operation were chosen because they were hypothesized to alter the workload and situation awareness of the human operators, allowing us to test our situation awareness and workload metrics. We do not imply that these concepts are being endorsed by any agency for implementation in NextGen. In ***Concept 1,*** pilots with equipped flight decks were responsible for conflict identification and resolution between Ownship and other equipped aircraft, aided by a conflict detection and resolution tool. Controllers managed only conflicts between unequipped aircraft. In ***Concept 2***, conflict identification and resolution was managed by air traffic controllers and automation, with more conflicts assigned to the controller than to the automation. In ***Concept 3***, conflict identification and resolution responsibility was also allocated to a human controller and automation system, but more types of conflicts were assigned to the automation system than to the human controller.

## Methods

### *Participants*

Eight experimental pilots were tested during each week of a two-week study. However, the performance, workload, and situation awareness data are only reported for the second week of data collection due to equipment failures on some of the experimental runs during the first week. Table 1 shows the number of hours flown for pilots in Week 2. Five of the pilots were at the professional rank of captain and three were at the rank of first officer. None of the participants had any prior experience with merging and spacing operations, although three of the pilots had experience flying a continuous descent arrival (CDA).

**Table 1. Number of Pilots in Each Grouping of Total Flight Hours in General and with a “Glass” Cockpit**

| Total hours flown as a line-pilot | N | Total hours flown in "glass" cockpit | N |
|---|---|---|---|
| 1-1000 | 1 | 1-1000 | 4 |
| 1001-3000 | 0 | 1001-3000 | 1 |
| 3001-5000 | 4 | 3001-5000 | 3 |
| >5000 | 3 | >5000 | 0 |

A total of four experimental controllers were run, two in each week of data collection. As with the pilots, only data from Week 2 are reported in detail. The experimental controllers in Week 2 were retired radar certified controllers, with one having 34 years and the other 25 years of civilian air traffic control experience.

### *Simulation Environment*

The simulation environment was produced by the Multiple Aircraft Control System (MACS) software [14]. The merging and spacing and weather avoidance tasks were supported by the Cockpit Situational Display (CSD) software [15]. Both MACS and the CSD were developed at NASA Ames Research Center by the Airspace Operations Laboratory (AOL) and the Flight Deck Display Research Laboratory (FDDRL), respectively. Included in both software programs were tools that supported generation of conflict resolutions [16] and a version of the auto-resolver tool that could automatically generate a resolution upon request from the pilot or air traffic controller. The algorithms used for the auto-resolver tool were also used by a ground-based auto-resolver agent, which autonomously uplinked resolutions to the equipped flight decks in certain concepts of operation.

The airspace used in the simulation mimicked Kansas City Air Route Traffic Control Center (ZKC) and Indianapolis Air Route Traffic Control Center (ZID), with controllers managing Sectors ZKC 9- and ZID 91. Traffic in each sector was modeled after real traffic feeds, but was modified to create a 3X traffic density environment. First, the airspace consisted of a larger area by combining a high and super-high sector. With the additional airspace provided by the "super sector" (see Figure 1), additional aircraft was added to the current traffic flows to load the airspace with 3X current day traffic. Surrounding the two experimental sectors that were managed by the participant controllers were adjacent sectors that were managed by students and staff working in the Center for Human Factors in Advanced Aeronautics Technologies at California State University Long Beach (CSULB). These "ghost" sectors were needed to make and receive handoffs from the two experimental sectors.

Aircraft populating the simulation were designated as either TFR (Trajectory Flight Rules) or IFR (Instrument Flight Rules). TFR aircraft had equipped flight decks with conflict detection and resolution tools. TFR aircraft were not directly managed by the human controller and interacted with the controller only under specific circumstances (depending on the concept of operation being employed and the phase of flight). The IFR aircraft consisted of the non-equipped flight decks, and these aircraft were always managed by the human controller. All experimental participants flew simulated desktop stations of TFR aircraft.

