IDENTIFYING FUNCTIONAL REQUIREMENTS FOR FLEXIBLE AIRSPACE MANAGEMENT CONCEPT USING HUMAN-IN-THE-LOOP SIMULATIONS

Paul U. Lee, San Jose State University / NASA Ames Research Center, Moffett Field, CA

Kim Bender and Danielle Pagan, CSSI Inc., Atlantic City, NJ

Abstract

Flexible Airspace Management (FAM) is a mid-term Next Generation Air Transportation System (NextGen) concept that allows dynamic changes to airspace configurations to meet the changes in the traffic demand. A series of human-in-the-loop (HITL) studies have identified procedures and decision support requirements needed to implement FAM. This paper outlines a suggested FAM procedure and associated decision support functionality based on these HITL studies. A description of both the tools used to support the HITLs and the planned NextGen technologies available in the mid-term are presented and compared. The mid-term implementation of several NextGen capabilities, specifically, upgrades to the Traffic Management Unit (TMU), the initial release of an en route automation system, the deployment of a digital data communication system, a more flexible voice communications network, and the introduction of a tool envisioned to manage and coordinate networked ground systems can support the implementation of the FAM concept. Because of the variability in the overall deployment schedule of the mid-term NextGen capabilities, the dependency of the individual NextGen capabilities are examined to determine their impact on a mid-term implementation of FAM. A cursory review of the different technologies suggests that new functionality slated for the new en route automation system is a critical enabling technology for FAM, as well as the functionality to manage and coordinate networked ground systems. Upgrades to the TMU are less critical but important nonetheless for FAM to be fully realized. Flexible voice communications network and digital data communication system could allow more flexible FAM operations but they are not as essential.

Introduction

The Federal Aviation Administration (FAA) is in the process of building the Next Generation Air Transportation System (NextGen). NextGen aims to handle increased future traffic demand while providing more efficient and user-preferred routings, as well as fewer delays. One of the proposed concepts to achieve this overall goal is called Flexible Airspace Management (FAM) [1].

FAM is a mid-term NextGen concept that allows for tactical airspace adjustments in response to changes in traffic demands or flow patterns. In today's air traffic management (ATM) operations, sectors are combined, split, and reconfigured in a limited fashion in response to traffic demand. The reconfigurations are done by the Area Supervisors, local to an Area of Specialization (AOS), rather than as a part of the traffic flow management (TFM) functions. The FAM concept aims to expand the current airspace reconfiguration capabilities to allow more airspace configuration options that can be changed more frequently and responsively to the changing traffic demands. In addition, the FAM functions are added to the existing TFM functions to provide an expanded toolset that allows the traffic to be routed more efficiently.

Functions that are outlined in the FAM concept do not yet exist in today's ATM operations. In order for FAM to be a reality, modifications to existing team configurations and roles need to be defined, new procedures and decision support functionality needs to be introduced, and technologies needed to support the new functionality need to be identified. Collectively, these elements define the functional requirements for the infrastructure needed to support the FAM concept.

In order to explore team configurations, procedures, and functionality associated with a new concept, we used knowledge elicitation sessions with subject matter experts to develop an initial set of roles, procedures, and tool requirements. Then we refined them further by evaluating the concept using high fidelity human-in-the-loop (HITL) simulations [2,3]. Results from the HITL simulations identified tool capabilities and procedures needed to reap the benefits of a more flexible airspace environment.

The objective of this paper is to summarize the functional requirements that the knowledge elicitation sessions and HITL simulations conducted in 2010 identified and match them with enabling technologies that are likely to be in place in the mid-term NextGen environment [4].

Flexible Airspace Management HITL Studies

A pair of HITL simulations were conducted by Airspace Operations Laboratory at the National Aeronautics and Space Administration (NASA), in collaboration with the FAA Concept Development and Validation Group. The purpose was to assess potential user and system benefits of the FAM concept, as well as to design role definitions, procedures, and tools to support the FAM operations in the mid-term en route environment [2.3].

In 2009, a HITL simulation was conducted to understand the types of airspace reconfiguration that would be feasible and acceptable to controllers [2,5,6]. The results suggested that most of the airspace configuration options, except those with the largest airspace changes, were feasible and acceptable to the controller participants. The study also identified tools and procedures that allowed the controllers to effectively manage the airspace changes.

Building upon the tools, procedures, and lessons-learned from the study, a follow-up HITL simulation was conducted in 2010 to prototype and evaluate the roles assigned to the air traffic management team members who would assess and implement airspace reconfigurations in this environment, as well as the associated tools and procedures needed to implement the changes [3]. The study focused on the benefits and feasibility of flexible airspace reconfiguration in response to traffic overload caused by weather deviations versus a baseline condition with no airspace reconfiguration. The next couple of sections describe key roles, tools, and procedures used for the 2010 FAM study, followed by the results from the study.

Apparatus

The simulation was conducted using the Multi Aircraft Control System (MACS) and its advanced air traffic management and control prototype

functions on PC workstations [7]. Traffic Management Unit (TMU) and Area Supervisors had access to planner stations that included airspace and trajectory management functions. Radar controllers used a prototype of a mid-term controller workstation designed to support Trajectory-Based Operations (TBO) and FAM.

Planner Station

Fig. 1 illustrates the airspace planner station that was prototyped for the trajectory management and airspace reconfiguration functions used in this study. The planner station provided pre-configured airspace boundaries from a menu of configuration options within the Boundary Edit Window (see Fig. 1).
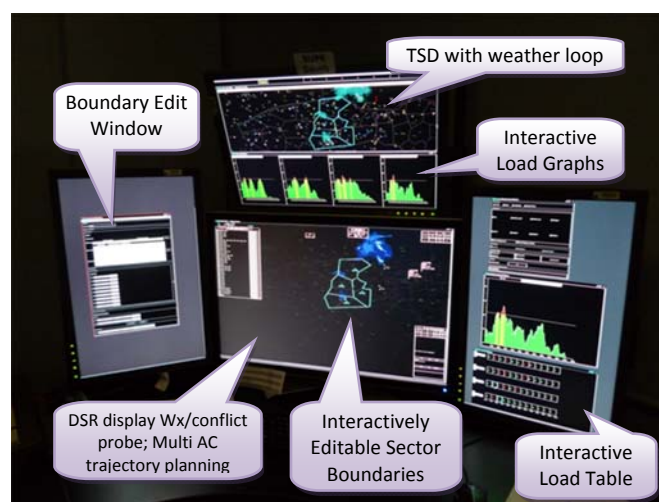

