RUNNING HEAD: DECISION AND ACTIONS OF PILOTS AND CONTROLLERS

Factors Influencing the Decisions and Actions of Pilots and Air Traffic Controllers in Three Plausible NextGen Environments

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Abstract

In the current air traffic management (ATM) system, pilots and air traffic controllers have well-established roles and responsibilities: pilots fly aircraft and are concerned with energy management, fuel efficiency, and passenger comfort; controllers separate aircraft and are concerned with safety and management of traffic flows. Despite having different goals and obligations, both groups must be able to effectively communicate and interact with each other for the ATM system to work. This interaction will become even more challenging as traffic volume increases dramatically in the near future. To accommodate this increase, by 2025 the national air transportation system in the U.S. will go through a transformation that will modernize the ATM system and make it safer, more effective, and more efficient. This new system, NextGen, will change how pilots and controllers perform their tasks by incorporating advanced technologies and employing new procedures. It will also distribute responsibility between pilots, controllers and automation over such tasks as maintaining aircraft separation. The present chapter describes three plausible concepts of operations that allocate different ATM responsibilities to these groups. We describe how each concept changes the role of each operator and the types of decisions and actions performed by them.

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The word *culture* is often used to refer to shared ways of thinking and behaving among members of any group (Kurosu & Hashizume, 2009). Cultures are also made up of subgroups, each with its own unique roles and obligations. Differences can thus arise between subgroups, as each one will have its own shared values, roles, and responsibilities. Cultures can change through time as the roles and responsibilities of the subgroups are altered. In this chapter, we explore differences between two professional groups of human operators in the air traffic management (ATM) system -- pilots and controllers. We examine how their interactions change when the current modes of operation are altered such that the pilots and controllers have to share responsibility for separation assurance with each other or with automation.

Air transportation is one of the safest modes of transportation, resulting in only 2 fatal accidents in 2008 for U.S. Air Carriers (operating under 14 CFR 121; National Transportation Safety Board - Aviation Branch, 2010) compared to 34,017 motor vehicle fatal crashes (National Highway Traffic Safety Administration, 2010) for that same year. Although the topic of safety is a concern to all operators in the ATM system, context and occupational culture are factors that influence decision-making and risk perception of operators. Mearns, Flin, and O'Connor (2001) studied pilots engaging in crew resource management training and noted, "Sources of conflict arise where different professional or occupational cultures clash in the view of how the workload should be managed, who should make decisions or how the situation should be resolved" (p. 378). This quote captures the importance of examining the roles and responsibilities of operators within a system. Understanding how differences in professional cultures influence operator decision-making and action is even more important when new technologies or procedures are

being introduced because these technologies change the roles and responsibilities of the operators employing them.

The impressive safety record of the National Airspace System is achieved in the current-day ATM system through a centralized system that is ground-based and human-intensive. The primary operators in this system are those of air transport pilots (ATPs) and air traffic controllers (ATCs). As shown in Table 1, the roles and responsibilities, activities, primary displays and training requirements for the two types of operator are very different. ATCs are responsible for the safe and expeditious movement of traffic. ATCs are trained on flight rules, air traffic management procedures, weather, communications and operational procedures that allow them to plan the movement of aircraft and transmit instructions to ATPs for carrying out their clearances. Because of the lateral separation precision needed to do their job, ATCs rely on a two-dimensional radar display that is best suited to show aircraft locations in their airspace. ATPs, on the other hand, are responsible for transporting passengers and cargo in a safe and expeditious manner. ATPs process instructions received from the ATC and act on them. The primary flight deck displays are designed for vertical profile planning, fuel management, and meeting flight scheduling requirements (Kerns, 1999). ATP training involves basic airmanship, aircraft systems operation, and navigation. As this brief description indicates, the primary operators in the National Airspace System use different procedures to accomplish their tasks, and the type of information and training they are given are not designed to achieve common tasks. Note also that the primary means of communication and coordination is through voice. A formalized language (“standard phraseology”) was developed for this purpose, but in busy traffic situations, voice communications may not follow these standard operating procedures.

Air Traffic Controller	Air Transport Pilot
Roles and Responsibilities • Responsible for safe and expeditious movement of air traffic • Pivotal role is planning movement of air traffic and transmitting instructions to carry out plan	**Roles and Responsibilities** **Managing Flight Deck Systems to:** • Transport people and cargo in a safe, efficient manner • Role is processing controller advisory information, accepting and acting on controller instructions • Managing relative to environmental conditions
Primary Display Characteristics • Two dimensional display with directional traffic symbols with data tags (speed and altitude) for 3-dimensional radar separation procedures and representations of vector solutions to separation and ascending/descending spacing profiles	**Primary Display Characteristics** • Flight management and display systems support lateral and vertical profile planning in all phases of flight, fuel management, system assessment and flight schedule management
Major Training Topics • Basic flight, weather • Flight rules, traffic control procedures and management, and sector specific information	**Major Training Topics** • Ground school basic flight (Visual Flight Rules, Instrument Flight Rules, Parts 91 & 121) • Basic airmanship, aircraft systems operation, navigation, weather

Table 1. Differences between current-day air traffic controllers and air transport pilots in roles and responsibilities, primary tasks and primary displays, and training requirements (adapted from Kern, 1999; Pohlman & Fletcher, 1999).

The Next Generation Air Transportation System (NextGen) is a nation-wide transformation of the ATM system in the U.S. that will modernize the system and increase its capacity (Joint Planning and Development Office, JPDO, 2010). To achieve these goals, NextGen will use advanced technologies such as (a) controller-pilot datalink communications, (b) cockpit displays of traffic, weather, and terrain, (c) conflict alerting and resolution tools, and (d) semi-autonomous automated agents. It will also involve adopting new procedures and operating concepts such as trajectory-oriented operations and performance-based navigation

procedures that will optimize the traffic flow (see, e.g., National Aeronautics and Space Administration, NASA, 2007). NextGen is expected to benefit everyone. The Federal Aviation Administration (FAA, 2010) estimates that by 2018, the NextGen program will reduce delays by 21%, save 1.4 billion cumulative gallons of fuel and eliminate 14 million tons of CO_2 emissions. However, for NextGen to fulfill its promise, its concepts of operation and technologies must be evaluated for their effect on human operator performance, as these operators must interact safely and effectively within the system.

One important cultural change expected from NextGen is distributed decision-making. Critical decisions that are currently the responsibility of the ATC will be made at a more local level by the operator with the most dependable information. Coordination between all operators in the system will be facilitated by real-time and shared information regarding traffic, weather, and aircraft intent. Because of the revolutionary changes being brought about by NextGen, it is how operator performance will change with the adoption of specific concepts and technologies need to be determined. Current-day ATC performance is measured in terms of safety and efficiency (e.g., Rantanen, 2004). Safety metrics include number of incidents and violations (e.g., losses of separation) and accidents (e.g., fatal vs. non fatal); efficiency metrics include average delays, and distance/time travelled per aircraft (e.g., Pierce, Vu, & Strybel, 2008). ATP performance is often measured by aircraft state (e.g., airspeed, descent rate, and glide slope; Gawron, 2000). However, both ATC and ATP performance is affected by the interaction of system and cognitive factors, and the cognitive constructs must be measured to evaluate how they are affected by the potential NextGen concepts of operation. Two of these critical operator cognitive factors are situation awareness and workload.