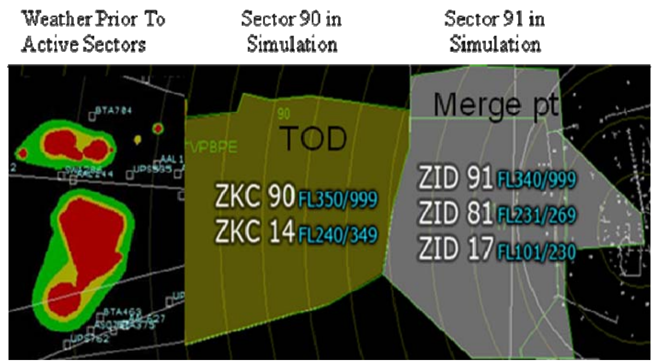


**Figure 1. Illustration of the Simulation Airspace. Weather was Located to the West of Sector 90. Sector 90 was a "Super Sector" Consisting of ZKC 90 and 14. Sector 91 was a Super Sector Consisting of ZID 91, 81, and 17.**

Both pilots and controllers were given several advanced tools for separation assurance. The first tool was the conflict probe, which detects conflicts up to 8 minutes prior to Loss of Separation (LOS) and alerts the pilot/controller (highlights aircraft in amber on the flight deck and flashes red on the controller radar; time to LOS was indicated on both displays). The second tool was the Route Assessment Tool (RAT) for pilots and the Trial Planner for air traffic controllers. The RAT and trial planner allows for manual creation of flight plan changes. Because this tool is coupled with the Conflict Probe, it allows the operator to determine whether proposed route changes are conflict free. Pilots can also use the RAT to re-route around weather. The third was the auto-resolver tool, which allows both pilots and controllers to request a resolution for a conflict. Finally, an auto-resolver agent was provided in

Concepts 2 and 3. The auto-resolver agent functioned autonomously to resolve conflicts between designated aircraft (e.g., TFR-TFR or TFR-IFR) once delegated this responsibility at the start of a scenario.

A distributed air-ground simulation environment was employed. Conducted over the Internet, four research labs participated in the simulation. Experimental pilots were located at FDDRL at NASA Ames Research Center. FDDRL also served as the simulation hub, consisting of the simulation manager, the voice server, and supporting workstations. The participant air traffic controllers were located at CHAAT CSULB. CHAAT also hosted confederate or “ghost” air traffic control sectors and pseudopilot stations which provided additional aircraft in the simulation that were not managed by the participant pilots being tested. Additional pseudopilot stations were located at the Systems Engineering Research Laboratory (SERL) at California State University Northridge, and the Human Integrated Systems Engineering Laboratory (HISEL) at Purdue University, to emulate 3X traffic density.

***Concepts of Operation***

Three concepts of operation that distributed separation responsibility across pilots, controllers, and automation were tested (see Table 1 for a summary). Again we emphasize that these concepts were selected because they were hypothesized to influence operator performance, workload, and situation awareness, allowing us to evaluate our probe tool.

In Concept 1, TFR pilots had the capability, responsibility, and authority for separating their ownship from other aircraft using the advanced traffic separation tools provided. Pilots made route modifications for traffic and weather avoidance and executed them; they did not have to datalink route modifications to a controller for approval. The air traffic controller was not responsible for TFR-TFR or TFR-IFR conflicts, except for the arrivals on their CDA. During the CDA, TFR pilots were instructed not to use the auto-resolver or RAT tools; the controller was to monitor them for conflicting traffic. TFR pilots were given voice frequencies to monitor but were told that they would not receive clearances from the air traffic controller unless they have discontinued spacing and given control back to the air traffic controller. IFR pilots did not have equipped flight decks and were always under the control of the human controller. IFR pilots received clearances via datalink, but they also monitored a voice channel. Controllers issued voice commands to any aircraft when needed. The controllers were responsible for resolving IFR-IFR conflicts. For TFR-IFR conflicts, the controllers were told that the pilot of the TFR aircraft was responsible for resolving the conflict.

In Concept 2, TFR pilots had the capability to separate Ownship from other aircraft by using the advanced traffic separation tools provided. However, TFR pilots did not have responsibility or authority for traffic separation. If the TFR pilots decided to use the advanced tools to generate a conflict resolution, they had to datalink the proposed solution to the air traffic controller for approval. Once the proposed route modification was received, the controller could approve/disapprove the request or issue another clearance. As with Concept 1, TFR pilots were given voice frequencies to monitor. IFR pilots were under the control of the human controller as in Concept 1. The human controller was responsible for resolving IFR-IFR and IFR-TFR conflicts. For IFR-TFR conflicts, the controller was to move the IFR aircraft. Conflicts between TFR-TRF aircraft were the responsibility of the autoresolver agent.