Figure 1.   Prototype Airspace Planner station

The station provided real-time filtering and analysis tools for traffic flow, sector load, and complexity assessment, including an interactive traffic Load Table, interactive Load Graphs, and plan view displays that were based upon the interactive Display System Replacement (DSR) and Traffic Situation Display (TSD). The Load Table and Load Graphs (see Fig. 2) provided predictive traffic load related information on current and proposed airspace configurations and "what-if" feedback on re-routes. The Load Table was a numerical representation of future traffic loads in selected sectors in 15-minute increments, and Load Graphs were a graphical representation of the same traffic load information with a 1-minute resolution. By selecting a certain cell or a time slice in the Load Table/Graphs, operators could highlight the associated aicraft on the DSR display. Highlighting aircraft from a specific

overloaded sector can help the planner to determine which aircraft contribute to the overloaded time period and develop a plan accordingly. The Table and Graphs can represent various factors such as aircraft count, number of aircraft predicted to be in conflict or penetrating weather cells, or the number of climbing/descending aircraft. These two tools can also show a *complexity* value that takes into account all individual factors described above.
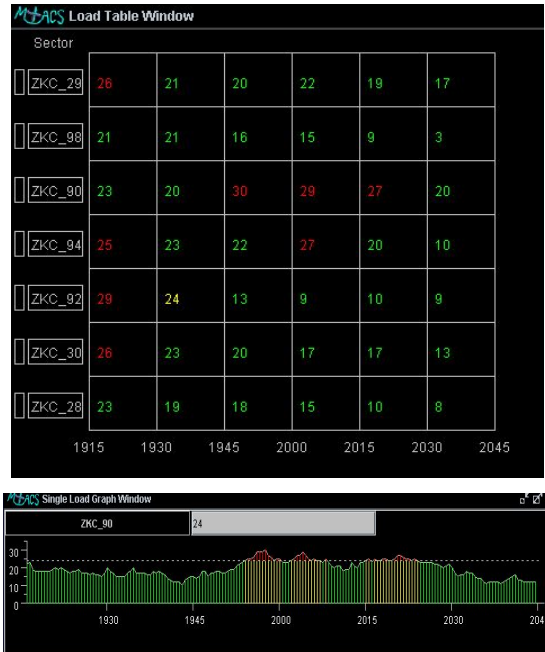

Figure 2. Prototype Traffic Load/Complexity Table/Graphs

Controller Station

The DSR based radar controller stations provided advanced functions for FAM and TBO. New features were added to the displays to receive new sector boundaries and superimpose them on the current boundaries, as well as a countdown timer giving the controllers five minute warnings before a change (Fig. 3).
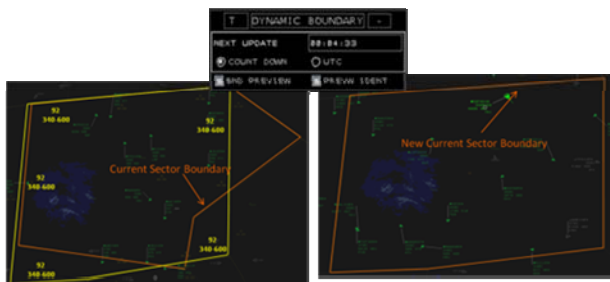

Figure 3. Radar Controller Boundary Change Preview Tool

The controller stations also included a powerful set of integrated tools for TBO, including the ability to receive trajectory changes digitally from other positions, such as the planner stations. Controllers could review and uplink the new trajectories to the aircraft as a clearance, or reject them. Other capabilities include advanced conflict detection and resolution (CD&R) automation that alerts the controllers of conflicts along the trajectories and suggest alternate trajectories.

Procedures for FAM Operations

The roles and procedures for FAM operations were prototyped. In the study, the airspace reconfiguration functionality and implementation capability were assigned to both Traffic Management Coordinators (TMCs) and Area Supervisors.

Using the interactive traffic Load Table/Graphs as reference, TMCs (referring generally to both TMC and Supervisory TMC) and Area Supervisors examined the impact of different airspace configuration options that had been pre-configured and loaded for the traffic situation and assessed which option would be most suitable. The TMCs generally focused on the traffic beyond 30 minutes but within their respective Air Route Traffic Control Center (ARTCC, or Center). The Area Supervisors focused on the traffic within 30 minutes and within their respective AOS.

During the airspace configuration selection process, either an Area Supervisor or a TMC proposed a new airspace configuration and coordinated it with other impacted Area Supervisors and TMCs. Proposed configurations were shared using ground-ground digital data exchanges of airspace configurations, which were displayed on the respective planners' stations. Planners (i.e. impacted TMCs and Area Supervisors) also discussed different airspace configuration options over the voice communication system. Once a final configuration was selected, the involved parties agreed upon a time to implement the change.

The impacted Area Supervisors then coordinated the changes with the controllers. A preview of the new sectors was projected onto the control room wall and the Area Supervisors briefed their radar control staff. Five minutes prior to the boundary change, the new sector boundaries were displayed on the controllers' scopes. The controllers then transferred

the aircraft ownership to the appropriate new sectors. Unlike current operations, the controllers conducted a "briefing by exception" wherein the hand-off controller only briefed accepting controllers on aircraft in conflict or deviating from their intended trajectory. In this study, handoffs and transfer-of-communication triggered automatically when the aircraft were near the sector boundary. However, controllers often handed off the aircraft manually during the airspace reconfiguration to eliminate the possibility of operational deviations. Pilot check-in was also omitted to reduce the overall workload during the reconfiguration.

The communication pathways are shown in Fig. 4. The weight of the arrows denotes the likely communication frequency between the positions. The Supervisory TMC (STMC) and TMC were more likely to communicate frequently to discuss the airspace configuration options and associated traffic management plans. The STMC was also expected to coordinate with Area Supervisors about the execution of the plans. The TMC had the ability to call the Area Supervisors but he was more likely to let STMC handle the overall coordination. Area Supervisors in adjacent AOS also coordinated with each other to execute flow plans. Communication about the plan execution was done between Area Supervisors and controllers within their own respective AOS, who in turn communicate with the pilots to issue them as clearances.
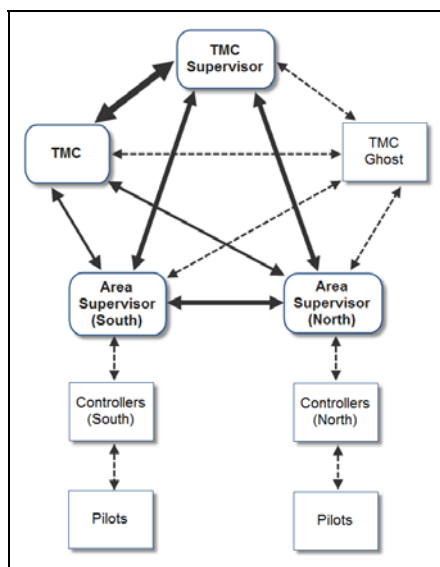

Figure 4.   Communication paths between STMC, TMCs, Area Supervisors, controllers, and pilots used in the HITL study (N.B. "TMC Ghost" represented TMUs from adjacent facilities)

Sectors that remained overloaded after the reconfiguration were managed further by rerouting aircraft out of the congested sectors. Peak traffic levels were maintained at or below a defined threshold. Aircraft count was used for the traffic threshold in the study for practical constraints, but a well-tuned traffic complexity metric that can account for other factors, such as number of climbing/descending aircraft, aircraft in conflict or predicted to penetrate weather, etc., might provide a better parameter for managing the traffic.