Situation awareness can be defined as an operator's "perception of the elements in the environment…the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995, p. 36). Situation awareness is particularly important to operators who work in a complex system where the environment is constantly changing and where there is a great deal of information to keep track of in order to anticipate future events (Durso & Gronlund, 1999). Poor situation awareness can lead to decisions that have fatal consequences. For example, Rodgers, Mogford, and Strauch (2000) examined ATC errors and found that the origins of many of the errors were in failures of situation awareness (see also Jones & Endsley, 1996). Although most of these studies are of pilot error in the U.S.A., failures of situation awareness have also been tied to operator error in Eastern cultures, such as India (e.g., Kumar & Malik, 2003).

Mental workload refers the cognitive demands placed on an operator relative to the operator's processing capacity (Hart & Staveland, 1988). Although situation awareness is considered to be a separate construct from mental workload, it is related to workload (Pierce, Strybel, & Vu, 2008): changes in workload can affect situation awareness and vice-versa. Jentsch, Barnett, Bowers, and Salas (1999), for example, searched NASA's Aviation Safety Reporting System (ASRS) database for aviation incidents in which loss of situation awareness was known to be a contributing factor. They identified 221 such cases and found that in 142 of them, the captain was flying the aircraft and in 79 the first officer was flying the aircraft. Jentsch et al. (1999) also found that the captain exhibited lower situation awareness and made more errors when s/he was flying the aircraft during critical periods compared to when the first officer was flying the aircraft. They attributed the captain's lower level of situation awareness to the additional workload produced by flying the plane while simultaneously engaging in critical,

decision-making activities. In other words, the captain's capacity to engage in cognitively demanding, decision-making tasks was reduced by the increase in workload associated with flying the plane.

Because NextGen will employ automation to help operators perform tasks that they may not have the capacity to do currently (see Prevot et al., 2009), the effect of automation on operator situation awareness, and workload must be evaluated. The costs and benefits of automation have been explored in aviation and other task domains (see Parasuraman & Wickens, 2008). Automation can reduce operator workload and allow the operator to take on additional roles and responsibilities; however, complete automation can also decrease the operators' decision-making capabilities by reducing their situation awareness. It is known that humans do not perform well on vigilance tasks (Mackworth, 1969), making them poor monitors of automation, yet, automation often puts the human operator in a supervisory or fail-safe (i.e., back-up) role in which the operator is essentially performing a vigilance task (e.g., JPDO, 2007). Moreover, early work on NextGen automation concepts has shown that attempts to reduce workload may have the opposite effect. For example, in a study of pilot acceptance of automated conflict resolutions in 3X traffic density, Battiste et al. (2008) found that pilots wanted to contact a human ATC to discuss and clarify 30% of the auto-resolutions sent to the flight deck. This number of inquiries would greatly exceed the controllers' capability, especially if put in a back-up mode. These results suggest that automating conflict resolutions for reducing ATC workload could create more workload if pilots are not able to interact with a human operator.

Although, separation responsibility is currently allocated to the controller, in NextGen pilots can also play a critical role in ATM decision-making. Dao et al. (2009) examined the effect of automation level on pilot situation awareness in a laboratory task. Pilots were presented

short, 3-minute scenarios in which their aircraft was in conflict with another aircraft and were asked to perform a conflict resolution task with or without the support of automation. On trials in which automation was available, pilots were able to modify proposed automated clearances in one block of trials, but only execute the automated clearances in another block. After resolving the conflict, pilots were probed for situation awareness. With the scenario frozen, but all displays still visible and active, pilots were asked questions relating to the scenario (i.e., about past events, current information displayed, or about future states if the scenario was to be resumed). Dao et al. found that situation awareness was lowest in the fully automated condition in which pilots evaluated and executed automated clearances for conflict resolution, regardless of the acceptability of the resolution. Situation awareness was higher when pilots created resolutions to the conflicts on their own or when they interacted with automation to modify initial clearances suggested by automation. These findings suggest that automation tools used to aid decision-making in conflict resolution, i.e., that leave the pilots in the loop, may be more effective in maintaining pilot situation awareness than the implementation of automated clearances.

In the remainder of the chapter, we provide an overview of a distributed air-ground simulation study that examined changes in performance, workload, and situation awareness as a function of three strategies for traffic-separation. These strategies differed in the operator most responsible for separation, either human pilots, human air traffic controllers, or automation, in a high-density traffic environment. It has been shown that current-day air traffic controllers are not likely to be able to manage this level of traffic density (3x) without alleviation (Prevot et al., 2009). Thus, the three concepts were chosen to partially reallocate separation responsibility to pilots or to automation. In Concept 1, responsibility was shared between pilots and controllers,

with pilots assigned the majority of conflicts. In Concepts 2 and 3, responsibility was shared between controllers and automation, with more conflicts allocated to controllers in Concept 2 and more to automation in Concept 3. It should be noted that these concepts of operation are not necessarily being endorsed by any agency as promising NextGen operational concepts. Rather, they were selected because they alter the decision-making characteristics of the pilots and controllers, and should therefore result in changes in performance, workload, and situation awareness.

All scenarios for the three concepts required the pilots we were testing to accomplish two tasks. First, the pilots had to develop a trajectory modification that would take them around enroute weather systems that lay between them and their arrival airport. Second, pilots were required to engage in a spacing task, where they had to follow a designated lead aircraft by 105 seconds at the merge point and to maintain that interval to the runway. Because spacing instructions were given before pilots modified their flight plans to go around weather, these modifications could make it impossible to space behind their originally assigned lead aircraft. Therefore, pilots sometimes needed to make subsequent requests to be re-sequenced (assigned a new lead aircraft) by the controllers who were responsible for re-sequencing the aircraft. Because separation responsibility for experimental aircraft was allocated to pilots in Concept 1 and to automation in Concepts 2 and 3, we were able to examine how controllers responded to these requests as well as assess the controller’s awareness of the aircraft making these requests.

Simulation Environment and Operator Tools

The simulation was conducted over the Internet, distributed across four research labs: the Flight Deck Display Laboratory (FDDRL) at NASA Ames Research Center, the Center for Human Factors in Advanced Aeronautics Technologies (CHAAT) at California State University

Long Beach (CSULB), the Systems Engineering Research Laboratory (SERL) at California State University Northridge, and the Human Integrated Systems Engineering Laboratory (HISEL) at Purdue University. Participant controllers were located at CSULB, and participant pilots were located at NASA Ames. Confederate pilots were located at all of the sites and confederate controllers were located at CSULB.