In Concept 3, pilots did not have conflict detection or resolution tools. Pilots did have the RAT for weather avoidance and for making other routing requests, but the RAT was not coupled with a conflict probe. All requests from pilots had to be datalinked to a controller for approval. All pilots monitored a voice frequency but most of the communication between pilots and controllers occurred via datalink. The human controller was responsible for resolving IFR-IFR conflicts. IFR-TFR and TFR-TFR conflicts were delegated to the auto-resolver agent. For IFR-TFR conflicts, the TFR aircraft was burdened to move unless it was an arrival aircraft on the CDA.

**Table 1. Tools Available and Operator Responsibility for Each of the Three Concepts of Operations**

| **Concept 1:** Pilot Primary; Controller Secondary | **Concept 2:** Controller Primary; Auto-resolver Agent Secondary | **Concept 3:** Auto-resolver Agent Primary, Controller Secondary |
|---|---|---|
| • Pilots have conflict detection and resolution tools and are responsible for solving conflicts with Ownship (75% of total conflicts)<br>• ATCs are responsible for resolving 25% of total conflicts<br>• Auto-resolver agent is not responsible for solving any conflicts | • Pilots have conflict detection and resolution tools but are not responsible for solving any conflicts<br>• ATCs are responsible for resolving 75% of total conflicts<br>• Auto-resolver agent is responsible for resolving 25% of total conflicts | • Pilots do not have conflict detection and resolution, and are not responsible for solving any conflicts.<br>• ATCs are responsible for resolving 25% of total conflicts<br>• Auto-resolver agent is responsible for resolving 75% of total conflicts |

### *Tasks and Procedures*

The pilots and controllers interacted in a real-time simulation environment. There were twelve, 90-minute scenarios, with four replications of each concept of operation. Separation requirements for all aircraft were 5nm lateral and 1000 feet vertical. In addition to performing the tasks specific to each operator role, described below, all participants were asked to answer situation awareness and workload probes.

Within the first 10 minutes of the scenario, pilots were assigned a lead aircraft and given spacing instructions. Pilots were asked to fly the Sea Biscuit One arrival into Louisville Standiford International Airport (SDF) while maintaining separation from other traffic (in Concept 1 only), avoiding convective weather, maintaining the assigned spacing interval relative to a lead aircraft at the final approach fix, and complying with Sea Biscuit One's altitude and speed restrictions. At the Sea Biscuit One fix, experimental aircraft performed a CDA to the 17-R runway. Experimental pilots were to notify air traffic control when they had discontinued spacing; at that time the aircraft was under the control of the air traffic controller. Depending on the condition being run, pilots were given a static depiction of weather on the CSD in the form of a Nexrad 2D or 3D display.

Controllers were asked to manage traffic in their sector. IFR traffic was displayed at full brightness and TFR aircraft were dimmed unless they were in conflict with an IFR aircraft. Controllers had a static image of weather (always located to the west of ZKC 90) on their radar that was similar to the Nexrad 2D display. Maintaining separation of aircraft to which they have been assigned responsibility was the task of greatest priority. In addition, controllers were asked to acknowledge voice check-ins for IFR aircraft, give clearances via pilot-controller datalink communications, re-sequence arrival aircraft on request, and provide traffic advisories, when time permits. The datalink clearances reflect trajectory changes to the aircraft flight plans and were to be the preferred mode of communication between the controller and pilot; however, to maintain safety, all pilots were monitoring the controller's voice frequency and could respond to verbal clearances when necessary. To alleviate controller workload, all handoffs and frequency changes were automated.

### *Situation Awareness and Workload Probes*

Starting at 4 minutes into the scenario, situation awareness and workload probes were presented at 3-minute intervals. The online probes were administered following the Situation Present Assessment Method sequence of events [8]. Operators were given an audio alert and a visual ready prompt to indicate that a probe question was available. When the operator indicated being "ready" by pressing the "ready" prompt on a touch screen, a probe question was administered. The question either queried the operator about workload [Rate your workload on a scale of 1 (very low) to 5 (very high)] or situation awareness. Sample situation awareness questions for pilots are listed below:

- "Will Ownship overtake UPS419?"
- "What was the last command you issued?"
- "How far will you deviate laterally for weather?"

Sample situation awareness questions for pilots are listed below:

- "Which quadrant of your sector currently has the most eastbound traffic?"
- "Will UPS914 and AAL114 maintain lateral separation if no further action is taken?"
- "What was the last command you issued via datalink?"