Experiment Design

For the study, four to seven test sectors across one to two AOSs were simulated high-performance en route airspace above FL340. The airspace assumed the following: full data communications (Data Comm) equipage of all aircraft occupying the airspace; automated conflict detection and resolution capabilities on the ground; ground-ground data exchanges of trajectory and airspace management plans; a number of pre-defined airspace configuration options; and tools that enabled air traffic operators to view the predicted traffic situation and modify either the airspace or aircraft trajectories when needed.

Test positions consisted of radar controllers, Area Supervisors, STMC, and TMC. There were two experimental conditions: Boundary Change (BC) and No Boundary Change (No BC). In BC condition, TMCs and Area Supervisors, worked together to manage the traffic by assessing different airspace configuration options and collectively selecting the best airspace configuration option before rerouting traffic. The BC condition was compared to a baseline condition in which no sector boundaries were modified (No BC condition). The surrounding airspace was staffed by a "ghost" controller and TMC positions. The TMC Ghost represented all adjacent facilities' TMUs which allowed the participant TMCs to coordinate with the surrounding Centers. The following section summarizes the overall results on the procedures and tools, as well as the benefits of the concept.

Results

Feedback on the Procedures

In the study, the traffic/airspace assessment and the coordination tasks associated with airspace reconfiguration were divided among the Area

Supervisors and TMCs. The Area Supervisors were asked to focus on the traffic situations that impacted their own AOS while the TMCs were asked to assess the impact of the predicted traffic situation within their facility, but across multiple AOSs. In addition to the TMC roles, the STMC was asked to play a central coordinator role between Area Supervisors, TMCs, and the TMU of the surrounding facilities.

Overall, this distribution of tasks worked well. Participants felt that the task distribution allowed each to perform a specific role and simplified the coordination process. They agreed afterwards that it was an efficient task distribution. They commented that although there was a "little bit of overlap" in their work, it posed no problem as long as there was a high level of communication and understanding within the team. The participants overwhelmingly stressed the importance of defining clear roles and adhering to a defined timeframe and airspace for the given position.

The TMCs and Areas Supervisors were asked to work out the best procedures for initiating and deciding on an airspace configuration. TMCs often took the lead on determining which airspace configuration would be implemented and when because their position provided them a view of the bigger, system-wide picture. However, the Area Supervisors' local knowledge of the airspace was highly regarded by the TMCs. A team effort developed over the course of the study and decisions were made with mutual agreements. In the event that a consensus could not be reached, the STMC became the arbiter of the final decision.

Overall procedures for airspace reconfiguration worked well for the controllers. They gave positive ratings on the airspace reconfiguration procedures. They also considered the reconfiguration process to be safe and reported that they were able to maintain good situation awareness throughout the process.

Feedback on the Tools and Capabilities

Another key component of the study was to prototype and evaluate the functions and tools that supported the planners in the reconfiguration process. Decision Support Tools (DSTs) were prototyped to manipulate the airspace designs, assess the impact of different airspace options, select and share those options with other team members, schedule a new configuration into the system, preview the new configuration on the controller stations, and implement the new configuration.

Although the tools were an initial prototype, they were rated highly in their usefulness and usability. Traffic and complexity Load Table and Graphs were integrated with the airspace configuration options such that they quickly reflected the changes in the traffic in response to each airspace configuration option. The tools related to selecting airspace configuration options, sharing them with other planner stations, and adding them to an active queue for implementation were built specifically for this simulation. Overall, these prototype DSTs were well received by the participants. However, some participants commented that some of the functions required an excessive number of button clicks. Participants also liked the ability to preview the new airspace configurations both on the planner and the controller displays.

Overall, the results and participants' feedback showed that the general functions provided by the tools were deemed both useful and usable by the participants. These findings provide a good foundation for defining the functional requirements for the FAM concept in high performance en route airspace with Data Comm equipage.

Benefits

FAM operations expected to better utilize the airspace by managing traffic congestion with airspace reconfigurations as well as rerouting aircraft. The airspace utilization was measured by taking the instantaneous aircraft counts at each time slice across all test sectors and averaging them across the simulation time. Fig. 5 illustrates the average number of aircraft for the seven test sectors plotted over time.
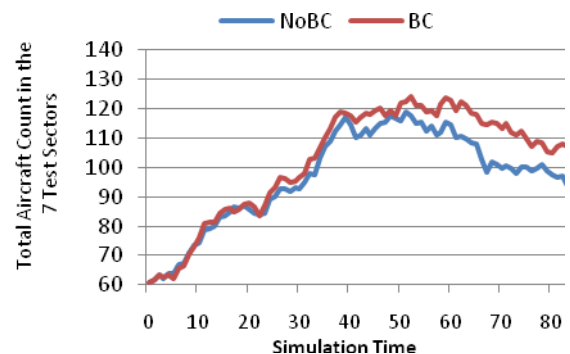

Figure 5.   Average aircraft count in the seven test sectors for the two experimental conditions, averaged across the simulation runs.

A paired samples *t*-test showed a significantly higher mean number of aircraft transited the airspace in the BC condition (M = 81.88) than in the No BC condition (M = 75.70) (paired *t*(5) = 3.90, *p* < .02). The results showed an average of 8% increase in the aircraft count over the traffic period in the BC condition, relative to the No BC condition.