The simulation was run using the Multiple Aircraft Control System (MACS) and Cockpit Situational Display software. MACS was developed by the Airspace Operations Laboratory at NASA Ames Research Center (see Prevot, 2002), and CSD was developed by the Flight Deck Display Research Laboratory at NASA Ames (see Granada, Dao, Wong, Johnson, & Battiste, 2005). Both MACS and the CSD can be configured to run current-day or future distributed air-ground ATM operations. Both included algorithms that supported conflict detection and manual resolutions via pilot/controller modification of flight plans. Both the CSD and MACS also incorporated an auto-resolver tool, based upon the work of Erzberger (2006), that that would automatically generate a suggested resolution upon request from the pilot or controller. Finally, the conflict detection and auto-resolution capability was the core of the ground-based auto-resolver agent, that autonomously uplinked resolutions to some of the flight decks in Concepts 2 and 3.

The simulation environment mimicked Kansas City Air Route Traffic Control Center, Sector 90, and Indianapolis Air Route Traffic Control, Sector 91, but consisted of a larger area of airspace (i.e., combining a high and super-high sector to form a super sector) to load the air traffic controller with 3 times current day traffic. Surrounding airspace was also included in the scenario (called Ghost Sectors because they were not being managed by a participant controller but by students and staff working in the CHAAT lab). Aircraft populating the simulation were

designated as TFR (Trajectory Flight Rules) or IFR (Instrument Flight Rules). TFR aircraft were never directly managed by the human controller and, depending on the concept of operation being employed, may also have had conflict alerting and resolution tools (Concepts 1 and 2) or were capable of interacting with an auto-resolver agent to negotiate flight plan changes independent of a human controller's involvement (Concepts 2 and 3). IFR aircraft were always managed by the human controller, had neither onboard conflict alerting nor the capability to interact with the auto-resolver agent. All experimental participants flew simulated desktop stations of TFR aircraft.

The controller's scope mimicked an Air Route Traffic Control Center (ARTCC) radar scope, with the active (controlled) sector highlighted. The controller radar display consisted of traffic and static weather. IFR aircraft were displayed at full brightness while TFR aircraft were low-lighted unless they were in conflict with an IFR aircraft. The weather display was static and depicted 2D Nexrad weather. Controllers were given the following advanced tools: conflict alerting (that alerts controllers about an upcoming loss of separation up to 8 minutes in advance, see Figure 1), trial planner (that provides controllers with a method of visually altering aircraft trajectory; when coupled with the conflict probe, allows controllers to create conflict-free trajectory changes within 8 minutes, see Figure 2). Controllers were also equipped with an auto-resolver tool that, at the request of the controller, brought up a suggested resolution to the conflict being probed. In Concepts 2 and 3 (to be described later), a proportion of the conflicts was delegated to an auto-resolver agent at the start of the scenario. Once it was delegated responsibility, the auto-resolver agent acted autonomously to resolve conflicts between designated aircraft (see Figure 3). Because of the high volume of traffic, several tools for alleviating controller workload were also included: autohandoff, autofrequency change, no radio

check-in for TFR aircraft (IFR aircraft performed radio checked in), and TFR radio contact only when discontinuing spacing or requesting conflict resolution (in an emergency).

Pilots flew a desktop simulator with flight deck controls similar to a Boeing 757 using the MACS interface. Pilots also interacted with the CSD (see Figure 4), which is a 3D volumetric display of traffic and weather information. The CSD provided pilots with the location of ownship and surrounding aircraft. It also allowed the pilots the capability to view the 4D trajectories of ownship and all traffic (Granada, Dao, Wong, Johnson, & Battiste, 2005). The CSD also provided a Route Assessment Tool (RAT, Figure 5), that allowed pilots to manually create flight plan changes around weather. In addition, in Concepts 1 and 2 (to be described later), pilots were given access to advanced conflict detection and resolution tools on the CSD. These included 1) a conflict probe that detected and alerted pilots of an upcoming loss of separation, and which, when coupled with the RAT, allowed pilot generated resolutions or deconflictions for traffic; and 2) an auto-resolver tool (see Figure 6) that at the request of the pilot finds a resolution to the current conflict. When possible, more than one alternative was presented to the pilot (i.e., a lateral versus vertical maneuver).

To assess situation awareness and workload, a separate touch screen tablet computer was used to administer online queries (probe questions to pilots and controllers). Administration of the probe questions followed the Situation Present Awareness Method (SPAM, Durso & Dattel, 2004). A ready prompt appeared approximately every 3 minutes. The ready query was accepted by operators when they felt that the workload was reasonable enough for them to be able to read the question (and answer it). The time to accept a ready query can be used as a measure of workload because if the operator is busy at the time of the probe, it should take him or her longer to accept the probe. Following the acceptance of the ready query, a probe question was

immediately presented that asked the operator about his/her workload (workload probe) or situation awareness (situation awareness probe). The workload probe asked the operator to "Rate your workload" on a scale of 1 (low) to 5 (high). The situation awareness probes varied in content, from information about the conflicts (e.g., Will UPS549 be in conflict with another aircraft within the next 5 minutes?), sector status/traffic or effect of weather avoidance (e.g., In which direction did your lead aircraft deviate to avoid weather?), and commands/communications (e.g. Was the last command you issued a frequency change?). If the time to accept a ready probe does in fact measure workload, we expect those times to correlate with the workload ratings given for the workload probes. The time to answer the situation awareness probes (as well as accuracy) was our measurement of operator situation awareness, with faster reaction times indicating greater situation awareness.

Concepts of Operation

In Concept 1, pilots were given the primary responsibility for separation assurance. TFR aircraft had on-board conflict alerting, the RAT, and auto-resolver tool. IFR aircraft did not have on-board conflict alerting and could not interact with the auto-resolver tool; the RAT was available for modifying Ownship's route for weather avoidance for both IFR and TFR aircraft. TFR Pilots were responsible for managing separation between TFR-TFR and TFR-IFR aircrafts (75% of the conflicts). For TFR-TFR conflicts, *Rules of the Road* were built into the system, where the burdened aircraft (i.e., the aircraft that has responsibility for moving) appeared in amber and the non-burdened aircraft appeared in blue on the CSD tool bar. For TFR-IFR conflicts, pilots of TFR aircraft were instructed to maneuver their aircraft; the IFR pilot was not responsible for resolving conflicts. The human ATC was equipped with conflict alerting, the trial planner, and auto-resolver tool. ATC was responsible for IFR-IFR conflicts and for

conflicts with any experimental aircraft on their CDA, giving the experimental arrival aircrafts priority. The auto-resolver agent has no responsibility.