These questions were designed to query for information about traffic flows, conflicts, merging and spacing status, and weather. Some questions were general and could be asked at any place in the scenario (e.g., what was the last command you issued?) and to any operator (pilot or controller). Other questions were tailored to the scenario for relevance (e.g., "How far will you deviate laterally for weather?") was asked to a specific operator, the pilot, prior to the aircraft passing weather.

## Results and Discussion

Pilot workload and situation awareness data from the simulation have been reported in detail by in other papers [17, 18]. The present paper compares pilot workload and situation awareness to controllers. Because there were only 2 controllers, and each controller was responsible for a different sector, inferential statistical analyses were not performed. Rather descriptive data are reported and trends between controllers and pilots are discussed.

### *Performance*

Loss of Separation (LOS) was the performance metric of interest for separation assurance. The number of LOS was determined for pilots and controllers as a function of the concept of operation being employed. The data from 1 pilot had to be removed from the sample due to non-compliance with experimental instructions. On average, experimental aircraft had one LOS on every other run. The number of LOS was higher in Concept 1, when the pilots were responsible for resolving the conflicts, than in Concepts 2 and 3, when the controller and auto-resolver agent were responsible (see Figure 2). It is important to note that the traffic density was 3X and that the responsibility for resolving conflicts for pilots is one that they are not given in current day operations.

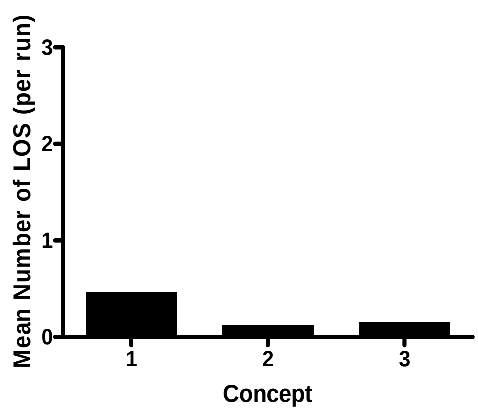


**Figure 2. Mean Number of LOS per Experimental Flight Deck and Scenario as a Function of Concept of Operation.**

For the two participant controllers, the number of LOS for each sector as a function of concept of operation is shown in Figure 3. On average, the controller for sector 90 had 3 LOS on each run, and the controller for sector 91 had 1 LOS on each run. Again, it is important to note that the traffic density was 3X in these scenarios. Also, it is worth noting that the sector characteristics were different for sector 90 and 91. Sector 90 was a larger sector with traffic flows being affected by convective weather, west of the sector. It also contained the Top of Descent (TOD) for arrival aircraft into SDF. The controller for sector 90 was also responsible for re-sequencing of the experimental aircraft if requested by the pilot. Sector 91 contained the merge point for the experimental aircraft; the controller for that sector managed crossing traffic so that it did not interrupt the arrival streams. The sector 91 controller was also given the responsibility for issuing clearances to the arrival aircraft to maintain the spacing interval if the aircraft discontinued spacing. Given the varied nature of the two sectors, it is likely that differences between the numbers of LOS in each reflected sector properties rather than differences in controller ability. One pattern that did emerge for both controllers was that the number of LOS was greater in Concept 2, when they were responsible for 75% of conflicts in the sector than in Concepts 1 and 3, when they were responsible for only 25% of the conflicts. Note also that the mean number of LOS were slightly higher in Concept 1 (shared responsibility with pilots) than Concept 3 (shared responsibility with an automated agent).

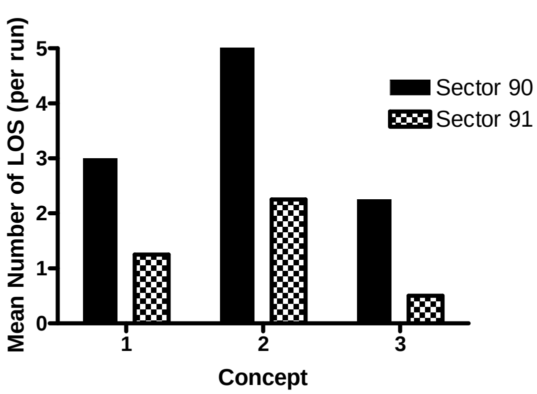


**Figure 3. Mean Number of LOS per Experimental Sector and Scenario under 3X Traffic as a Function of Concept of Operation.**