FAM operations also expected to result in fewer delays or shorter flight distance for the rerouted aircraft. Flight efficiency was examined by measuring the path length changes for the rerouted aircraft. As expected, even when the paths were extended, the BC condition resulted in shorter paths compared to the No BC condition (Fig. 6): path lengths increased by 9.84 nmi in the BC condition compared to 18.63 nmi in the No BC condition (paired *t*(5) = 2.64, *p* < .05). Similarly, when paths were shortened, they were shorter in the BC condition (M = -14.28 nmi) than in the No BC condition (M = -12.96 nmi) although this difference was not significant (paired *t*(5) = 1.27, *p* > .2).
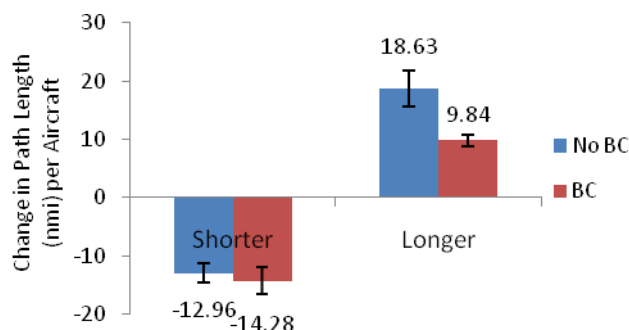

Figure 6.   Average change in the path length per aircraft for the aircraft that had longer or shorter final path lengths compared to their original trajectories.

Overall, FAM operations showed significant system-wide benefits as well as benefits to individual flights.

Recommended Capabilities based on HITL Studies

Using the general procedures and tools developed in the HITLs as a basis, this paper outlines the recommended FAM-related capabilities and maps them to the appropriate planned mid-term NextGen technologies. This exercise, in turn, can help develop functional requirements needed to implement the FAM concept.

In the 2009 and 2010 HITL studies, new roles, procedures, and DSTs were designed for airspace above FL340 and with all aircraft equipped with Data Comm. Based on the assumptions that the aircraft were fully Data Comm equipped and that the higher altitudes had lower traffic complexities, large airspace changes were allowed during the reconfigurations. Further research should be conducted to test the procedures and DSTs in less ideal environments, such as mixed airspace with both Data Comm and non-Data Comm aircraft or airspace with more complex traffic (e.g. climbing/descending aircraft). Nevertheless, the FAM-related capabilities identified in the FAM HITLs so far provides a good starting point to identify the functional requirements needed for the FAM concept.

The HITL studies identified three main steps to FAM operations: 1) assessment of the airspace configuration options; 2) coordination of the new airspace configuration among the air traffic personnel; and 3) execution of the airspace reconfiguration. The FAM operations were considered to be a part of normal traffic flow management functions rather than an independent activity. Therefore, the timeframe of airspace reconfiguration is expected to be consistent with the expected traffic flow problem. Within this context, the roles of assessing and coordinating the airspace configurations were given jointly to the TMCs and Area Supervisors and the execution of the reconfigurations were ultimately given to the AOSs, with Area Supervisors providing the coordination with the controllers.

Following are some of the new capabilities that were identified for TMU and Area Supervisor stations as a part of flexible airspace assessment and coordination:

- Ability to store and access multiple pre-defined airspace configuration options
- "What-if" function to assess the impact of airspace reconfiguration to the predicted traffic load
- Ability to digitally share the airspace configurations and implementation parameters between planners

Within the context of airspace assessment, there should be a capability to store multiple pre-configured airspace configuration options that can be

accessed for a variety of traffic and weather situations. Automation support to provide recommendations on the best set of configuration options would be desirable. These options should be accessible by all planners.

In order to assess which airspace configurations are appropriate for given traffic situations, there should be an ability to foresee the impact of the potential airspace reconfiguration to the projected traffic loads. In the HITL studies, a "what-if" function was integrated into the airspace configuration options in conjunction with the Load Table/Graphs. As new configurations were selected, immediate feedback was given to assess the changes in the traffic load and/or complexity values.

When a new configuration has been identified, the coordination of the airspace changes should be facilitated by a capability for all planners to look at the same airspace configuration and its impact prior to executing the change. In the HITLs, all of the planner stations were able to send and receive airspace configuration plans digitally. Once a plan is decided upon, it is sent to the controller stations.

Once the airspace change is ready to be executed, new functions on the controller stations should be added to facilitate the change:

- Ability to preview the new boundaries on the radar display with a time indication for when the reconfiguration will occur
- Ability to display sector relevant information, such as sector identifications (IDs), altitudes, radio frequencies, etc.

During the reconfiguration process, the ability to overlay the current and new sector boundaries on the radar controllers' displays greatly aided the transfer of aircraft ownership from one sector to another. A countdown timer that showed how much time was left until the change in the configuration was helpful to the controllers to plan their activities during the reconfiguration.

In situations where the new sector boundaries changed the relationship with the upstream and downstream sectors, the ability to display sector IDs, altitudes, and radio frequencies also supported the controllers to gain better situation awareness in an unfamiliar environment.

In addition to new capabilities on the planner and the controller stations, additional tools and technologies can also help the FAM operations to be successfully utilized. Some key additional capabilities are:

- Offline, flexible airspace design tool
  - Ability to quickly and flexibly create different airspace designs
  - Ability to assess the feasibility of the airspace designs
  - Ability to flexibly map the radio frequencies to the reconfigured sectors
  - Ability to validate surveillance coverage is sufficient
- Data Comm

An examination of the current air traffic management tools available for airspace reconfiguration show that the rudimentary versions of the FAM operations can be done without many upgrades. However, key limiting factors seem to be an easy way of pre-designing new airspace configurations, assessing the feasibility of the airspace designs, checking to see if the airspace conforms to both the availability and coverage of radio frequencies, and being able to correctly connect all of the sector-related information to the correct controller consoles without laborious manual checks. A set of tools that can make this process easier and less error-prone can help develop and maintain a greater number of usable pre-configured airspace boundaries.

Finally, Data Comm equipage on the flight deck can significantly reduce controller tasks during airspace reconfiguration. Data Comm can support automatic transfer of communications, reducing the controller's workload to simply monitoring transfers. Automating the mechanism for sending messages reduces the amount of information controllers need to memorize, such as adjacent sector frequencies, relieving the controller task load. Data Comm also allows an easier mechanism to send flight trajectories directly to the flight deck, which reduces the number of aircraft vectors that takes the aircraft off of their flight plans. Keeping aircraft on their intended trajectories during airspace reconfigurations prevents situations in which a controller puts an aircraft on a vector and loses track of it in the midst of the airspace changes.

An unrestricted version of the FAM concept permits any airspace reconfiguration to be carried out real-time without constraint. An examination of the NextGen program suggests that unrestricted version of FAM will not be available in the mid-term timeframe. However; further inspection of a subset of the technologies planned for mid-term implementation suggests that a limited version of FAM is feasible within this timeframe. These mid-term technologies include updated TMU displays, updated controller display support in En Route Automation Modernization (ERAM), National Voice Switch, Data Comm, and Airspace Resource Management System (ARMS). Each technology has different level of risks associated with potential implementation delays and a different level of impact on the FAM concept's feasibility should it be unavailable. The following sections describe aforementioned mid-term technologies, the functional FAM requirements associated with the technologies and explains how the concept might change should the technology be unavailable.