In Concept 2 controllers were given the primary responsibility for separation assurance. As in Concept 1, TFR aircraft had on-board conflict alerting, the RAT, and auto-resolver tool. The IFR aircraft did not have on-board conflict alerting and were not able to interact with the auto-resolver tool. IFR pilots were able to use the RAT to modify Ownship's route for weather avoidance. TFR pilots were not responsible for managing separation, but because they have onboard alerting, TFR pilots could interact with auto-resolver agent and propose conflict resolutions for consideration by the controller/auto-resolver agent. At the beginning of the trial, the auto-resolver agent was allocated responsibility for managing TFR-TFR conflicts (25% of conflicts). The human ATC was equipped with conflict alerting, trial planner and the auto-resolver tool. ATC was responsible for TFR-IFR and IFR-IFR conflicts (75% of conflicts). For TFR-IFR conflicts, the controller was instructed to move the IFR aircraft. As in Concept 1, ATC was responsible for conflicts with any experimental aircraft on a continuous descent approach (CDA).

In Concept 3 the automation was given the primary responsibility for separation assurance. Both TFR and IFR aircraft were not equipped with on-board conflict alerting. However, the RAT tool was available to aid rerouting for weather avoidance. TFR and IFR pilots were not responsible for managing separation. At the beginning of the trial, the auto-resolver agent was allocated responsibility for managing TFR-TFR and TFR-IFR conflicts (75% of conflicts). For TFR-IFR conflicts, the auto-resolver agent was programmed to move the TFR aircraft. The human ATC was equipped with conflict alerting, the trial planner, and auto-resolver tool. ATC was responsible for IFR-IFR conflicts (25% of conflicts). In addition, ATC was

responsible for conflicts with any experimental aircraft on their CDA, giving the experimental aircraft arrival priority.

Operator Demographics and Tasks

The simulation was run over a two week period. During each week, 8 pilots and 2 controllers participated as test participants (referred to as experimental pilots/controllers). The remaining pilot and controller duties were carried out by our confederates (mainly students and staff working in the various labs; referred to as pseudo-pilots and ghost controllers). Due to some technical difficulties, though, we were not able to run all the test trials in week 1. Thus, the performance data described are only from the experimental pilots and controllers from the second week. However, because all participants from both weeks were able to experience the variety of tasks and concepts, data described from the post-experimental questionnaires and debriefing consist of comments and ratings from all participants.

For experimental pilots in Week 2, the professional position most recently held was captain by 5 of the pilots and first officer by the remaining 3. None of the participants had any prior experience with merging and spacing operations, and only 3 had flown a CDA. Four of the pilots had between 3,000-5,000 flight hours, and three had over 5,000 flight hours. All pilots had glass cockpit experience, with three having over 3,000 hours of glass cockpit experience. The experimental controllers were both retired, radar certified, ARTCC controllers. One controller had 34 years of experience, and one had 25 years of civilian center control experience.

Pilots flew and controllers managed traffic in twelve, 90-minute scenarios, each concept of operation appearing in four of the scenarios. Again, we emphasize that these concepts of operation, which allocate separation responsibility across pilots, controllers and automation, are not necessarily being endorsed by any agency for implementation as NextGen operational

concepts. They were selected, however, because they should produce measurable changes in operator performance, workload, and situation awareness. In all scenarios, experimental pilots flew arrival aircraft into Louisville International-Standiford Field (SDF) Airport under one of the three different concepts of operation. At the start of the simulation, they were assigned a lead aircraft and given spacing instructions. Prior to entering sector 90, the first active sector controlled by an experimental controller, pilots encountered convective weather and had to reroute around weather by using the RAT tool. Both controllers and pilots were asked to answer the situation awareness and workload probes.

Effect of Operational Concepts on Operator Decision-Making and Action

This section summarizes the findings from the simulation in terms of how the three concepts of operation influenced pilot and controller decision-making and action. More details regarding operator performance, workload, and situation awareness under the three concepts of operation can be found in papers by Dao et al. (2010), Ligda et al. (2010), Vu et al. (2010) and Strybel et al. (2010).

Performance

Although there were many different performance metrics that could have been analyzed as an indicator of safety (e.g., violations of separation and collisions) and efficiency (e.g., distance traveled and fuel consumption), in this chapter we focus on loss of separation (i.e., aircraft within 5 nautical miles and 1000 ft of altitude) as the safety metric of interest in evaluating pilot and controller performance. The experimental (TFR) pilots lost separation more often when they were responsible for separation of Ownship from surrounding traffic in Concept 1 (M = 0.47 LOS per run) than in Concept 2 when the human controller was responsible (M =

0.13 LOS per run), and in Concept 3 (M = 0.16 LOS per run), when the auto-resolver agent was responsible.

Cultural differences can be seen in how pilots resolved conflicts compared to controllers. Although all operators tended to rely on lateral maneuvers to resolve conflicts (about 60% of conflicts), the ground operators (human controllers and auto-resolver agent) were more likely to use altitude (i.e., vertical) resolutions compared to pilots. One reason for why pilots would prefer to make lateral resolutions is that pilots would typically be flying at their optimal cruise altitude, making them more resistant to deviate from that altitude when given a choice. Controllers, on the other hand, would be more willing to use altitude resolutions when two aircraft are in conflict. Moreover, controllers were the only operators to utilize speed and combinations of lateral and vertical tactics to resolve conflicts. The auto-resolver tool implemented in the simulation did not have the algorithms to perform such resolutions.

Pilot comments in a post-simulation questionnaire and debriefing session yielded qualitative information about factors that influenced their decision-making for separation assurance under the different concepts of operation. When given the role for separation, experimental pilots indicated that they needed information regarding the nature of surrounding traffic. This information was provided by the CSD, which aided their decision-making capabilities. Pilots also indicated that they wanted intent information from surrounding aircraft (i.e., their plans to alter a trajectory before actually executing the change). This intent feature was not implemented in the present simulation. Although sharing of information in real-time is one of the features that will be characteristic of the NextGen environments, it is acknowledged that there may be delays in communication due to the transmissions needed to exchange information.

In general, pilots thought all three concepts were workable in theory. Pilots were not apprehensive about taking responsibility for separation. However, they did want ATC involvement as either a back-up or a consultant for resolutions, and as a monitor to oversee the traffic. This finding is not unexpected given the pilots' limited experience with resolving traffic conflicts. Currently, pilots are not given the responsibility for resolving conflicts, so this additional responsibility changes how they would respond to conflicts when they arise. Many pilots expressed concerns that the human controller lacked awareness of their aircraft when requesting help (this concern was confirmed when controllers acknowledged that they did not have much awareness of what the experimental aircraft were doing, as they were not given responsibility for TFR aircraft at the onset of the simulation). Pilots also indicated that knowing the goals of the surrounding aircraft was an important factor in their decision-making. Although the data tags of the aircraft had information about destination (which allowed pilots to project the general direction where the aircraft was heading and general goals of the aircraft, such as aircraft near their destinations are likely to descend when in conflict), many pilots indicated that additional information about other pilots' goals would have been helpful as well. For example, one pilot indicated that s/he was a cargo pilot and was willing to go through mild weather because passenger comfort is not a concern, while cargo delivery time was a central concern. This type of information could help pilots, especially those who are engaging in self-spacing responsibilities to anticipate maneuvers and preferences of lead and surrounding aircraft.