### *Workload*

The probe technique allowed for two different measurements of workload. The first is the ready latency, which is the time from presentation of the ready prompt to the controller indicating that s/he was ready for a probe question by pressing the prompt on a touch screen display. If workload was low, the operator should have been able to accept the ready prompt more quickly than if workload was high. The ready prompt timed-out after one minute. For the workload probes, a second metric is obtained, the workload rating (1-5 scale). For the workload probes, there was a significant correlation between the ready latency and workload rating, $r = .25$, $p < .001$ [17]. Thus, the ready latency was used as a measure of workload.

Ready latencies were influenced more by time in scenario than by concept of operation. Pilots had higher ready latencies during the first 9 minutes of the scenario, when they encountered the weather, and after 45 minutes into the scenario, when they were landing. Controllers showed higher latencies after 27 minutes into the scenario, when the experimental aircraft started to enter their sectors.

For the workload ratings on the workload probes, pilots reported lower levels of workload (*M*s = 1.7 to 1.8) compared with controllers (*M*s = 2.5 to 3.0) across all concepts. Controllers reported that workload was highest in Concept 2 ($M$ = 3.9), where controllers had the most responsibility. Lower workload levels were reported for Concept 1 ($M$ = 3.1, when pilots were responsible for the majority of conflicts) and Concept 3 ($M$ = 2.5, when automation was responsible for the majority of conflicts).

### *Situation Awareness*

The probe technique allowed for two different measurements of situation awareness. First, the percentage of probes answered correctly could be used as an indicator of awareness. Lower errors indicate higher awareness. The second metric is the probe latency. It is assumed that the lower the latency, the higher the awareness of the operator for the information being queried.

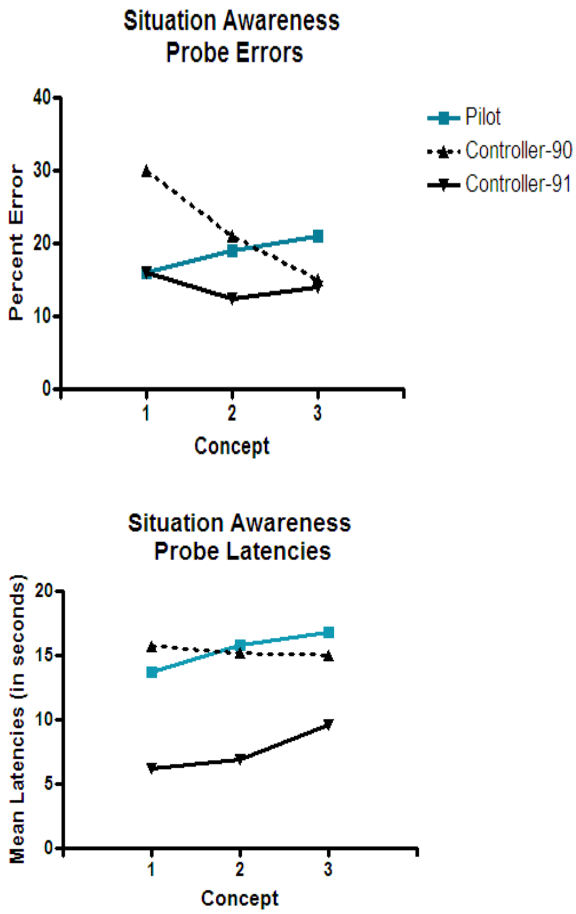


**Figure 4. Top: Mean Percent Error to Situation Awareness Probes for Pilots and Controllers as a Function of Concept of Operation; Botton: Mean Situation Awareness Probe Latency for Pilots and Controllers as a Function of Concept of Operation**

As shown in Figure 4, pilots showed fewer errors and shorter latencies to the probes in Concept 1, when they were responsible, than in Concepts 2 and 3 (detailed analyses can be found in [18, 19]). For controllers, the data pattern was less clear. Error rates on the probe questions tended to be higher in Concept 1 than in Concepts 2 and 3. However, because the data were from only two controllers, and each one was responsible for a different sector, the differences among controller awareness cannot be attributed solely to concept of operation.