Enabling Technologies for Mid-term FAM Operations

Traffic Management Unit Technology Upgrades

Currently, there are multiple efforts planned to update the capabilities of the Traffic Management Unit that affect the FAM operations. The Trajectory Based Flow Management Program plans to upgrade the current traffic Load Table/Graphs within the TFM displays. Recommended upgrades include the ability to filter traffic and configure traffic views differently, as well as the ability to consider traffic loads in terms of complexity rather than traditional Monitor Alert Parameter numbers [8]. Mid-term systems also plan to provide more sophisticated weather processing [9] along with upgraded traffic forecasting prediction tools to allow more proactive TFM actions.

Another initiative underway within TFM is to field a new tool called the Collaborative Airspace Constraint Resolution (CACR). CACR is expected to integrate tactical and strategic weather forecasts and evaluate airspace constraints based on predicted sector demand and uncertainty via the TSD. CACR automation can then develop and suggest traffic management solutions by assigning the affected aircraft feasible options for the departure times and

routes up to 45 minutes before departure, integrated into the TSD [8]. It is expected to provide traffic managers with the ability to share their display screen improving the ability to share TMI modeling information [11].

A third set of capability planned for TFM are the pre-departure Execution of Flow Strategies (XFS) and Airborne Reroute Execution (ABRR) systems which allow the electronic negotiation of trajectories for both pre-departure and airborne flights. Currently, this process is time consuming and work intensive. Pre-departure XFS institutes an automated mechanism for routes generated within the TFM system to be transmitted to ERAM. ABRR provides the ability to electronically send TFM generated airborne reroutes to En Route automation to be issued as clearances by the controllers [8,11].

Potential Gap between Capabilities in HITLs and Planned Mid-term Capabilities

In the HITL studies, the planner stations had the ability to store multiple airspace configuration options, assess their impact on the traffic using the traffic Load Table/ Graphs, and share the airspace configurations with other planners. The planned mid-term TMU upgrades discussed include the Load Table/Graphs with better weather and traffic predictions, and a collaborative planning tool used to share their display screens. However, there is no explicit mention of integrating airspace configurations as a part of these capabilities.

Impact of TMU Technology Upgrades on FAM

Currently known functions of the planned TMU upgrades will allow better traffic predictions in weather and other off-nominal situations. However, these upgrades on their own do not impact the feasibility of FAM operations. The FAM concept would benefit from a collaboration tool that integrates proposed airspace configurations on the display. This would allow planners to share proposed airspace configuration information on their displays in order to expedite collaboration and share situational awareness. With an effective collaboration tool, the TMUs could implement the best solution for the system, not just for the individual facilities or AOSs within a facility. In addition, multiple and/or more complex configurations could possibly be implemented to make the NAS more efficient.

Limited FAM operations without the aforementioned TMU capabilities may be a fixed set of configuration options that could be stored in another platform (e.g. ERAM) and the planners could verbally coordinate with each other on which configuration to consider. TMU would need to rely on their past experience to determine which configuration option to execute because without an integration of the airspace functions into TMU tools, the impact of the reconfiguration on the current and predicted traffic is unlikely to be available for a preview.

En Route Automation Modernization (ERAM)

ERAM replaces the current HOST Computer System and provides new radar display interface for the En Route controllers by replacing the current DSR with an updated DSR and User Request Evaluation Tool (URET) functionality incorporated into the ERAM infrastructure.

ERAM enhances a number of airspace related functions. Airspace coverage is expected to extend beyond facility boundaries, enabling controllers to handle additional traffic more efficiently. Flight plan processing is also expected to improve, and when aircraft divert from their planned course hand-offs are done automatically rather than manually. ERAM also has increased flexibility in routing around weather and other airspace restrictions and automatic flight coordination increases efficiency and capacity [12].

With the deployment of ERAM, sectors will be comprised of Fixed Area Volumes (FAVs) instead of the FPAs that are currently used in HOST. FAVs have enhanced capability over current FPAs [13]. In ERAM, each sector can have multiple FAVs which allow the sectors to be partitioned into smaller chunks of airspace in much greater number than is available using current FPAs. This is expected to allow more alternatives when creating pre-defined airspace configuration options.

ERAM provides the ability to store twenty map buttons per unique airspace configuration as opposed to four in HOST. These additional map buttons could be used to store alternative configurations to allow controllers to overlay the new configuration over the existing configuration in order to gain awareness of their new area prior to a configuration change.

ERAM baseline is designed to process data from 64 radars instead of the current 24, further supporting FAM operations. This additional surveillance allows alternative airspace sector configurations that would not have been possible in HOST because the surveillance coverage was not sufficient. Expanding radar input allows for more overlapping coverage with adjacent facilities and expand inter-facility FAM opportunities.

The existing conflict probe functionality will be integrated into the ERAM display for the baseline release, offering the controller additional situation awareness and tactical support, and eliminating the need to access this information on a separate display. Controller displays are expected to have current and predicted air traffic volume and workload/sector complexity for all sectors in the controller's AOS [12]. Conflict Resolution Advisories is a more automated conflict resolution capability that aims to ease en route controller workload and eliminate controller tasks associated with determining conflict resolutions [14]. Conflict resolution capabilities have also been found to be very beneficial to controllers in previous FAM studies [6].

Potential Gap between Capabilities in HITLs and Planned Mid-term Capabilities

Unlike airspace configurations used in the HITLs, those in ERAM are likely to be much more constrained. The creation of airspace configurations are constrained by the FAV boundaries with the introduction of ERAM. In the initial ERAM implementation, FAV boundaries are tied to current ground equipment locations. However, ERAM may potentially allow more flexible configurations in the later implementations.

The airspace configurations can be previewed through map buttons. However, ERAM only accommodates twenty map buttons limiting the potential number of configurations to a maximum of twenty in between the new updates to the map. In the HITL, overlaying the new configuration over the existing one has assisted the controllers in gaining better situational awareness during a boundary change [5,6]. Controllers were also greatly aided by the displays of sector IDs, frequency, and altitudes for the new airspace configuration. In addition, a countdown timer that alerted the controller to the time to reconfiguration facilitated synchronized reconfiguration of sectors across multiple AOSs at a pre-defined time in the HITL. Without such function, reconfigurations may need to be done similarly to

today's operations, in which the impacted controllers signal when they are ready for the change and an Area Supervisor changes them on-demand. This type of procedure may be feasible only for reconfigurations involving just a few sectors and within an AOS. An automated overlay of the new configuration and sector-related information along with a countdown timer prior to the change would be preferable on the controller's display, but no such capabilities are planned for ERAM at the moment.

