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## Metrics for Operator Situation Awareness, Workload, and Performance in Automated Separation Assurance Systems

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## Acronyms and Definitions

4D-CSD .....	Four-Dimensional Cockpit Situation Display
ADRS .....	Aeronautical Data Link and Radar Simulator (NASA Ames Research Center)
ADS-B .....	Automatic Dependent Surveillance – Broadcast
ASAS .....	Automated Separation Assurance Systems
ATC .....	air traffic control
ATM .....	air traffic management
AT-SAT .....	Air Traffic Selection and Training
CDA .....	continuous descent approach
CHAAT .....	Center for Human Factors in Advanced Aeronautic Technologies (California State University, Long Beach)
CSULB .....	California State University, Long Beach
CSUN .....	California State University, Northridge
FDDRL .....	Flight Deck Displays Research Laboratory (NASA Ames Research Center)
HSEL .....	Human Integrated Systems Engineering Laboratory (Purdue University)
IAS .....	indicated air speed
JPDO .....	Joint Planning and Development Office
LOS .....	loss of separation
MACS .....	Multi Aircraft Control System
NASA .....	National Aeronautics and Space Administration
NextGen .....	Next Generation Air Transportation System
NRA .....	NASA Research Announcement
RAT .....	route assessment tool
SA .....	situation awareness
SAGAT .....	Situation Awareness Global Assessment Technique
SAWTOOTH II .....	Situation Awareness in Trajectory Oriented Operations with Weather II
SDF .....	Louisville International Airport
SERL .....	Systems Engineering Research Laboratory (California State University, Northridge)
SJSUF .....	San Jose State University Foundation
SPAM .....	Situation Present Assessment Method
ZID .....	Indianapolis Center
ZKC .....	Kansas City Center

## Executive Summary

A research consortium of scientists and engineers from California State University Long Beach (CSULB), San Jose State University Foundation (SJSUF), California State University Northridge (CSUN), Purdue University, and The Boeing Company was assembled to evaluate the impact of changes in roles and responsibilities and new automated technologies, being introduced in the Next Generation Air Transportation System (NextGen), on operator situation awareness (SA) and workload. To meet these goals, consortium members performed systems analyses of NextGen concepts and airspace scenarios, and concurrently evaluated SA, workload, and performance measures to assess their appropriateness for evaluations of NextGen concepts and tools. The following is a summary of our activities and accomplishments that were supported by the NASA Research Announcement (NRA).

- *Distributed Simulation.* Concept and metric evaluation required that we develop a distributed simulation network in which each laboratory participated in large-scale simulations of NextGen concepts. With this distributed-simulation foundation established, two distributed-simulation demonstrations and two distributed-simulation experiments were completed in year 3 of the NRA.
- *Metric Development.* Based on our review of SA and SA measurement, we determined that probe techniques are the most promising measures for evaluating the impact of NextGen changes in roles and responsibilities on operator SA and workload. The probe techniques have been shown to have relatively good psychometric properties, especially predictive validity and diagnosticity. We modified the method developed by Durso (e.g., Durso and Dattel, 2004) by automating SA probing, improving on the method of presenting probe questions and collecting operator responses, working toward a standard set of probe questions (or probe question categories) and adding workload queries. Several simulations were run on both pilots and air traffic controllers (ATCs). These provided evidence for the validity, sensitivity and diagnosticity of the method.
- *Systems Analysis.* System analyses of potential NextGen concepts of operation were also reviewed. We determined that these concepts could be distributed along two axes: the degree to which responsibility for separation assurance and collision avoidance is assigned to the controllers versus the pilots, and the degree to which automation augments or replaces controller and pilot functions. Interviews with air traffic controllers and commercial pilots for task goals information requirements were also done. ATCs were also interviewed about training requirements for NextGen operators. ATCs responded that the next generation of air traffic controllers would not benefit much from previous experience with computers and games because the perceptual motor skills are not the most important skill involved in air traffic management.
- *Part-Task Simulations.* A series of part-task simulations and experiments were conducted within each consortium organization. These were focused on conflict detection and resolution in NextGen, development of metrics for SA and workload in NextGen, application of the metrics to NextGen airspace environments, and the evaluation of NextGen concepts of operation for separation assurance. These were followed by a series of distributed air-ground simulations that involved simulation roles (flight decks, controllers,

pseudo-aircraft, etc.) being played by two or more member organizations. Part-task-simulation experiments directed at metric development established the validity, sensitivity and diagnosticity of the modified online probe technique. Experiments on pilot conflict resolution showed that pilots were not comfortable accepting automated conflict resolutions and desired to communicate with ATCs more than is anticipated in NextGen.

- *Large-Scale Simulations.* Our distributed simulations evaluated plausible NextGen concepts of operations, and cockpit automation tools for traffic separation, weather avoidance, merging and spacing, and communications. These projects simulated sectors in Kansas City Center (ZKC) and Indianapolis Center (ZID), with participant pilots flying en route, arrival and approaches to Louisville International Airport (SDF), while avoiding weather and managing spacing. Three concepts of operation were evaluated that allocated primary responsibility for traffic separation between pilots, ATCs and automation. We determined that SA was highest when pilots were responsible for traffic separation. Workload was unaffected by adding responsibility for traffic separation. Workload was only affected by task demands related to flight phase. Weather perturbations did create situations in which aircraft spacing was negatively affected regardless of whether the pilot faithfully followed the leading aircraft around weather.

As a result of this NRA, we have gained a greater understanding of SA and its measurement, and have shared our knowledge with the scientific community: During the NRA, we published 20 technical papers, made 21 presentations at conventions, presented 6 briefings to the National Aeronautics and Space Administration (NASA), and prepared 5 unpublished reports. Additional technical papers based on the NRA work were also published after the funding period. Through the success of our distributed-simulation network, we have shown how to create a flexible and cost-effective test bed for simulations and research involving current and future airspaces. This network provides a mechanism for consortium members, colleagues, and students to pursue research on other topics in air traffic management and aviation, thus enabling them to make greater contributions to the field.



# 1. Introduction

## 1.1 Objectives

Introducing new air traffic management (ATM) concepts, Automated Separation Assurance Systems (ASAS), and other automation technologies proposed by Next Generation Air Transportation System (NextGen) can significantly impact workload and situation awareness (SA) for operators in future airspace systems. Successful implementation of these solutions, for achieving Joint Planning and Development Office (JPDO) goals, demands that we identify the information required of each operator in performing his/her new role, and the impact of new technologies on operator SA and workload. As a result, current metrics need to be revised or new measurement techniques need to be developed to ensure that they are reliable, valid, and sensitive to the changes in operator SA and workload brought about by NextGen innovations. The objectives established for our NASA Research Announcement (NRA) are as follows:

- Develop methods for quantifying required and actual operator SA, workload, and performance in relation to:
  - Operator (flight crew and controller) role in Automated Separation Assurance Systems
  - The impact of these factors on system safety and performance under NextGen
- Characterize individual and shared SA in NextGen environments.
- Support program capability for human-in-the-loop simulations of NextGen concepts and evaluations of SA, workload, and performance.