The human controllers lost separation of aircraft in their sector more often in Concept 2 (M = 6 LOS), i.e., when they were responsible for 75% of the conflicts, than in Concepts 1 and 3 (Ms = 2 LOS), when they were responsible for only 25% of the conflicts. Although the number of LOS may appear to be high (i.e., ideally LOS should be 0), we want to emphasize that the

traffic volume was extremely high (3x), so these numbers are not unexpected for the types of scenarios tested in this simulation. For example, Prevot et al. (2009) found that once traffic levels exceed 1.5x, controller performance decreases. The controllers exhibited different strategies for resolving conflicts as a function of the concept of operation. In Concepts 1 and 3, where they were only responsible for resolving 25% of conflicts, controllers used lateral and vertical tactics at a similar rate. However, in Concept 2, where they were responsible for resolving the majority of conflicts, controllers relied on vertical separation strategies more often than lateral ones. At the same time, it should be noted that these findings regarding controllers should be taken with caution, as only two controllers were tested and each one was managing a different sector.

Similar to the pilots, the participant controllers indicated that all three concepts were workable in theory. However, in the post-simulation questionnaire and debriefing, they did identify some factors that influenced their actions and decision-making under the different concepts of operations. For example, in Concept 1, controllers commented on the lack of experience that experimental pilots had with resolving conflicts. Because pilots are not given this responsibility currently, this culture shift in allocation of separation assurance responsibility caused more workload for the controllers when pilots called in for help. Controllers also expressed concerns about the transitioning of responsibilities. In all concepts, the controllers were not generally responsible for experimental aircraft until they started their descent and were on their CDA. Thus, when TFR aircraft became their responsibility in “emergency” situations (i.e., when conflicts arose), the controllers reported that it was difficult for them to gain an understanding of the situation in order to help the pilots. Indeed, controllers indicated that they did not have much awareness of the TFR aircraft because they were not responsible for them.

Thus, having the controller as a back-up conflict resolver did not work well in the scenarios tested.

Workload and Situation Awareness

Pilot and controller workload and situation awareness were also measured in the simulation. For pilots, workload measures from four separate metrics (latency to ready prompts, workload ratings on workload probes, post-trial questionnaire and post-simulation questionnaire) all indicated that workload was relatively low and did not differ significantly between concepts (see Ligda et al., 2010, for more details). In contrast, workload measures from the same four metrics indicated that workload was moderate to high, and that it changed as a function of sector properties and concept of operation (see Vu et al., 2010, for more details). The controller for sector 90 showed higher levels of workload compared to the controller for sector 91. This difference is related to sector properties of the simulation. Sector 90 was a larger sector and was affected by the weather re-routings made by pilots; the sector 90 controller was also responsible for re-sequencing of experimental pilots if they had to discontinue spacing. The Top of Descent point was also located in sector 90, which is where the pilots begin their CDA. The merge point for the experimental aircraft arriving into SDF was located in sector 91. The differences in workload for the two groups of operators (pilots vs. controllers) and within a group of operators (e.g., controllers managing different sectors) illustrate the importance of testing the effects of new concepts and technologies across a range of operators and air traffic situations.

Our situation awareness metrics (latency to situation awareness probes and accuracy to the probe questions) indicate that pilots were more aware of conflicts, surroundings, and communications/commands issued in Concept 1, when they were actively engaged in separation responsibility (see Dao et al., 2010, for details). However, as noted above, in Concept 1 they

actually lost separation more often than in Concepts 2 and 3. This indicates that situation awareness, although required for good decision-making (Rodgers et al., 2000), does not ensure good performance. Controller situation awareness, as measured by our metrics, showed a more complex picture. Because we only have data from two controllers, each managing a different sector, we will not characterize controller situation awareness here. Rather, we note that the two controllers showed different levels of awareness based on the information requirements of the sector and concepts of operation (see Vu et al., 2010 for a descriptive summary of their behavior).

Summary and Future Research Directions

We started this chapter by noting how cultural differences between professional groups can affect operator decision-making and actions. The *Situation Awareness in Trajectory Oriented Operations with Weather* simulation reported in the chapter examined how the performance of pilots and controllers were affected by three concepts of operations that uniquely allocated separation responsibility between pilots, controllers, and automation. Implementing a strategy where pilots or automation are primarily responsible for maintaining separation, would involve an important cultural shift from the present situation, where controllers are primarily responsible for separation assurance. Both groups of human operators indicated that all concepts tested were workable in theory; however, the data showed that the three concepts produced different effects on performance, workload, and situation awareness. Pilots showed little change in workload across the three concepts, but higher awareness when actively engaged in Concept 1. Controllers showed sector-specific changes in awareness and workload depending on concept of operation.

Because the current ATM system allocates separation responsibility to the human controllers, they appear to be a natural back-up to pilots and automation when the pilots are not able to find acceptable solutions to conflicts. Pilots used the auto-resolver tool to resolve conflicts when they were responsible in Concept 1. However, they had a tendency to revert to controller intervention when their solutions failed (or when the auto-resolver agent did not come up with a resolution in a time frame comfortable for pilots). This finding of reliance on the human controller is consistent with the findings of Battiste et al. (2008), mentioned previously, where pilots wanted to coordinate with the controller on 30% of automated resolutions provided to them. However, when pilots called the controllers for help, the controllers were not always aware of the situation and thus unable to help the pilots. Controllers showed little awareness of aircraft for which they were not responsible from the outset, which included the experimental pilots in all concepts tested. Thus, the notion of using the human controller as a backup to automation may not work in real-life settings unless controllers can become more aware of pertinent information regarding these aircraft when emergency situations arise. Controllers did use the auto-resolver tool to bring up potential conflict resolutions, but they used the technology merely as a tool and not as a back-up to any decision-making fails.

Although NextGen applies to the ATM system in the US, similar efforts are being made in other regions of the world (e.g., EUROCONTROL, 2010, The Single European Sky program). Thus, the influence of geographical and ethnic differences in decision-making should be explored in future studies. Li, Harris, and Chen (2007) conducted a meta-analysis of human factors mishaps in three regions of the world: Taiwan, India, and the United States. They specifically examined 18 categories of error outlined by the Human Factors Analysis and Classification System and found that national culture was associated with the management style

of the crew. Crews in the U.S., whose national culture is more individualistic and less authoritarian compared to Indian and Taiwanese culture, resulted in fewer aviation accidents. Li et al. (2007) attributed this finding to the crew members being more comfortable discussing problems/solutions with the captain rather than following orders. Because Li et al. noted that "global aviation is strongly influenced by the United States and Western Europe" (2007, p.420), it is important to understand the factors that affect human performance among pilot and controller cultures in the US and in other regions around the world.