Lastly, the TMU in the HITL sent the reconfiguration selection and the "switch" time directly to the controllers' displays which then automatically switched the configuration at the planned time. As currently planned, ERAM would require a manual reload of the configuration. Without the ability to transfer the airspace configuration from a TMU tool to ERAM, the reconfigurations will likely need to be verbally coordinated to the Area Supervisors directly to execute the changes.

Impact of ERAM Capabilities on FAM

Upgrading the HOST computers to ERAM will be a critical first step in performing FAM operations that are qualitatively different than the airspace reconfigurations that are done today. Without FAVs in ERAM, the airspace sectors cannot be divided into smaller chunks of airspace, thereby limiting the number of airspace configuration options.

Even with the presence of ERAM, the current plan for ERAM functionalities is likely to significantly limit the scope of the airspace reconfigurations. Without the airspace preview, countdown functions, or the ability to send the reconfiguration selection from the TMU tools to ERAM, the reconfiguration options may be limited to those that only affect two to three sectors at a time within a single AOS. With such a setup, an Area Supervisor would verbally coordinate with his controllers on both the configuration and the time-to-change. The lack of airspace preview functions may also limit the complexity of the airspace changes to those that the controllers can store cognitively.

Further research is needed to limit the scope of FAM operations from prior HITLs to be consistent with the current ERAM implementation plans. The changes in the procedures should be identified and evaluated to measure the potential benefits in this new context.

Airspace Resource Management System (ARMS)

In current operations, airspace reconfiguration is a manual, laborious, and potentially error-prone process. There are few tools to support designing, evaluating and analyzing airspace designs. During the airspace design process, mapping sectors to the available radio frequencies and the NAS infrastructure in general is also challenging. In addition, during an actual airspace change, the Area Supervisors have to know the facilities available frequencies and coverage and manually remap each voice frequency to the appropriate controller station.

The Airspace Resource Management System (ARMS) is a proposed DST designed to facilitate these processes. Planned functionality is ARMS is described as being both an offline airspace design tool that also has the ability to automate the dynamic management of the reconfiguration of NextGen networked ground systems. ARMS is expected to be a nationally distributed system.

At the moment, ARMS is in the initial planning stages and therefore specific details of ARMS functionalities are uncertain. To the best of authors' knowledge, ARMS is expected to provide tools to design, evaluate, and analyze airspace configurations during the offline design process and interface to automation systems to communicate airspace changes. The tools may evaluate the airspace design for surveillance coverage, route suitability as well as configuring the assignment of voice frequencies to support the design.

ARMS is also expected to provide automation to manage flexible networked ground system that can be dynamically reconfigured to many more options than is possible in today's operations. ARMS may provide capability to ensure that the airspace configuration has adequate radio coverage and absent of gaps in surveillance. In addition, ARMS may provide the frequency mapping to the automation in support of handoff actions.

Potential Gap between Capabilities in HITLs and Planned Mid-term Capabilities

The functionality proposed by ARMS seems to capture the capability needs as identified in the HITL studies. However, the expected implementation timeframe of ARMS is currently unknown. Specific details of ARMS functionalities are still in

development, hence it is difficult to assess what types of tools in the ARMS or other related tools will be available to facilitate the airspace design and assessment process. Investigation into this functionality as it progresses is warranted.

Impact of ARMS Capabilities on FAM

The current system is severely limited by its ability to design, test, and map new airspace configurations and to propagate them to the appropriate controller stations and assign appropriate voice frequencies. Without DSTs that can facilitate the airspace design and verification process, the airspace reconfiguration process may remain similar to those of today's operations.

National Voice Switch (NVS)

The National Voice Switch (NVS) is a Voice over Internet Protocol (VoIP) capability that is expected to replace today's hard-wired inflexible voice communication system. The current system limits a controller to a finite number of available radio and phone connections available and is prone to failures. NVS uses the FAA's Telecommunications Infrastructure as its networking backbone resulting in a more flexible, robust, and reliable voice and radio capability to serve the needs of controllers in Air Traffic Control Towers (ATCTs), Terminal Radar Approach Control facilities (TRACONs), and ARTCCs. Controllers will be able to talk to aircraft or controllers in any air traffic control sector based on what the operational protocols allow. In addition, coordination between ARTCCs, TRACONs and ATCTs is expected to become much easier because a VoIP system allows connections to be made anywhere in the NAS.

The ability for controllers to utilize and access frequencies in different sectors is an important aspect of the FAM concept. The NVS program will allow the FAA to achieve voice switching modernization objectives such as network-based infrastructure, and evolution of ATC toward a flexible communications routing that support dynamic airspace reconfiguration, resource reallocation, and airspace redesign. While NVS is not a requirement for the FAM, it is expected to enable expanded airspace configuration options because configurations will no longer be constrained by the frequency coverage limitations [16].

Potential Gap between Capabilities in HITLs and Planned Mid-term Capabilities

In the HITLs, sector boundaries were altered without imposing any limits on the frequency coverage. Such an assumption would be achievable if NVS becomes available in the mid-term timeframe.

Impact of NVS Capabilities on FAM

Without NVS, boundary movements will be limited by frequency coverage. However, in the midterm, FAM operations can function without NVS by validating frequency coverage before an implementation of a new airspace configuration. The resulting configurations may be limited in the amount of airspace volume changes allowed, but overall, such constraint should not eliminate the benefits or feasibility of FAM operations.

Data Comm

Data Comm represents the FAA's transition from the current air-to-ground analog voice system to a system in which digital communication becomes an alternative communication mechanism. Data Comm will allow messages to be sent directly to pilots, with flight deck automation facilitating loading of some messages (e.g. route clearances) into flight management systems. Data Comm augments existing voice communications and provides two way data interchange between controllers and flight crews for ATC clearances, advisories, flight crew requests and reports [17]. The Data Comm program also expects to provide more timely and effective clearances and reduce controller workload by automating repetitive tasks, eliminating the need for pilot read-backs, and generating less workload intensive data communications through interface design and function.

Data Comm also supports trajectory-based routing that is expected to transform ATM from short-term tactical control to strategic gate-to-gate flight management [17]. The trajectory-based routing is achievable by integrating Data Comm with the Flight Management System (FMS). FMS integrated Data Comm systems provide the capability for a flight crew to auto-load a data communications message into the FMS. This allows controllers to issue complex clearances (e.g. latitude/longitude type of clearances) for "auto-load" into the aircraft's FMS thereby allowing for an air-to-ground data exchange

that cannot effectively be performed using voice due to the proclivity to error and workload restrictions. Complex clearances allow for more flexible and efficient routings, particularly during weather events and more efficient and easy way of offsetting and moving flows without concern for errors or workload.