## 1.2 Approach

A research consortium of scientists and engineers from California State University Long Beach (CSULB), San Jose State University Foundation (SJSUF), California State University Northridge (CSUN), Purdue University, and The Boeing Company was assembled. Our approach to the development and evaluation of SA, workload, and performance was characterized by systems analysis (conducted by systems engineers and operations experts, with inputs from NASA) of NextGen concepts and airspace scenarios. Concurrently, metric evaluations of existing measures of SA, workload, and performance were conducted to assess their ability to predict SA in NextGen environments. These parallel approaches drove the design of simulations to evaluate candidate measures for their ability to reflect changes in operator SA, workload, and performance that might be induced by NextGen concepts.

Our multidisciplinary team of universities and private industry established the technological capacity to conduct networked, human-in-the-loop simulations for assessing candidate SA metrics, workload, and performance for individual pilots and air traffic controllers (ATC), pilot-controller teams, and pilot-controller interactions with ASAS. All members of the consortium have extensive knowledge and experience in the areas of human performance and ATM operations. Table 1 describes the member organizations in terms of the institution, key personnel, and the role of each team member in the NRA.

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Table 1. Consortium Organizations and Descriptions of  
Principal Investigators (PI) and Co-Investigators (CI)

---

*California State University, Long Beach; Center for Human Factors in  
Advanced Aeronautic Technologies (CHAAT)*

- Thomas Strybel, PI; Professor of Psychology and Director of  
CHAAT
  - Kim-Phuong L. Vu, Co-I; Associate Professor of Psychology and Co-  
Director of CHAAT
- 

*San Jose State University Foundation*

- Vernol Battiste, Co-I; Senior Research Associate for the FDDRRL at  
NASA Ames Research Center
  - Arik-Quang V. Dao, Co-I; Research Associate for the FDDRRL
- 

*Purdue University, Human Integrated Systems Engineering Laboratory  
(HSEL)*

- Steven Landry, Co-I; Assistant Professor of Industrial Engineering  
and Director of HSEL
- 

*California State University, Northridge; Systems Engineering Research  
Laboratory (SERL)*

- Nhut Ho, Co-I; Associate Professor of Mechanical Engineering and  
Director of SERL
- 

*The Boeing Company*

- John P. Dwyer, Co-I; Technical Fellow, Human Systems Integration
- 

By taking advantage of the unique strengths and capabilities of each member the consortium, we made significant progress in achieving the goals of the NRA. Our objectives were accomplished through:

- Part task, in-house simulations conducted individually at consortium laboratories
- Distributed simulations involving two or more consortium organizations
- Laboratory experiments conducted individually within the consortium organizations
- Systems analyses and concept papers developed by one or more Co-Investigator.

Our accomplishments with respect to the objectives of this NRA are detailed in the subsequent pages. They have been organized into three major sections. Section 2 summarizes the methods we developed for distributed simulation capability, and SA and workload measurement. Section 3 summarizes systems analyses we conducted of operator roles and responsibilities in NextGen, information requirements and implications of NextGen concepts on operator training. Section 4 summarizes the results obtained from application of the methods, the knowledge we have obtained regarding how to measure SA, workload, and performance in NextGen air traffic environments, and evaluations of NextGen concepts in terms of changes in operator roles and their effect on operator SA, workload, and performance.

## 2. Method Development

### 2.1 Distributed Simulation Capability

Our consortium members have established a simulation network infrastructure that permits interaction between controllers, pilots, and experimenters over the Internet. This capability is made possible through the implementation of software donated to the consortium members by NASA Ames Research Center: Aeronautical Data Link and Radar Simulator (ADRS), Multi Aircraft Control System (MACS), Four Dimensional Cockpit Situation Display (4D-CSD), and Distributed Air/Ground Voice communication. Taking advantage of both the existing infrastructure at each consortium site and the adaptability of NASA Ames' simulation software, we created an extremely flexible simulation network. Building on NASA's own plan for a versatile simulation environment, our distributed simulation capability enabled us to readily host large simulations that can vary the number of self-separation-capable aircraft, simulate current day, NextGen, or mixed-equipage airspace environments, and assess how different levels of automation associated with different NextGen concepts of operations affect operator and system performance.

The distributed simulation capability was successfully demonstrated in 2008. First, we established connectivity and ensured adequate bandwidth at each facility. Then we installed simulation software and trained personnel at each facility on simulation software and procedures, thus expanding the capacity for airspace simulations in one facility (CHAAT at CSULB) and creating two additional simulation facilities in consortium laboratories (SERL at CSUN and HISEL at Purdue). Once operational, FDDRL engineers improved the distributed simulation network by creating a capability for remote startup of all simulation stations to ensure that all stations at each facility were appropriately connected and configured before the start of a simulation run. With this distributed simulation foundation established, two distributed-simulation demonstrations and two distributed-simulation experiments were completed in year 3 of the NRA. Table 2 shows the distributed simulation configuration for one of the simulation experiments, the Situation Awareness in Trajectory Oriented Operations with Weather II (SAWTOOTH II) simulation that was conducted between August and September 2009, described in Section 4.2. This simulation involved over 30 workstations at four consortium laboratories.

Table 2. Distributed Simulation Components for the Situation Awareness and Workload in Trajectory Oriented Operations with Weather Simulation\*

<i>FDDRL (NASA Ames Research Center)</i>	<i>CSAAT (Calif. State Univ., Long Beach)</i>	<i>HISEL (Purdue Univ.)</i>	<i>SERL (Calif. State Univ., Northridge)</i>
<ul style="list-style-type: none"><li>• 6 participant pilot stations</li><li>• 5 single pseudopilot stations</li><li>• 1 777 simulator</li><li>• 1 eye-tracking station</li><li>• 1 Simulation Manager station</li><li>• 1 Voice Server</li><li>• 1 ADRS station</li></ul>	<ul style="list-style-type: none"><li>• 2 participant ATC stations</li><li>• 2 ghost/confederate ATC stations</li><li>• 8 multi-pilot stations</li><li>• 2–4 probe stations</li><li>• 1–2 ADRS stations</li></ul>	<ul style="list-style-type: none"><li>• 1 ADRS station</li><li>• 2 single pseudopilot stations</li></ul>	<ul style="list-style-type: none"><li>• 2 single pseudopilot stations</li><li>• 1 ADRS station</li></ul>

\* See Section 4.2.

In summary, our development of a distributed simulation capability not only created a mechanism for running large-scale simulations of most NextGen operator roles, but also expanded the number of universities capable of performing NextGen airspace simulations.

## 2.2 Metric Development

NextGen innovations must be developed using a system-comprehensive, user-centered strategy that promises continuing improvement in efficiency and maintenance—and even enhancement—of safety. However, NextGen automation solutions may alter operator SA and workload in negative ways, and it is important that valid and reliable measures be available for evaluating SA, workload, and performance in NextGen. As part of the NRA, we evaluated existing metrics, and developed new techniques, for quantifying operator SA in current day and NextGen aviation environments.