## Post-Simulation Questionnaire and Debriefing

As noted in the method section, the simulation was run over a two week period, with different experimental pilots and controllers in each week. Due to equipment failure in Week 1, not all data runs were collected to allow for appropriate counterbalancing of conditions. Although the data reported for performance, workload, and situation awareness probes were only reported for Week 2 of data collection, all 16 pilots and 4 controllers experienced all three concepts of operations and were given the same post-simulation questionnaire. We report the data from all the participants here for a more representative picture of operators' perceptions of the three concepts of operations tested.

Tables 3 and 4 lists the pilot and controllers responses to three questions relating to the plausibility of the concepts of operation tested, the operator perceived workload given the tools provided, and the level of operator awareness for experimental aircraft in the simulation.

**Table 3. Pilot Responses in the Post Simulation Questionnaire (Scale of 1: strongly disagree to 5: Strongly agree)**

| Question | Concept 1 | Concept 2 | Concept 3 |
|---|---|---|---|
| Concept (1,2,3) is in principle a workable concept | 4.53 | 4.65 | 4.71 |
| Overall workload is manageable using the tools provided | 4.41 | 4.59 | 4.65 |
| I felt that ATC was adequately aware of what was going on with my aircraft | 2.94 | 3.14 | 3.59 |

In general, all operators indicated that the three concepts were workable in theory. Pilots strongly agreed that their workload was manageable given the tools provided. Controllers indicated their workload was the most manageable in Concept 3, where separation responsibility was shared between the controller and automation, but the auto-resolver agent was allocated the responsibility for resolving the majority of conflicts. Given that the experimental aircraft were all TFR aircraft for which the controllers were not assigned responsibility, the controllers indicated that they were not adequately aware of what the experimental pilots were doing. Similarly, the experimental pilots indicated that they did not feel that controllers were adequately aware of their aircraft.

**Table 4. Controller Responses in the Post Simulation Questionnaire (Scale of 1: strongly disagree to 5: Strongly agree)**

| Question | Concept 1 | Concept 2 | Concept 3 |
|---|---|---|---|
| Concept (1,2,3) is in principle a workable concept | 4.25 | 4.5 | 5.0 |
| Overall workload is manageable using the tools provided | 3.5 | 3.75 | 4.5 |
| I felt adequately aware of what the Exp Pilots were doing | 2.5 | 2.5 | 2.5 |

From debriefing, both pilots and controllers commented on the level of traffic being high. Pilots were less influenced by the traffic level because they were mainly responsible for separating their aircraft from others. However, controllers had to be aware of all aircraft in their sector, so traffic level was a major factor influencing their performance. Controllers also indicated that they did not mind sharing separation responsibility with other operators because workload would be reduced if everything worked as planned. However, the controllers indicated when they were not responsible for a subset of aircraft, it was very hard for them to be able to assist those aircraft subsequently. For example, when the auto-resolver agent was unable to resolve a conflict in a timely manner, the pilot would call the human controller for assistance. In these circumstances, the controllers sometimes could not locate the aircraft in a timely manner to assist in the conflict resolution.

## Conclusions

Pilots and Controllers were affected differently by the three concepts of operation. Pilots indicated that all concepts were workable and showed little change in workload across the three concepts. Moreover, pilots showed higher levels of awareness when they were actively engaged in separation assurance responsibilities in Concept 1. Although the controllers also indicated that all concepts were workable, they showed sector-specific changes in awareness and workload depending on concept of operation. Pilots tended to revert back to controller intervention when for assistance when their solutions (or the auto-resolver agent's solutions) failed. In these situations, though, the human controllers showed very little awareness of the experimental aircraft and were not be able to help the pilots with resolving conflicts. This finding, although preliminary, has implications for models of NextGen that put the human controller in a back-up role for other human operators or for automation failures.

## References


[1] Joint Planning and Development Office, 2010, NextGen. Available at: http://www.jpdo.gov/nextgen.asp. Retrieved August 4, 2010.

[2] NASA, 2007, Next Generation Air Transportation System White Paper. Available at: http://www.aeronautics.nasa.gov/nextgen_whitepaper.htm. Retrieved June 13, 2010.

[3] Durso, F. T., Gronlund, S., 1999, Situation awareness. In F. T. Durso, R. S. Nickerson, and R. W. Schvaneveldt, *Handbook of Applied Cognition*, New York: John Wiley and Sons, pp. 283-314.