Future studies should also examine the leadership role of the individuals to determine the effect that different roles and responsibility have on decision-making, performance, and situation awareness. Thunholm (2009) found that military leaders reported higher levels of naturalistic decision-making (e.g., more spontaneous and less rational) compared to their team members and that this style resulted from the fact that the leader should display decisive and action-oriented decision-making qualities. Finally, research should be conducted to examine the effect of new technologies and procedures not only on current day operators, but on future ones as well. The ATC Strike of 1981, where the Professional Air Traffic Controllers Organization (PATCO) union declared a strike was considered illegal because it violated a law {5 U.S.C. (Supp. III 1956) 118p.} that banned strikes by government unions. At that time, U.S. President, Ronald Reagan, ordered those remaining on strike to return to work within 48 hours or forfeit their jobs. Not all controllers returned to work and President Reagan fired 11,345 striking controllers (Wikipedia, n.d.). The FAA had to replace these controllers over the following 10 years, but these replacement controllers are now at or close to retirement age (currently, controllers must be hired prior to their 31st birthday and retire by their 56th birthday).

Another important factor to examine has to do with the subculture of student versus expert controllers. We have conducted a simulation study comparing these two groups, in which we found that highly trained students on a sector did not differ much from actual ATCs on many of the sector performance variables measured in the simulation (Vu et al., 2009). However, there were several differences evident between students and controllers. In particular, students were more compliant with experimental procedures and were more willing to use new technology and procedures (prior knowledge did not prevent them from taking on the new roles). Students also reported that their SA and workload was more negatively affected by scenario difficulty than did controllers. Finally, students relied more on automation and alerting tools. These differences need to be taken in account when evaluating new technologies using current operators as they may not be viewed in the same way by the group that will inherit the system.

NextGen will change how pilots and controllers perform their tasks by incorporating advanced technologies, employing new procedures, and having operators engage in collaborative decision-making. Thus it is important to evaluate cultural factors influencing the decisions and actions of NextGen operators with respect to their profession (e.g., pilots versus controllers), their roles and responsibilities, geographic region and culture, and their age group (e.g., cohort effects).

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Figure Captions

Figure 1. Illustration of conflict detection tool on the controller's scope. Conflicted aircraft flash red up to 8 minutes prior to loss of separation.

Figure 2. Illustration of the trial planner implemented on the controller's scope. Controllers can click on a portal (arrow next to the call sign in the data tag) to bring up the current flight plan trajectory (highlighted in blue). The controller can modify the flight plan by clicking on the path to insert a waypoint and drag the waypoint across the scope to make a new path. Although not illustrated, the controller can click on the altitude in the data tag to select alternative altitudes for conflict resolution as well.

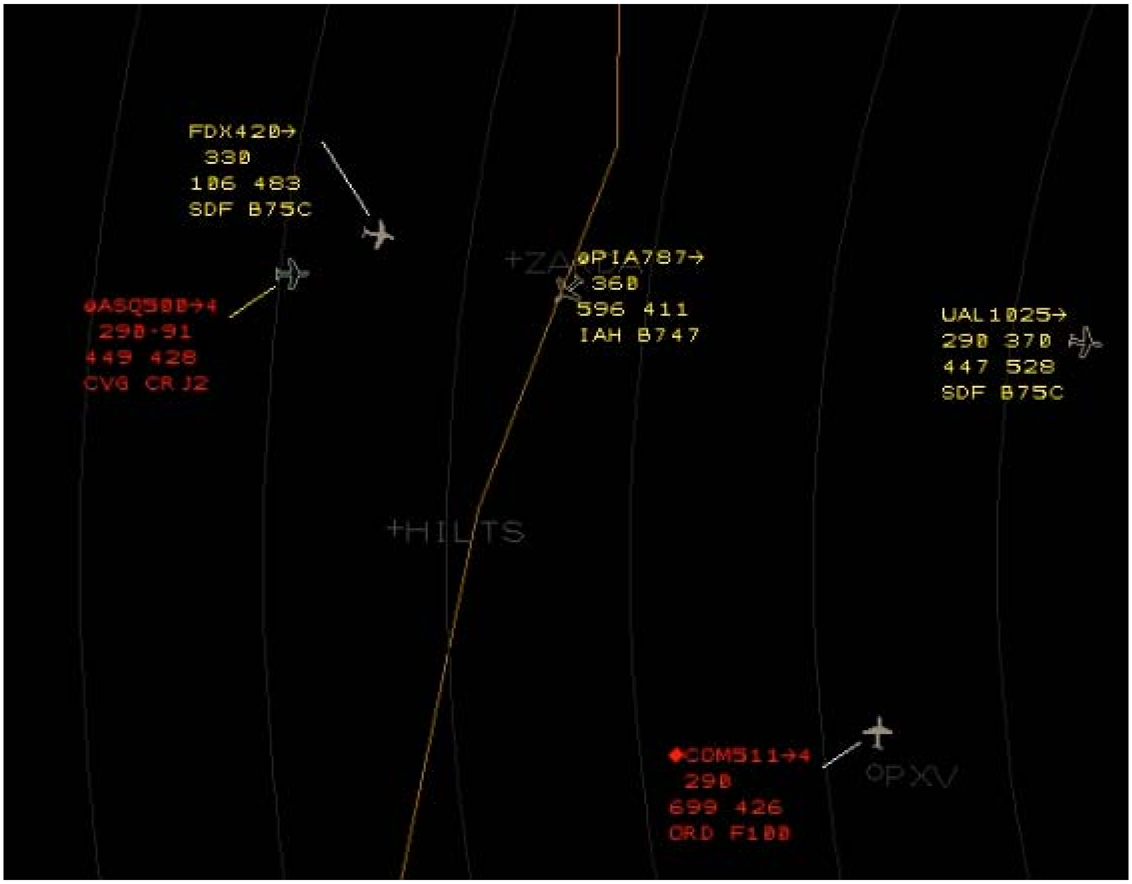
Figure 3. Illustration of the autoresolver agent implemented for the ground. The autoresolver agent detects and sends up a resolution to the flight deck without intervention of a human operator.

Figure 4. Illustration of cockpit situational display enabled with conflict detection. The system detects and alerts an upcoming loss of separation within 8 minutes. Conflicts are highlighted in amber and the data tags of conflicting aircraft are expanded.

Figure 5. Illustration of the route assessment tool (RAT), a feature of the cockpit situational display that a*llows pilots the capability to manually created flight plan changes.* When the RAT is used with the Autoresolver tool, the pilot can engage in conflict resolution and weather avoidance.

Figure 6. Illustration of the autoresolver tool implemented in a cockpit situational display. The tool uses algorithms to find a resolution for conflicting traffic at the request of the pilot. The proposed solutions are graphically displayed to the operator.