We first reviewed existing metrics of SA, workload, and performance, and evaluated each metric for metric properties of reliability, validity, sensitivity, diagnosticity, usability, and operator acceptance. Based on our review of SA and SA measures, we determined that probe techniques are the most promising measures for evaluating the impact of NextGen changes in roles and responsibilities on operator SA and workload. The probe techniques have been shown to have relatively good psychometric properties, especially predictive validity and diagnosticity (e.g., Endsley, 1990; Endsley & Smolensky, 1998). With regard to existing probe techniques, we determined that real-time probe methods were more advantageous than freeze-probe methods because real-time probes are not heavily dependent on working memory and can assess SA when operators off-load information to the environment (Chiappe, Strybel, & Vu, in press). We also determined that some issues related to the existing real-time probe technique, the Situation Present Assessment Method (SPAM), needed to be addressed to make the method applicable for NextGen investigations of SA and workload. In particular, we determined that the impact of workload must be clearly identified in the use of online probes because workload can impact operator performance independent of SA. Relating to this point, we ran several studies that examined how workload and other factors affected SA measures using the on-line probe technique. We found:

- Latencies to SA probes can be influenced by the response input method. Therefore, we streamlined the administration of probes from free-responses to multiple-choice and true/false or yes/no format, to reduce the added workload produced by the query task. We also improved the apparatus for presenting queries and collecting operator responses.
- We determined that a standard method for developing probe queries needed to allow comparison of SA metrics across simulation studies. In our approach, queries were created beforehand in conjunction with scenario development. Subject matter experts were consulted, but we also created queries based on categories relevant to SA: processing level, time frame, and information content. After several part task simulations, we determined that questions should be based on information requirements. Moreover, once categories are established, we found that it was important to design probes so that each combination of categories is probed an equal number of times and the order in which information queries are presented must be counterbalanced across scenarios and participants.

We ran several simulations for refining and validating our online probe technique. The technique is based on Durso's SPAM technique (Durso & Dattel, 2004; see Figure 1). To ensure that response latency was related to SA and not workload, each query begins with a "Ready" prompt and audio alert. Operators were instructed to respond "yes" to the ready prompt only when they had sufficient time to take a SA question. If the operator, for example, a pilot, responded affirmatively to the ready response, the probe question was immediately presented and the pilot responded by selecting the

answer (typically yes/no or multiple choice). The results of our metric-development work, including a description of the administration and question development techniques were documented in a Manual for Online Probing that was submitted to our NASA Technical Monitor in January 2011 (Strybel et al., 2011). Results of simulations using the real-time probe technique are summarized in Section 4.

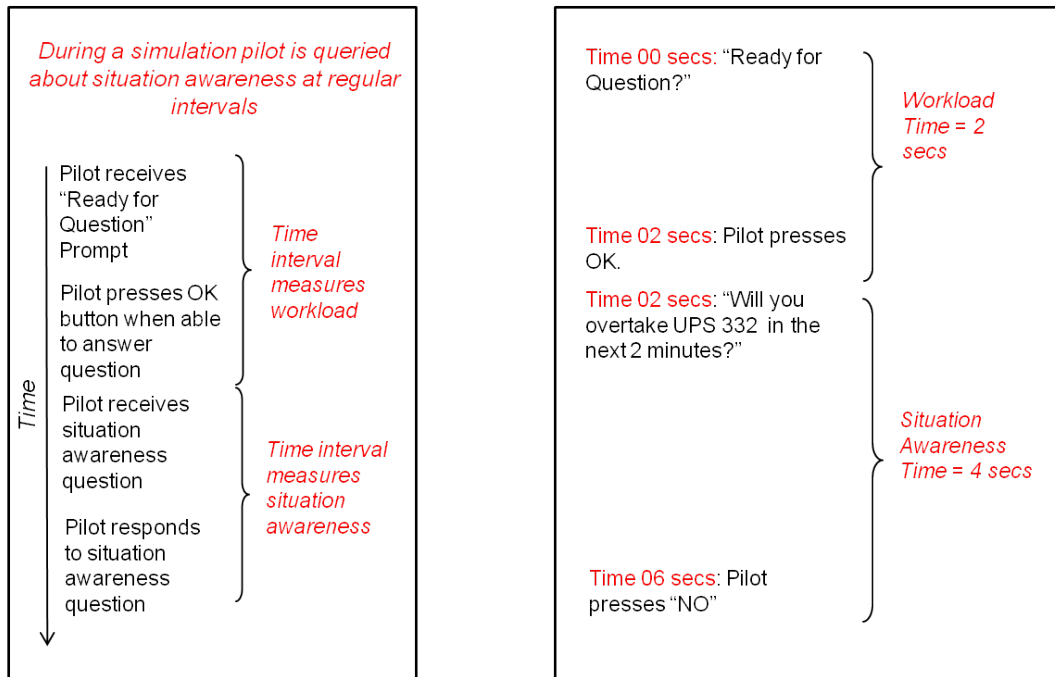


Figure 1. Assumptions and example (pilot query) of our real-time SA and workload probe technique.

### 3. Systems Analysis of NextGen Concepts of Operation

Analyses of the information requirements for pilot and ATC tasks under different NextGen function allocation and automation concepts was performed in years 1 and 2 of the NRA. Because a clear picture of the most likely NextGen solutions was not yet available, we surveyed the views of NASA scientists on the proposed NextGen solutions and determined the impact that each solution would have on operator roles and responsibilities, workload, and SA. Interviews with pilots and ATCs were also conducted to determine the impact of specific changes in roles and responsibilities on the information and training requirements of future operators.

#### 3.1 Evaluation of NextGen Concepts of Operation

In parallel with the information requirements analyses, we also conducted a review of separation assurance and collision avoidance operational concepts for NextGen. The review showed that the concepts can be distributed along two axes: the degree to which responsibility for separation assurance and collision avoidance is assigned to the controllers versus the pilots, and the degree to which automation augments or replaces controller and pilot functions. Based on an analysis of the implications of these concepts to NextGen, from a human factors standpoint as well as the technological readiness of the concepts, it was concluded that some form of supervisory control of separation assurance by controllers is the most viable concept. For additional details see Table 3 and Dwyer and Landry (2009).

**Table 3. Taxonomy of Separation Assurance Concepts and Projected Impact on Situation\***

		<i>Expected Impact Comparing NextGen Environment to Current Environment</i>					
	Concept	Expected technological readiness	ATC situation awareness	ATC workload	Pilot situation awareness	Pilot workload	Concept appears viable?
	Shared responsibility no automation	High	Small reduction	Excessive	Moderate increase	Excessive	No
ATC automation	Conflict ID only	Medium-high	Neutral	Excessive	Neutral	Neutral	No
	Conflict ID with resolution tools	Medium	Neutral	Very large increase	Neutral	Neutral	Yes
	Conflict ID with resolution options	Medium	Small reduction	Moderate increase	Neutral	Neutral	Yes
	Conflict Id with auto-resolver	Medium	Large reduction	Moderate reduction	Neutral	Neutral	Yes
	Distributed control	Low	Very large reduction	Large reduction	Large increase	Large increase	No
	Mixed concepts	Medium-low	Moderate reduction	Moderate increase	Moderate increase	Moderate increase	Yes

\* Dwyer and Landry, 2009.