The workload associated with an airspace reconfiguration has to be considered when deciding when and how to reconfigure the airspace. During a reconfiguration controllers may be required to initiate handoffs and accept handoffs concurrently with the rerouting of aircraft. This process includes communicating frequency change messages, rerouting of aircraft, and initiating and receiving hand-offs. Data Comm can potentially automate these functions allowing controllers to handle an increased number of aircraft.

Potential Gap between Capabilities in HITLs and Planned Mid-term Capabilities

Data Comm was cited as an important enabler for the FAM concept in the HITLs primarily due to the reduction in workload it provided [6]. In these HITLs, Data Comm enabled auto transfer-of-communicaton and eased other repetitive tasks resulting in an overall reduction in controller workload, in turn, expanding the ability to reconfigure the airspace.

Although the HITLs assumed 100% Data Comm equipage, it is unlikely that such environment will exist in the mid-term timeframe. Further research is needed to evaluate the feasibility of mixed equipage airspace. Since Data Comm reduces controller workload during reconfiguration and reduces the number of sector-related information that the controllers have to retain (e.g. frequency information) lack of adequate Data Comm equipage is likely to limit the types of airspace reconfigurations that can be considered.

Impact of Data Comm Capabilities on FAM

Data Comm helps reduce controller workload during reconfiguration. It also reduces the number of sector-related information that the controllers have to remember. Lack of Data Comm is expected to impact the complexity of the airspace reconfigurations that can considered, but more limited FAM operations should be feasible.

The midterm environment does not expect to have a high percentage rate of Data Comm equipped aircraft. Thus, researching the affects of FAM with no Data Comm or varying ranges of this functionality would be needed to assess the feasibility of the FAM concept in this environment.

FAM Operations using Mid-term NextGen Technologies

In the previous sections, mid-term NextGen technologies were described individually, along with their difference from the HITLs and their impact on the FAM concept. In this section, we summarize how they might be used *together* in FAM operations.

Mid-term FAM operations should have as many reconfiguration options as needed available to solve specific traffic problems. The details of ARMS capabilities are uncertain at the moment, but if we can assume ARMS-like capabilities are available they should be able to facilitate this airspace design process by enabling facilities to design and test various airspace configurations offline. These functions may assist airspace designers in evaluating surveillance coverage and configuration of voice frequencies assignment to support the sector design. Also, once airspace is designed and tested, this tool may be able to interface with ERAM to communicate airspace changes.

Prior to the actual air traffic operations, multiple airspace adaptation files with pre-defined airspace configuration options should be stored in ERAM. The pre-defined configurations in ERAM should be greater in number and selected based on the predicted traffic situation for the day, allowing more flexibility in its use. Unlike FPAs in HOST, ERAM has the ability to allow facilities to design configurations in adaptation that require FAVs to move from one facility to another, thereby allowing inter-facility reconfiguration if needed. In addition, NVS will eradicate the radio frequency constraints by allowing any controller to address and communicate with any aircraft via VoIP communications.

With more airspace configuration options to choose from, the selection of the most beneficial configuration will be more difficult without a tool to directly examine the operational impact of specific configurations on a situation. Using interactive traffic Load Table/Graphs and more accurate observed and

forecasted weather conditions, planners (TMCs and Area Supervisors) should be better able to evaluate the traffic situation for a given time period and assess, based on past experience or speculation, which airspace configuration option should be most suitable for the given day or anticipated ATM event.

During the airspace configuration selection process, Area Supervisors and TMCs could evaluate and propose a new airspace configuration and coordinate with other impacted TFM(s) possibly using a TFM collaboration tool as described in the CACR ConOps [11]. However, without an automated mechanism to share views of the predicted traffic situation and make decisions about how to modify airspace or aircraft trajectories, shared awareness may decrease and a time-consuming coordination process may ensue. A well-designed DST could assist planners in deciding how and when to implement a boundary change and a collaboration tool could assist in planning and communicating those changes among all involved parties, thereby increasing the possible scope of FAM operations. It should be noted that ERAM may be able to assist with this process as it plans to support the coordination of airspace configuration changes between the initiator of the change, impacted controllers, and TMU. However, the mechanism to do so has not been defined.

Once planners identify a configuration "switch" time, Area Supervisors could begin coordinating the change with impacted controllers. Controllers could then select the appropriate map button to overlay the planned configuration on the current configuration to gain situation awareness for the new area and begin making preparations for the change. In the absence of a countdown timer, the Area Supervisor could then verbally apprise controllers of the time to change at specified intervals to assist controllers with timing reconfiguration tasks, such as hand offs and reroutes.

At the specified "switch" time, impacted controllers could affirm they are ready for the change and Area Supervisors could manually load the new configuration into ERAM to execute the change. The actual implementation of a new configuration should occur seamlessly while ERAM is still operational. However, without an automated load process that supports Area Supervisors and controllers the coordination and execution process will be more laborious, coordination laden, and time consuming.

Ideally, the TMU could trigger an automated process which would send the reconfiguration selection and "switch" time directly to ERAM. ERAM would then overlay of the new configuration and sector-related information along with a countdown timer automatically onto the controller's display and the new configuration would be seamlessly loaded into ERAM at the specified time.

Data Comm in conjunction with conflict detection and resolution tools could reduce controller workload during the execution of the change, enabling controllers to better handle the transitional workload associated with airspace reconfigurations. The alleviation of workload and task shedding that is provided by the automation of repetitive tasks will allow more resources for developing and maintaining situation awareness. In combination, the lightening of these constraints could allow for larger airspace volume changes.

Conclusion

This paper compared the capabilities from FAM HITL studies with those in NextGen technologies and discussed potential differences in both the substance of the technologies and how they are implemented. Overall comparisons suggest that mid-term NextGen technologies provide similar functions to those in the HITLs but lack some capabilities. Mid-term NextGen technologies that were identified as being relevant for FAM were capabilities planned for TMU upgrades, ERAM, ARMS, NVS, and Data Comm. It is important to note these specific systems are not considered requirements for FAM, rather they possess the capabilities required to support the FAM concept.

From the identified technologies, functionalities in ERAM and ARMS seem to be most critical to enable an expanded FAM operation. A flexible airspace management that is qualitatively different than today's operations require greater number of airspace configuration options that can be more flexibly designed and can be more easily stored and maintained. ERAM is expected to provide such expanded capability. Additional functionalities, such as the ability to overlay new airspace configuration on the current one or the ability to display sector IDs, altitudes and frequencies, are not planned for ERAM at this time but would also facilitate the reconfiguration process.