Figure 1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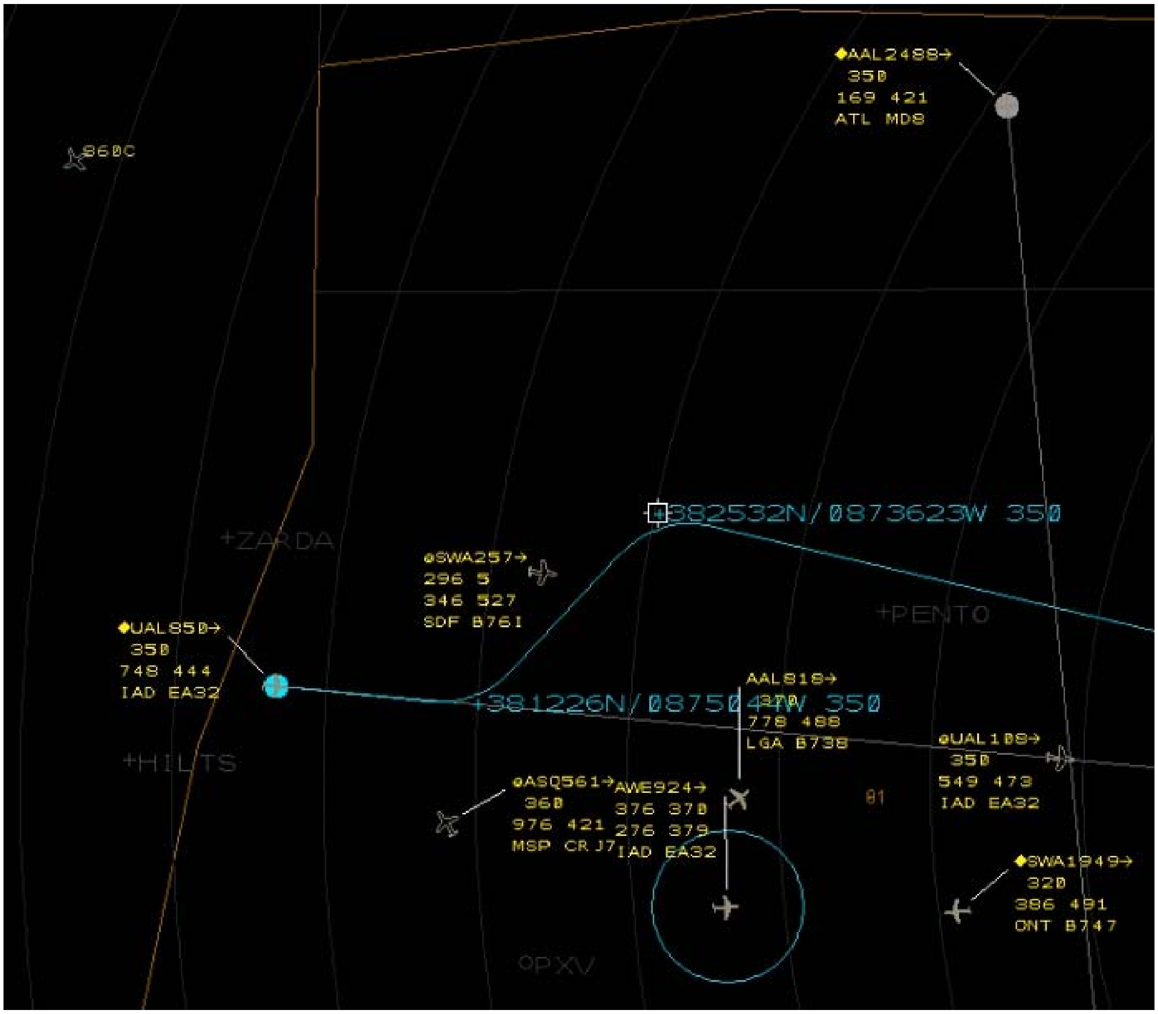
ORD F100
PXV

Figure 2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748 444
IAD EA32
AAL818→
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778 488
LGA B738
HILTS
UAL108→
350
549 473
IAD EA32
ASQ561→
360
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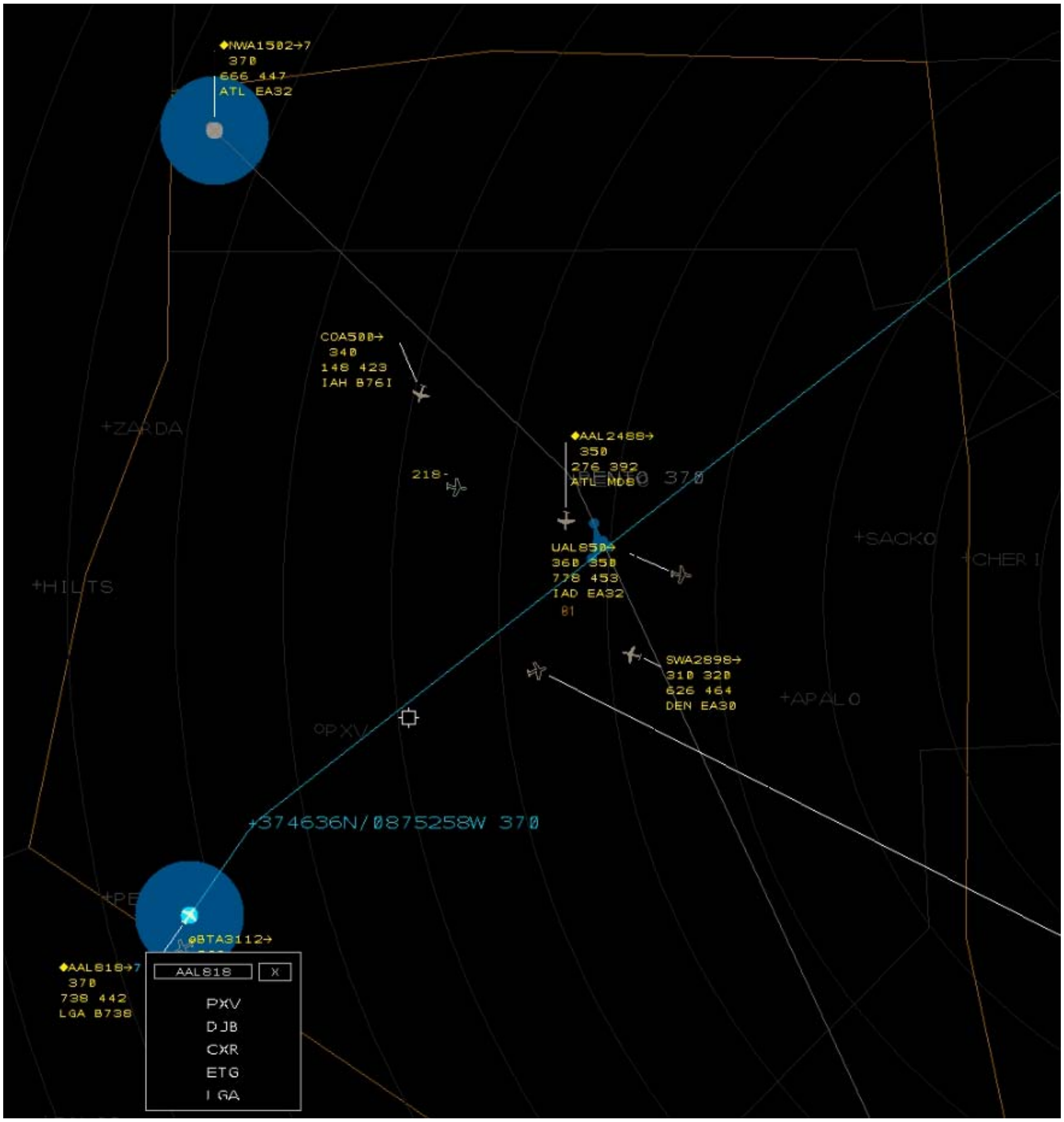
ONT B747
PXV