### 3.2 Analysis of Information Requirements

To support the evaluation of feasible function allocation concepts for separation assurance systems, and to develop a better understanding of the specific information requirements for key tasks (resolving conflicts, avoiding weather, and merging and spacing), air traffic controllers and commercial pilots were interviewed for their goals, sub-goals, and the individual and shared information needed to perform the tasks. For high-level goals, the two pilots interviewed were in general agreement in terms of their responses, even though they flew for different airlines. The two controllers interviewed were also in consensus. However, for the same high-level goals, the sub-goals of the pilots and the controllers showed more differences than similarities. For example, in the conflict resolution task, the effect of allocating separation responsibility to pilots (Concept 1), ATCs (Concept 2) and Automation (Concept 3) is shown in Table 4. Pilots based their decision for trajectory changes on factors such as fuel consumption, time to destination, secondary conflicts, and passenger comfort. The controllers, on the other hand, based their decisions on factors such as the

effect that the trajectory change has on the entire traffic flow, additional conflicts induced, and workload. Thus, while the controllers and the pilots shared common goals at the highest level, the controllers' motivations are system-centric, while the pilots are aircraft-centric. This point was further reinforced in the group interview session in which the controllers confirmed that they rarely take into account the sub-goals that are important to the pilots, while the pilots indicated that they prefer the controllers to take into account as much as possible the sub-goals that are important to them. The key information requirements obtained can be used as input to ascertain which information is most needed when developing probe questions for measuring individual and shared SA. The knowledge elucidated also provided insights into the interaction among the controllers, pilots, and automation, and their perception of the feasibility of different concepts for separation assurance.

Table 4. Pilot and ATC Goals and Sub-goals Across Function Allocation Concepts for Resolve Conflict Task\*

	<i>Concept 1</i>	<i>Concept 2</i>	<i>Concept 3</i>
PILOT			
Goals	<ul style="list-style-type: none"> <li>• Aware of conflicts near and far</li> <li>• Avoid secondary conflict</li> </ul>	<ul style="list-style-type: none"> <li>• Avoid conflict</li> </ul>	<ul style="list-style-type: none"> <li>• Avoid conflict</li> </ul>
Sub goals	<ul style="list-style-type: none"> <li>• Fuel management</li> <li>• Time management</li> <li>• Manage alt/head</li> <li>• Communicate with ATC</li> </ul>	<ul style="list-style-type: none"> <li>• Fuel management</li> <li>• Passenger comfort</li> <li>• Communicate with ATC</li> </ul>	<ul style="list-style-type: none"> <li>• Fuel management</li> <li>• Passenger comfort</li> <li>• Communicate with ATC</li> </ul>
ATC			
Goals	<ul style="list-style-type: none"> <li>• Separation</li> </ul>	<ul style="list-style-type: none"> <li>• Separation</li> </ul>	<ul style="list-style-type: none"> <li>• Separation</li> </ul>
Sub goals	<ul style="list-style-type: none"> <li>• Reduce workload</li> <li>• Communicate less</li> <li>• Sector traffic</li> <li>• Fuel levels for sequence priority</li> </ul>	<ul style="list-style-type: none"> <li>• Reduce workload</li> <li>• Communicate less</li> <li>• Sector traffic</li> </ul>	<ul style="list-style-type: none"> <li>• Fuel levels for sequence priority</li> <li>• Reduce sector workload</li> </ul>

\* Ho, Martin, Bellissimo, and Berson, 2009.

### 3.3 Implications of NextGen Roles and Responsibilities for Operator Training

Dwyer, Gershohn and Thorpe (2011) conducted interviews of ATCs who participated in a distributed simulation of potential NextGen Concepts of Operation (see Section 4.2) to assess their opinions on current and future training needs. Although ATC participants were initially skeptical of some concepts (i.e., allocated separation responsibility to the flight deck), once additional modifications were made to the procedures being simulated, and the ATCs were able to practice the concepts, they were more accepting of these concepts of operation. Dwyer et al. also asked ATCs about how NextGen tools will affect the training of future controllers, specifically with respect to the

high computing and gaming backgrounds of this generation of controllers. The majority of ATCs indicated that a computer gaming background might improve perceptual-motor skills, but these are not the critical factors determining success. In NextGen, it is likely that ATCs will be working with automation in the course of conducting sector-level traffic flow management tasks. Moreover, one ATC noted that attrition rates for trainees (which were estimated at 50%) are typically the result of operational errors and conducting unsafe separation operations. Perceptual-motor skills most likely would not contribute to these errors.

## **4. Results**

### **4.1 Part-Task Simulations and Experiments**

A series of part-task simulations and experiments were conducted within each consortium organization to meet specific NRA objectives. These studies were focused on the conflict detection and resolution in NextGen, development of metrics for SA and workload in NextGen, application of the metrics to NextGen airspace environments, and the evaluation of NextGen concepts of operation for separation assurance.

#### ***4.1.1 Conflict Detection with NextGen Flight-Deck Tools***

An airside part-task study was designed and run individually at NASA Ames' FDDRL and three consortium laboratories: CSULB, CSUN, and Purdue. Flight crew responses to ground-side automation-derived conflict resolutions were evaluated under three flight-deck decision-aiding modes: automated aiding, interactive aiding, and manual resolution. In the automated aiding condition, pilots executed all resolutions generated by the automation. In the interactive condition, automation suggested a maneuver, but pilots had the choice of accepting or modifying the provided resolution. In the manual condition pilots generated resolutions independently. Pilots' acceptability of different types of conflict resolutions provided by the automation (vertical and horizontal) at different ranges (near and far) from ownship was measured. Pilot SA was also determined for each of the flight-deck decision-aiding modes. Findings from this study were summarized in Dao et al. (2009) and Battiste et al. (2008).

Conflict resolutions created either by the automation or by flight crews were safe; all resolutions maintained a separation distance greater than 5 nm. Crews rated approximately 30% of automated resolution as problematic and reported that they would seek ATC input. However, when allowed to modify automated resolutions with flight-deck route-planning tools, the crews wanted to consult with ATC on approximately 8% of the resolutions. Finally, crews reported that the decision to accept, reject, or modify an automated resolution is a complex and situation-dependent decision. When close to TOD they generally preferred to descend, but when 500 nm or more from TOD they generally preferred to climb. Situation awareness was measured with probe questions using a technique that was a combination of online- and freeze-probe methods. SA was higher in the manual- and interactive-aiding conditions compared with the automated condition, suggesting that pilots had higher SA when they were actively engaged in the conflict resolution task. It was also shown that pilots were more comfortable reviewing automated conflict resolutions, as well as modifying those resolutions before execution, compared to simply executing the resolution sent to them by the automated system.

#### ***4.1.2 Metrics for Situation Awareness and Workload***

We performed several simulations to develop tools and methods for evaluating NextGen ATM concepts in terms of operator SA, workload, and performance, and the impact of these factors on



system safety and performance. Although each simulation involved both ATCs and pilots, only one operator role was evaluated in each study. In each study we investigated the validity, reliability, sensitivity and diagnosticity of workload and SA probe latencies and accuracy.