The capabilities identified for ARMS are another critical technology that would enable the FAM concept. An offline tool that can facilitate the airspace design, evaluation, and mapping of the resulting airspace configurations to ERAM is greatly needed. An automatic process to evaluate the airspace designs against appropriate surveillance coverage, voice frequency coverage, and route suitability would remove significant portion of time consuming, error-prone, manual process. In addition, during the implementation of a boundary change, an automatic mapping of the sectors to appropriate voice frequencies and controller consoles would also facilitate the process. ARMS may be able to provide all of the aforementioned functionalities however, ARMS is still in the early stages of development, so it is unclear if and when such functionalities will be available in NextGen.

The capabilities in the HITLs included a number of tools on a planner station for TMU and Area Supervisors. The capabilities included the ability to store multiple airspace configuration options in the same tool as the one that assesses the predicted traffic so that the airspace reconfiguration options can be evaluated based on their impact on the predicted traffic. An ability to digitally share different configuration options between TMU and AOSs was envisioned in the HITLs as a modified TMU display. Planned TMU upgrades in the mid-term include a number of functionalities that improve traffic assessments. However, no current plans exist to include airspace configuration options as a part of the tool suite. Without an integration of airspace-related capabilities into TMU tools, limited FAM operations should be possible by assessing the airspace configurations via ERAM. However, such solution would deprive the ability to assess the airspace and traffic together, thereby reducing the number of configuration options a facility could choose from due to the requirement for the planners to intuitively decide which configuration would work best for a given situation.

Lastly, capabilities for NVS and Data Comm play important roles in allowing flexible FAM operations but they are not as critical for more limited FAM operations. Lack of NVS would limit the airspace boundaries to match the frequency coverage but an ARMS-like tool that can check the airspace boundaries to appropriate frequencies would mitigate this problem. Without Data Comm, the types of reconfigurations would be limited to those that are manageable cognitively for the controllers, but the limitations are probably similar in scope to those already described in previous paragraphs.

In summary, a limited version of the FAM concept should be possible with a minimal set of NextGen technologies. Since many of the NextGen technologies are still in development, there may still be opportunities to include some of the decision support functionalities into the future plans of the aforementioned technologies. If such opportunities arise, this paper could provide an initial guidance on how to prioritize the critical functionalities needed for FAM operations.

References

[1] Federal Aviation Administration, 2010, *Operational concept for Flexible Airspace Management.* Washington, D.C.: Air Traffic System's Concept and Validation Group, AJP-66.

[2] Homola, Jeffrey, P. U. Lee, T. Prevot, H. Lee, A. Kessell, C. Brasil, and N. Smith, 2010, "A human-in-the-loop exploration of the Dynamic Airspace Configuration Concept", *AIAA Guidance, Navigation, and Control (GNC) Conference and Exhibit*, Toronto, Canada.

[3] Lee, Paul, C. Brasil, J. Homola, A. Kessell, H. Lee, and M. Mainini, 2011, "Benefits and feasibility of the Flexible Airspace Management Concept: a human-in-the-loop evaluation of roles, procedures, and tools", *Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011),* Berlin, Germany.

[4] Federal Aviation Administration, in press, *Flexible Airspace Management Enabling Technologies Analysis*. Washington, D.C.: Air Traffic System's Concept and Validation Group, AJP-66.

[5] Lee, Paul, T. Prevot, J. Homola, H. Lee, A. Kessell, and N. Smith, 2010, "Sector design and boundary change considerations for Flexible Airspace Management", *10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference*, Fort Worth, TX.

[6] Lee, Paul, T. Prevot, J. Homola, H. Lee, A. Kessell, C. Brasil, and N. Smith, 2010, "Impact of Airspace Reconfiguration on Controller Workload and Task Performance", *Third International Conference on Applied Human Factors and Ergonomics.* Miami, Florida.

[7] Prevot, Thomas, P. Lee, T. Callantine, J. Mercer, J. Homola, N. Smith, et al., "Human-in-the-loop evaluation of NextGen concepts in the Airspace Operations Laboratory," AIAA-2010-7609 *AIAA Modeling and Simulation Technologies Conference*, Toronto, Ontario, Aug. 2-5, 2010.

[8] Metron Aviation, 2010, *MSP functional analysis against current systems* (DTFAWA-10-D-00033: Task Order 004).Dulles, VA.

[9] Joint Planning and Development Office, 2009, *NextGen Weather Plan, Version 1.1.* Washington, D.C.

[10] Ryan, T., J. Tuell, and B. Lambert, B, 2009, *The 4-dimensional weather data cube.* Retrieved March 2, 2011 from the Aeronautical Information Exchange Website:http://www.aixm.aero/gallery/content/public/2009_AIXM_Met_Conf/Day 1-06 --- 4-D Weather Data Cube (Tom, Jason, and Bruce).pdf

[11] MITRE Corporation Center for Advanced Aviation System Development, in press, *Collaborative Airspace Constraint Resolution (CACR) Concept of operations..* McLean, Va..

[12] Federal Aviation Administration, 2010, *Program requirements for Post ERAM Release 3.* Washington, D.C.

[13] G. Loude and K. Levin, 2007, *Airspace roadmap: Airspace evolution plan, version 1.0* (MTRW000X). McLean, Va: MITRE Corporation Center for Advanced Aviation System Development.

[14] MITRE Corporation Center for Advanced Aviation System Development., 2011, *Concept of operations for initial Conflict Resolution Advisory (CRA).* McLean, Va.

[15] Federal Aviation Administration, 2010, *NVS brings controller communications into the internet era.* Retrieved from Federal Aviation Administration Website on February 20, 2011 from https://employees.faa.gov/org/linebusiness/ato/news/headquarters/story/index.cfm?newsId=61890

[16] Federal Aviation Administration, 2010, *National Airspace System Voice Switch (NVS).* Retrieved from Federal Aviation Administration Website on February 20, 2011 from http://www.faa.gov/about/initiatives/nextgen/portfolio/trans_programs/nvs/index.cfm

[17] Federal Aviation Administration, 2010b, *FAA Data Communications "how we want to fly"* brochure. Retrieved on February 20th 2011 from http://www.faa.gov/ about/office_org/headquarters_offices/ato/service_units/techops/atc_comms_services/datacomm/documentation/media/brochures/09818_DataComm_Broch_PRINT2.1.pdf

Acknowledgements

30th Digital Avionics Systems Conference

October 16-20, 2011