Figure 3



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666 447
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COA500→
340
148 423
IAH B76I
+ZARDA
218-
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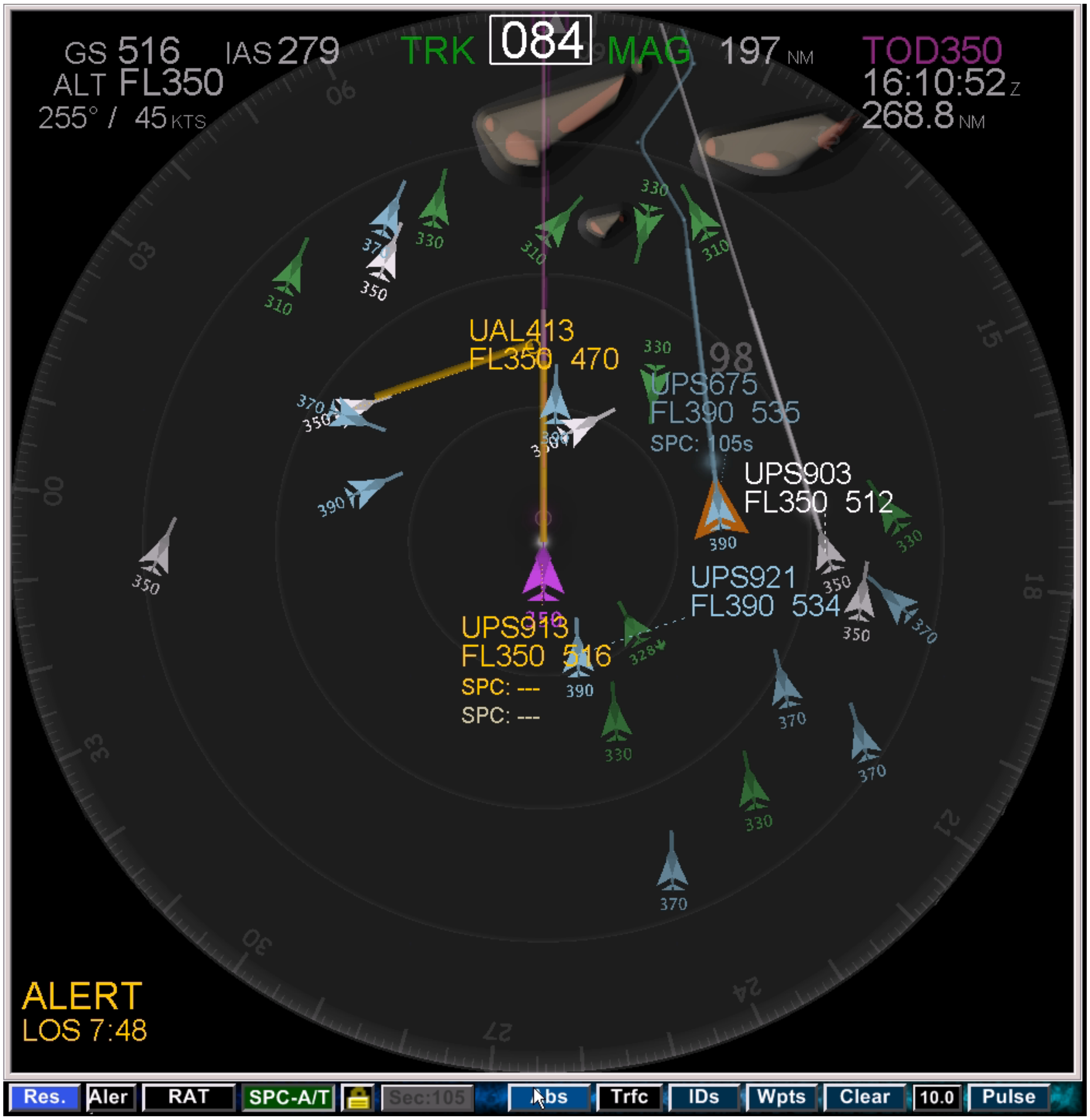
350
276 392
ATL MD8
UAL850→
360 350
778 453
IAD EA32
81
+SACKO
+CHER I
+HILTS
SWA2898→
310 320
626 464
DEN EA30
+APALO
°PXV
+374636N/0875258W 370
◆BTA3112→
◆AAL818→7
370
738 442
LGA B738
AAL818
X
PXV
DJB
CXR
ETG
LGA

Figure 4


GS 491 IAS 271
ALT FL390
000° / 0 KTS
TRK 325 MAG
160 NM
BTY-209
20:41:20 z
61.7 NM
UAL408
FL390 458
NASA1702
FL390 491
ALERT
LOS 7:26
Res
Alert
RAT
SPC
Abs
Trfc
IDs
Wpts
Clear
2.0
Pulse

Figure 5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ALT FL350
255° / 45 KTS
TRK 084 MAG 197 NM
TOD350
16:10:52 Z
268.8 NM
UAL413
FL350 470
UPS675
FL390 535
SPC: 105s
UPS903
FL350 512
UPS921
FL390 534
UPS913
FL350 516
SPC: ---
SPC: ---
ALERT
LOS 7:48
Res.
Aler
RAT
SPC-A/T
Sec:105
Abs
Trfc
IDs
Wpts
Clear
10.0
Pulse

Figure 6


GS 491 IAS 271
ALT FL390
000° / 0 KTS
TRK 325 MAG
20 NM
BTY-209
18:26:11 Z
68.9 NM
10
390
NASA1702
FL390 491
ALERT
8:24
Timeout
66
ALT400
HDG337
RTA
ETA
00:00:00
Alt
0
Reset
Datalink
Execute
Res.
Alrt!
RAT
Enter
Undo
Abs
Trfc
IDs
Wpts
Clear
2.0
Pulse