Strybel, Vu, Kraft, and Minakata (2008) compared two methods of SA assessment with easy and hard self-spacing scenarios: a freeze-probe technique in which the scenario is frozen and pilots are administered a battery of SA questions, and an online-probe technique in which SA questions are administered while pilot is engaged in the primary task (flying). Performance was assessed with the mean and standard deviation of the indicated air speed (IAS), and number of missed ATC instructions. Freeze-Probe accuracy was marginally correlated with IAS variability, and online probe latency was significantly correlated with both IAS variability and missed ATC instructions. Moreover, a significant correlation between post-scenario NASA TLX and SPAM ready Latency was obtained, which confirmed the assumption regarding the relationship between ready latency and workload. A second simulation provided additional support for the diagnostic capability of online probes (see Section 4.2).

The validity and diagnosticity of the online probe technique for ATCs was demonstrated in three part-task simulations. Strybel, Minakata, Nguyen, Pierce, and Vu (2009) examined the relative effectiveness of online questions designed to measure the types of processing required (recall, comprehension), time frame (present, future), and information/task content (sector status, conflicts, and command/communication). Both experienced (retired) ATCs and student ATCs were tested. The best types of probe questions queried operators about future conflicts and were in multiple-choice format. Latencies for probe questions that addressed conflicts significantly accounted for the variance in task performance measures (loss of separation [LOS], average vertical distance, and number of traffic advisories) related to safety.

Bacon et al. (2011) examined SA, workload, and performance of retired ATCs and student ATCs in a simulation of mid-term NextGen airspaces. Scenarios differed in the percentage of equipped (DataComm, ADS-B) aircraft. ATCs could manage equipped aircraft with NextGen tools (DataComm, conflict probe, and a trial-planner). Conflict alerts were provided only for conflicts between two equipped aircraft. To obtain an overall measure of ATC performance, each scenario run was recorded, and ATC performance was rated by three expert controllers using a modified FAA Air Traffic Selection and Training (AT-SAT) Over-the-Shoulder Rating form. The modifications allowed for ratings regarding the use of DataComm. Experienced ATCs resolved more non-alerted conflicts (fewer losses of separation) than student ATCs. Experts showed lower workload (shorter ready latencies) and higher SA (lower SA probe latencies) than students, especially for probes relating to conflict queries. SA probe latency and workload (ready) latency significantly accounted for variance in three AT-SAT Rating Dimensions: “Maintaining Attention and Situation Awareness,” “Maintaining Separation” and “Overall performance.” These findings provided additional evidence for the validity of an online SA and workload probe method.

Strybel et al. (2011) examined SA, workload, and performance of ATCs when the mixture of equipped and unequipped aircraft changed *within* a scenario and the change was accompanied by an increase in traffic, thus replicating a situation in which the percentage of equipped aircraft changes during an ATC’s work shift. ATC workload increased in the second half of the scenario presumably because of the increase in traffic. The number of LOSs between non-alerted aircraft was affected only by the number of conflicts. Other measures of ATC performance suggested that the strategies used for separating aircraft changed as a function of equipage change: When the percentage of equipped

aircraft increased in the second half of the scenario, the mean vertical separation between aircraft increased and the mean lateral separation decreased, compared with scenarios in which the percentage of equipped AC either decreased in the second half or remained constant. Moreover, SA of sector status information decreased (probe latencies increased) in the second half of scenarios in which the percentage of equipped aircraft decreased suggesting that SA was lower when an increase of unequipped aircraft was introduced into the scenario.

In summary, our work on metric development and evaluation, specifically with the online probe technique, can be summarized as follows:

- Situation awareness probe latencies are related to performance outcomes (LOS, conflict resolution time) that affect separation assurance for pilots and ATCs.
- Situation awareness probe latencies for pilots are sensitive to changes in responsibility for separation assurance and changes in scenario difficulty brought about by weather. Workload probe latencies were unaffected by changes in responsibility for traffic separation. However, pilot workload increased throughout the descent phase, and reached a peak when queried before the CHRCL (outer marker) waypoint (directly before landing).
- Situation awareness probe latencies for ATCs are sensitive to scenario manipulations such as equipage, and number of conflicts. Probe latencies were shown to discriminate between student and expert performance in mixed equipage environments, consistent with expert AT-SAT ratings of overall performance, maintaining separation and maintaining attention and SA. Probe latencies for sector status information increased when the percentage of equipped aircraft increased, but latencies for conflict information was unchanged, suggesting that only awareness of status information was reduced when the percentage of equipped aircraft was reduced.

#### **4.1.3 Alternative Approach to Situation Awareness Measurement and Validation: A Set Theoretic Framework**

Landry and Surakitbanharn (2011) proposed a framework for assessing the relationship between SA and performance based on identifying information requirements for good performance, and measuring operator recall of these using a freeze probe technique such as the Situation Awareness Global Assessment Technique (SAGAT). Moreover, once information requirements are known, it should be possible to identify a “mapping function” that mathematically describes the relationship between performance and recall of required information. If mapping functions can be found that relate performance to recall using SAGAT, then the value of SA for that aspect of performance can be validated.

**Framework:** The framework assumes that certain knowledge is necessary to properly perform a task, and that we can model the set of all such elements of knowledge as the “target set,” as shown in Equation (1).

$$_T K = \{ {}_T K_1, {}_T K_2, K, {}_T K_n \} \quad (1)$$

The “actual” set of knowledge available to the person(s), i.e., that person’s SA, is shown in Equation (2). (The definition of “available” is non-trivial, but is simplified here to mean “recallable”).

$$_{SA} K = \{ {}_{SA} K_1, {}_{SA} K_2, K, {}_{SA} K_m \} \quad (2)$$

A mapping function  $f_{C_i}$  that relates a general set of knowledge  $K$  to some performance criterion relates the effect on the performance criterion of possessing  $K$ . For example, if one of the elements of SA is that my building is on fire, where the performance criterion is the probability I would evacuate, that probability of evacuating would be higher than if I did not possess that knowledge.

We then define subsets  ${}^q_T K \subset {}_T K$  and  ${}^r_T K \subset {}_T K$  such that:

$$\exists C_i \text{ s.t. } f_{C_i}({}_T K) > f_{C_i}(\neg K), \forall \neg K \cap {}_T K = \emptyset \quad (3)$$

$$\exists {}^q_T K \text{ s.t. } f_{C_i}({}^q_T K) \geq f_{C_i}({}^r_T K), \forall r \neq q \quad (4)$$

where:

$$f_{C_i}(K) = C_i \quad (5)$$

Equation (3) states that there must exist some performance criterion  $C_i$  such that performance given the knowledge from the target set is better than if no knowledge from the target set is available. Equation (4) states that there exists some subset of the target set that results in as good as, if not better, performance than any other subset.