[4] Jones, D. G., Endsley, M. R., 1996. Sources of situation awareness errors in aviation. *Aviation, Space and Environmental Medicine, 67(6)*, 507-512

[5] Hart, S. G., & Staveland, L. E. (1988). Development of NASA TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkahi (Eds.), *Human Mental Workload*, Amsterdam, Netherlands: North-Holland, pp. 139-183.

[6] Yerkes, R. M., Dodson, J. D., 2008, The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*, 459-482.

[7] Lee, P. U., 2005,. A non-linear relationship between controller workload and traffic count. *Human Factors and Ergonomic Society Annual Meeting Proceedings, Human Performance Modeling, 5*, 1129-1133.

[8] Durso, F. T., Bleckley, M. K., Dattel, A. R., 2006. Does SA add to the validity of cognitive tests? *Human Factors*, 48, 721-733.

[9] Strybel, T. Z., Vu, K.-P. L., Kraft, J., Minakata, K., 2008,. Assessing the situation awareness of pilots engaged in self spacing. *Proceedings of the Human Factors and Ergonomics Society* 52nd *Annual Meeting*, New York, NY. pp. 11-15.

[10] Strybel, T. Z., Minakata, K., Nguyen, J., Pierce, R., Vu, K.-P. L., 2009. Optimizing online situation awareness probes in air traffic management tasks. In M. J. Smith and G. Salvendy (Eds.): *Human Interface, Part II, HCII 2009, Lecture Notes in Computer Science, 5618*, 845-854.

[11] Pierce, R., Vu, K.-P. L., Nguyen, J., Strybel, T., 2008. The relationship between SPAM, workload, and task performance on a simulated ATC task. *Proceedings of the Human Factors and Ergonomics Society* 52nd *Annual Meeting*, New York, NY. pp. 34-38.

[12] Dao, A.-Q. V., Brandt, S. L., Battiste, V., Vu, K.-P. L., Strybel, T., Johnson, W., 2009. The impact of automation assisted aircraft separation on situation awareness. In M. J. Smith and G. Salvendy (Eds.): *Human Interface, Part II, HCII 2009, Lecture Notes in Computer Science, 5618*, 738-747.

[13] Vu, K.-P. L., Minakata, K., Nguyen, J, Kraut, J., Raza, H., 2009. Situation awareness and performance of students versus experienced air traffic controllers. *Human Interface, Part II, HCII 2009, Lecture Notes in Computer Science, 5618*, 865-874.

[14] Prevot, T., 2002. Exploring the many perspectives of distributed air traffic management: The Multi Aircraft Control System: MACS. *International Conference on Human-Computer Interaction in Aeronautics, HCI-Aero 2002, 23-25* October, MIT, Cambridge, MA.

[15] Granada, S., Dao, A. Q., Wong, D., Johnson, W. W., Battiste, V., 2005. Development and integration of a human-centered volumetric cockpit display for distributed air-ground operations. *Proceedings of the 12th International Symposium on Aviation Psychology*, Oklahoma City, OK

[16] Erzberger, H., 2006. Automated Conflict Resolution for Air Traffic Control. *Proceedings of the 25th International Congress of the Aeronautical Sciences (ICAS)*, Germany.

[17] Ligda, S., Dao, A.V., Vu K.-P. L.. Strybel, T. Z., Battiste, V., & Johnson, W.W., in press. Impact of Conflict Avoidance Responsibility Allocation on Pilot Workload in a Distributed Air Traffic Management System. *Proceedings of the 54th Meeting of the Human Factors and Ergonomics Society, Sept 27 - Oct. 1*. San Francisco, CA.

[18] Dao, A.-Q. V., Brandt, S. L., Bacon, P., Kraut, J., Nguyen, J., Minakata, K, Raza, H., Rozovski, D., & Johnson, W. W. (2010). *Conflict resolution, automation, and pilot situation awareness.* Manuscript in preparation.

[19] Strybel, T. Z., Vu, K-P. L., Bacon, L. P, Kraut, J. Minakata, K., Battiste,V. & Johnson, W., 2010; this volume. Diagnosticity of an Online Query Technique for Measuring Pilot Situation Awareness in NextGen. *Proceedings of the 29th Digital Avionics Systems Conference*, Salt Lake City, UT, Oct. 3-7.

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## Disclaimer

Any opinions or conclusions are those of the authors alone, and do not necessarily reflect the official position or policy of NASA, SJSU Foundation, CSULB, or the CSULB Foundation.

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