Landry argues that *unless (3) is true, situation awareness has no value as a construct*. That is, if it is possible to achieve all performance criteria without the need to possess at least one particular and identifiable set of knowledge, SA is not a useful concept. It is possible that such a set is non-exclusive—there may be multiple identifiable sets, where any one of those sets is capable of providing the best performance; it is only necessary that these sets provide better performance than other sets. An important conceptual implication of this framework is that it makes the concept of SA falsifiable. If there are no performance criteria for which identifiable sets of knowledge improve performance, then SA has no validity.

A flight simulator experiment was run in which particular aspects of performance, for which a target set of information and a mapping function was defined. The purpose of the experiment was, in part, to validate or invalidate such mapping functions. That is, this experiment was primarily designed to exercise the framework rather than to test the particular relationships identified. Eighteen pilot participants flew five profiles in which general performance data was collected, as well as their performance on a particular “focus event.” For each of these events, a target set of information and mapping function was identified.

Half of the pilots underwent SAGAT probes during the trials, with the other half acting as a control to ensure that SAGAT provided neither an interruption effect nor a tip-off effect. The mapping functions served as a predictor of performance based on a SAGAT response to a particular question. SAGAT produced neither a significant tip-off nor interference effect. Overall pilot performance at the SAGAT queries was slightly below 50%, as was performance at the focus events. The data, in particular the post-hoc questionnaires, have so far suggested that the mapping functions are invalid. (The ability to invalidate a mapping function is useful in that it demonstrates the capability of the method to eliminate incorrect mapping functions.) Specifically, although the events were chosen for their simplicity of mapping, it appears that the mapping is more complex and that “inverse” mappings are largely inaccurate. Additional data analysis is being conducted to try to define accurate mapping functions which can then be verified in future experiments.

## 4.2 Distributed Air-Ground Simulations

A series of distributed air-ground simulations were run during the period of the NRA. These involved simulation roles being played by two or more member organizations. Scenarios for each distributed simulation conducted as part of the NRA were based on sectors in Kansas City Center (ZKC) and Indianapolis Center (ZID), with participant pilots flying en route, arrival and approaches to Louisville International Airport (SDF), while avoiding weather and managing spacing, as shown in Figure 2.



*Figure 2. Simulated airspace for distributed air-ground simulations.*

### 4.2.1 Trajectory Oriented Operations with Limited Delegation during Convective Weather (TOOWiLDx) Simulation Demonstrations

FDDRL led two simulation demonstrations in 2008 that explored flight-crew-based arrival management in the context of convective weather during en route and arrival operations. We examined whether pilot performance was affected by cockpit weather display type (current-day radar vs. 3D CSD). For this project, the simulation network consisted of two consortium facilities (FDDRL and CSULB). Participant pilots were located at FDDRL; ATC confederates were located at CSULB CHAAT. This demonstration was used to design two distributed simulations in 2010.

### 4.2.2 Evaluation of Automated Spacing Support Tools for Interval Management Operations under Hazardous Weather Conditions

Planning currently underway for future airspace management assumes that flight decks will play an increased role in managing the intervals between ownship and a lead aircraft when approaching an airport. In this study, pilots were asked to achieve a specific time-in-trail while flying an arrival into the SDF airport. Shortly before reaching their top of the descent, pilots were responsible for avoiding weather. A spacing tool calculated airspeeds designed to achieve the desired time in trail at the final approach fix. Pilots were exposed to four experimental conditions which varied in how strictly the pilots were to follow these calculated speeds, and whether these speeds had to be entered into the autopilot manually. Giving the pilots more discretion had little effect on the final spacing interval. However, when pilots were required to enter speeds into the system manually, they were less accurate and failed to meet altitude restrictions significantly more often. Moreover, requiring the pilots to manually enter speeds into the system frequently led to poorer energy management and higher spacing interval errors at the final approach fix, even in the conditions where pilots were instructed to strictly follow speed guidance. This finding was traced to poorer compliance with the automated speed guidance, lack of awareness of this poor compliance, and insufficient awareness of the energy state of the aircraft. These results suggest that some form of energy guidance may be needed to augment interval management. To do this, recommendations were made for integrating the spacing interval management automation with near-term and far-term energy management systems. While

these results may not always generalize to alternative spacing implementations, one should not assume that pilots manually closing the loop on automated commands can perform as well as a fully automated system. For additional details regarding this simulation see (Dao et al., 2010; Johnson et al., 2010).

#### **4.2.3 Situation Awareness with Trajectory Oriented Operations in Weather (SAWTOOth)**

A multi-participant distributed simulation experiment was run to examine the robustness of interval management during continuous descent approaches (CDAs) along the CBSKT 1 Arrival into SDF. Eight experimental pilots started the scenario in an en-route phase of flight and were asked to avoid convective weather while performing merging and spacing tasks along with a CDA into SDF. Two controllers managed the sectors through which the pilots flew, with one managing a sector that included the Top of Descent (ZKC-90), and the other managing a sector that included the merge point for arrival (ZID-91) into SDF. We determined the impact of changes in responsibility for separation assurance on the workload, SA, and performance of pilots and ATCs. Three plausible strategies for separation assurance were simulated and evaluated.

*Concept 1: Pilot Primary.* Pilots flying equipped aircraft were given the primary responsibility for separation assurance between ownship and all other aircraft. Equipped aircraft had on-board conflict alerting, a route assessment tool (RAT), and auto-resolver tool. ATC was responsible for resolving conflicts between unequipped aircraft and all conflicts with experimental aircraft on their CDA. The human ATC was equipped with conflict alerting, a trial planner, and auto-resolver tool. The ground-based auto-resolver agent had no responsibility.

*Concept 2: ATC Primary.* ATCs were given the primary responsibility for separation assurance. As in Concept 1, equipped aircraft had on-board conflict alerting, the RAT, and auto-resolver tool, but these were used for weather re-routing and proposing conflict resolutions. ATCs had responsibility for equipped-unequipped and unequipped-unequipped conflicts only, and for conflicts between any aircraft on a CDA. The autoresolver agent was responsible for equipped-equipped conflicts.

*Concept 3: Autoresolver Primary.* In Concept 3, the autoresolver agent was responsible for resolving most conflicts. Aircraft were not equipped with conflict alerting conflict resolution capabilities, but the RAT was available to aid re-routing for weather avoidance. Pilots had no responsibility for separation. The autoresolver agent was responsible for conflicts between equipped-equipped and equipped-unequipped aircraft. The human ATC was equipped with conflict alerting, the trial planner, and auto-resolver tool. ATC was responsible for conflicts between unequipped aircraft only, and for conflicts between any aircraft on a CDA.

In all scenarios, pilots initially engaged a spacing tool which was designed to achieve a spacing interval of 105 seconds from a designated lead aircraft at the final approach fix, and then re routed around weather. If a pilot felt that his/her weather avoidance maneuver made it unlikely that the spacing goal would be met, the pilot could request ATC to assign a new lead aircraft. Two additional variables were manipulated, weather complexity (high vs. low) and type of weather display (NextRad vs. 3D NextRad). High-complexity weather contained more weather cells, and covered more airspace. Low-complexity weather consisted of fewer weather cells.

A set of performance measures enabled us to determine the effects of changes in responsibility for traffic separation on pilots and ATCs in the experiment. However, because only two ATCs were

tested in this study, the most reliable data was obtained from pilots. We evaluated the impact of each scenario manipulation on pilot workload, SA, spacing performance, weather avoidance, and CDA profile. Some of the major findings are as follows (for more information see Vu et al., 2010a,b; Strybel et al., 2010; Ho et al., 2010).

- The SA and workload of pilots changed with concepts of operation. Pilots indicated that all concepts were workable and showed little change in workload across the three concepts. Pilots showed higher levels of awareness when they were responsible for maintaining separation with other aircraft. Although the controllers also indicated that all concepts were workable, they reported increased workload depending on concept of operation and sector.
- The online probe method for assessing pilot SA was effective in detecting changes in pilot roles and responsibilities for traffic separation. The change in pilot tasks regarding traffic separation could be determined from the response latencies for questions related to traffic conflicts. These changes in awareness could not be attributed to workload because workload probe latencies were unaffected by changes in responsibility.
- Weather perturbations can create situations in which aircraft spacing can be negatively affected regardless of whether the pilot faithfully followed the leading aircraft around weather. If pilots do not fully understand the rationale and logic of the spacing automation and its limitations, then trusting the automation to be able to resolve a spacing error (i.e., being ahead or behind schedule) to regain a lost or interrupted spacing assignment requires that pilots be highly confident in the automation.

## 5. Conclusions

Our multidisciplinary, research consortium of scientists and engineers from California State University Long Beach, San Jose State University Foundation, California State University Northridge, Purdue University, and The Boeing Company was successful in meeting the majority of our proposed NRA objectives. Because of the knowledge and experience of our members, as well as the unique approaches taken by them, we were able to work in parallel to identify SA and performance requirements brought about by anticipated changes in NextGen airspaces, develop SA and workload metrics, distributed simulation capabilities for evaluating NextGen concepts of operation, and assess the impacts of potential NextGen concepts of operations on SA, workload, and performance.

As a result of this NRA, we have gained a greater understanding of SA and its measurement, and have shared our knowledge with the scientific community: During the NRA, we published 20 technical papers, made 21 presentations at conventions, presented 6 briefings to NASA, and prepared 5 unpublished reports. Additional technical papers based on the NRA work were also published after the funding period. Our metric work improved and validated existing tools for measuring SA and workload, and the resulting probe tool we developed can be used by air traffic management scientists and engineers for assessing new concepts of operation, determining the effectiveness of automated tools, comparing different interface designs, and establishing training requirements. We also recommended a set of performance measures that will make it easier for researchers to compare results between experiments, simulations, and operational settings.

Through the success of our distributed-simulation network, we have shown how to create a flexible and cost-effective test bed for simulations and research involving current and future airspaces. This network provides a mechanism for consortium members, colleagues, and students to pursue research on other topics in air traffic management and aviation, thus enabling them to make greater contributions to the field.

## 6. Publications and Presentations Citing the NRA

### Year 1 (October 2006–September 2007)

#### **Publications**

- Battiste, V., Johnson, W. W., Johnson, N. H., Granada, S., & Dao, Q. (2007). Flight crew perspective on the display of 4D information for en route and arrival merging and spacing. In J. Jacko (Ed), *Human-Computer Interaction, Part I, HCII 2007, Lecture Notes in Computer Science 4551* ISBN: 978-3-540-73106-1. Berlin: Springer-Verlag.
- Strybel, T. Z., Vu, K.-P. L., Dwyer, J. P., Kraft, J., Ngo, T. K., Chambers, V., & Garcia, F. P. (2007). Predicting perceived situation awareness of low altitude aircraft in terminal airspace using probe questions. In J. Jacko (Ed), *Human-Computer Interaction, Part I, HCII 2007, Lecture Notes in Computer Science 4550* ISBN: 978-3-540-73104-7. Berlin: Springer-Verlag.

#### **Presentations**

- Battiste, V., Johnson, W. W., Johnson, N. H., Granada, S., & Dao, Q. (2007, July). Flight crew perspective on the display of 4D information for en route and arrival merging and spacing. Paper presented at *Human Computer Interaction International 2007 Conference*. Beijing, China.
- Strybel, T. Z., Vu, K.-P. L., Dwyer, J. P., Kraft, J., Ngo, T. K., Chambers, V., & Garcia, F. P. (2007, July). Predicting perceived situation awareness of low altitude aircraft in terminal airspace using probe questions. Paper presented at *Human Computer Interaction International 2007 Conference*. Beijing, China.
- Strybel, T. Z., Vu, K.-P. L., Battiste, V., & Johnson, W. W. (2007, November). Conducting Distributed Simulations Over the Internet. Poster accepted for presentation at the *37<sup>th</sup> Annual Meeting of the Society for Computers in Psychology*. Long Beach, CA.

#### **Unpublished Reports**

- Strybel, T. Z., Vu, K.-P. L., Battiste, V., Dao, A. Q., Dwyer, J. P., Ho, N., & Landry S. (2007). NRA Year 1 Report.

#### **Briefings**

- Strybel et al. (2006). Metrics for Operator Situation Awareness, Workload and Performance in Automated Separation Assurance Systems *Kickoff Briefing*, January, 2007.
- Strybel et al., (2007). Metrics for Operator Situation Awareness, Workload and Performance in Automated Separation Assurance Systems. *Presented at the NASA Ames Technical Interchange Meeting*, March, 2007

## **Year 2 (October 2007–September 2008)**

### **Publications**

- Pierce, R., Strybel, T., & Vu, K.-P. L. (2008). Comparing situation awareness measurement techniques in a low fidelity air traffic control simulation. *Proceedings of the 26th International Congress of the Aeronautical Sciences (ICAS)*. Anchorage, AS.
- 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 52nd Human Factors and Ergonomics Society Annual Meeting*. New York, NY.
- 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 52nd Human Factors and Ergonomics Society Annual Meeting*. New York, NY.
- Battiste, V., Johnson, W. W., Dao, A.-Q., Brandt, S., Johnson, N., & Granada, S. (2008). Assessment of Flight Crew Acceptance of Automated Resolutions Suggestions and Manual Resolution Tools. *Proceedings of the 26th International Congress of the Aeronautical Sciences (ICAS)*. Anchorage, AS.

### **Presentations**

- Pierce, R., Strybel, T., & Vu, K.-P. L. (2008). Comparing situation awareness measurement techniques in a low fidelity air traffic control simulation. *Presented at the 26th International Congress of the Aeronautical Sciences (ICAS)*. Anchorage, AS.
- Pierce, R., Vu, K.-P. L., Nguyen, J., & Strybel, T. (2008). The relationship between SPAM, workload, and task performance on a simulated ATC task. *Presented at the 52nd Human Factors and Ergonomics Society Annual Meeting*. New York, NY.
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- Battiste, V., Johnson, W. W., Dao, A.-Q., Brandt, S., Johnson, N., & Granada, S. (2008). Assessment of Flight Crew Acceptance of Automated Resolutions Suggestions and Manual Resolution Tools. *Presented at the 26th International Congress of the Aeronautical Sciences (ICAS)*. Anchorage, AS.
- Martin, P., Ho, N. and Berson, B. (2008) Identification of shared situation awareness information requirements for NGATS concepts. *Presented at Human Factors and NextGen; The Future of Aviation*, Arlington TX, May 2008.

### **Unpublished Reports**

- Dao, A-Q & Strybel, T.Z. (2008). Demonstration of distributed simulation capabilities. *Unpublished Report Prepared for the Consortium for the Study of Situation Awareness*.
- Dwyer, J.D. & Landry, S. (2008). Roles and responsibilities conceptualizations for next generation air transportation system. *Unpublished Report Prepared for the Consortium for the Study of Situation Awareness*.
- Strybel, T. Z., Vu, K.-P. L., Battiste, V., Dao, A. Q., Dwyer, J. P., Ho, N., & Landry S. (2008). *NRA Year 2 Report*.



## **Briefings**

Strybel et al. Metrics for operator situation awareness, workload and performance in automated separation assurance systems: year 2 progress report. Presented to Todd Farley and FDDRL, October, 2008.

## **Year 3 (October 2008–September 2009)**

### **Publications**

- Dao, A. Q., Brandt, S. L., Battiste, V., Vu, K.-P. L., Strybel, T. Z., & Johnson, W. W. (2009). The impact of automation assisted aircraft separation on situation awareness. *Human Interface, Part II, HCII 2009, Lecture Notes in Computer Science*, 5618, 738-747.
- Dwyer, J. P., & Landry, S. (2009). Separation assurance and collision avoidance concepts for the Next Generation Air Transportation System. *Human Interface, Part II, HCII 2009, Lecture Notes in Computer Science*, 5618, 748-757.
- Ho, N. T., Martin, P., Bellissimo, J., Berson, B. (2009). Information requirements and sharing for NextGen function allocation concepts. *Human Interface, Part II, HCII 2009, Lecture Notes in Computer Science*, 5618, 776-785.
- Ligda, S. V., Johnson, N., Lachter, J., & Johnson, W. W. (2009). Pilot confidence with ATC Automation using cockpit situation display tool in a distributed traffic management environment. *Human Interface, Part II, HCII 2009, Lecture Notes in Computer Science*, 5618, 758-775.
- Strybel, T., Minakata, K., Nguyen, K., Pierce, R., & Vu, K.-P. L. (2009). Optimizing online situation awareness probes in air traffic management tasks. *Human Interface, Part II, HCII 2009, Lecture Notes in Computer Science*, 5618, 845-854.
- 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.

### **Presentations**

- Dao, A. Q., Brandt, S. L., Battiste, V., Vu, K.-P. L., Strybel, T. Z., & Johnson, W. W. (2009). The impact of automation assisted aircraft separation on situation awareness. *Presented at HCI International*, San Diego, CA, July, 2009.
- Dwyer, J. P., & Landry, S. (2009). Separation assurance and collision avoidance concepts for the Next Generation Air Transportation System. *Presented at HCI International*, San Diego, CA, July, 2009.
- Ho, N. T., Martin, P., Bellissimo, J., Berson, B. (2009). Information requirements and sharing for NGATS function allocation concepts. *Presented at HCI International*, San Diego, CA, July, 2009.
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- Vu, K.-P. L., Minakata, K., Nguyen, J., Kraut, J., & Raza, H. (2009). Situation awareness and performance of students versus experienced air traffic controllers. *Presented at HCI International*, San Diego, CA, July, 2009.

### **Unpublished Reports**

Strybel, T. Z., Vu, K.-P. L., Battiste, V., Dao, A. Q., Dwyer, J. P., Ho, N., & Landry S. (2007). *NRA Year 3 Report*.

### **Briefings**

Strybel, T.Z. & Johnson, W. Situation awareness with trajectory oriented operations in weather (SAWTOOth): Design Review. *Presented to NASA Ames* March, 2009.

### **Year 4 (October 2010–January 2011)**

#### **Publications**

- Dao, A-Q.V., Lachter, J., Battiste, V., Brandt, S.L., Vu, K-P.L., Strybel, T.Z., Ho, N., Martin, P., & Johnson, W.W. (2010). Automated spacing support tools for interval management operations during continuous descent approaches. In *Proceedings of the 54<sup>th</sup> Annual Meeting of the Human Factors & Ergonomics Society*, San Francisco, CA: Human Factors Society.
- Ho, N., Johnson, W., Martin, P., Lachter, J., Dao, A.-Q., Brandt, S & Battiste, V. (2010). Pilot response to off-nominal conditions in merging and spacing operation. *Proceedings of the 29th Digital Avionics Systems Conference*. Salt Lake City, Utah: IEEE.
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- Vu, K-P. L., Strybel, T. Z., Battiste, V. & Johnson, W. (in press). Factors Influencing the Decisions and Actions of Pilots and Controllers in Three Plausible NextGen Environments. In R. W. Proctor and S. Nof. Y. Yih, (Eds.) *Cultural Factors in Decision Making and Action*. CRC Press.

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- Dao, A-Q.V., Lachter, J., Battiste, V., Brandt, S.L., Vu, K-P.L., Strybel, T.Z., Ho, N., Martin, P., & Johnson, W.W. (2010). Automated spacing support tools for interval management operations during continuous descent approaches. *Presented at the 54<sup>th</sup> Annual Meeting of the Human Factors & Ergonomics Society*, September 2010, San Francisco, CA.
- Ho, N., Johnson, W., Martin, P., Lachter, J., Dao, A.-Q., Brandt, S & Battiste, V. (2010). Pilot response to off-nominal conditions in merging and spacing operation. *Presented at the 29th Digital Avionics Systems Conference, October, 2010*, Salt Lake City, Utah.

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### **Post-Award Period Publications Citing Work Supported by the NRA**

- Bacon, L.P., Strybel, T.Z. Vu, K.-P.L., Kraut, J.M., Nguyen, J.H., Battiste, V., & Johnson, W. W. (2011) Situation awareness, workload and performance in midterm NextGen: Effect of variations in aircraft equipage levels between scenarios. *Proceedings of the 2011 International Symposium on Aviation Psychology* (pp. 32-37), Dayton, OH.
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<b>14. ABSTRACT</b> A research consortium of scientists and engineers from California State Univ. Long Beach, San Jose State Univ. Foundation, California State Univ. Northridge, Purdue Univ., and the Boeing Company was assembled to evaluate the impact of changes in roles and responsibilities and new automated technologies, being introduced in the Next Generation Air Transportation System, on operator situation awareness and workload. To meet these goals, consortium members performed systems analyses of NextGen concepts and airspace scenarios and concurrently evaluated SA, workload, and performance measures to assess their appropriateness for evaluations of NextGen concepts and tools. The following activities and accomplishments were supported by the NRA: a distributed simulation, metric development, systems analysis, part-task simulations, and large-scale simulations. As a result of this NRA, we have gained a greater understanding of situation awareness and its measurement, and have shared our knowledge with the scientific community. This network provides a mechanism for consortium members, colleagues, and students to pursue research on other topics in air traffic management and aviation, thus enabling them to make greater contributions to the field.					
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