Tools for Trajectory-Based Air Traffic Control and Multi Sector Planning

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ABSTRACT

A suite of integrated ground side tools is presented that enables trajectory based air traffic control operations on individual sectors and multi sector planning positions. With these tools controllers and traffic planners can assess complex traffic problems and easily create and communicate trajectory changes to other controllers and/or flight crews. A recent study at NASA Ames Research Center on multi sector planning conducted by the FAA, San Jose State University, and NASA yielded very positive results. Participants were able to use the provided automation to resolve conflicts, avoid convective weather cells and redistribute anticipated sector loads in challenging air traffic situations. This paper describes the tools and presents results from the recent simulation.

Keywords

Automation, 4-D Trajectories, Multi Sector Planning, Controller Tools

INTRODUCTION

Moving towards the Next Generation Air Transportation System (NGATS) will require substantial changes to organizational structure and support automation in the air traffic control domain [1, 2]. Organizational changes and new automation often go hand in hand, as one typically relies on the other to be most useful. A study on Multi Sector Planning (MSP) was conducted at NASA Ames Research Center by the FAA, San Jose State University, and NASA, observed by researchers from MITRE and Eurocontrol. The goal of this study was to evaluate two air traffic control team concepts that include an MSP position [3-5] supporting multiple radar controllers in comparison to the current team organization of radar controller and radar associate for each individual sector. One concept, termed “Multi-D”, took the traditional role of a data-controller but provided these types of services to several radar controllers (three radar controllers were assigned to be the responsibility of the data-controller in this experiment). In the second configuration, the MSP served functions often associated with “traffic flow” management, coordinating with external MSP areas and attempting to manage sector traffic levels in a proactive process balancing among the three sectors in their area of responsibility as well as with external areas. This function was termed “area flow manager”.

It was hypothesized that many of the tasks currently conducted by the radar associate could, in the future, be handled by advanced automation and the new multi sector position. As an additional potential benefit the strategic view provided at the multi sector planning position could also help create more efficient trajectory-based solutions to problems such as traffic congestion and weather that might otherwise be handled in a sequence of local tactical solutions. The impact of this operational change was investigated with a prototype system that includes one possible instantiation of the required advanced automation. The prototype was implemented into the Multi Aircraft Control System (MACS) that was used for the simulation [6].

The following sections describe first the method used for the multi sector planner simulation, then the tools provided to the sector controllers, the multi-D and the area flow position. Next, results with regard to the tools are presented. The general evaluation of the different operational concepts is the primary subject of other publications [7].

MULTI SECTOR PLANNER SIMULATION

Study design

A two week study was conducted in late January/early February 2006. Ten participants took part in the study. All were current sector controllers or traffic managers at Centers in the NAS. Two groups of 5 participants each conducted 10 runs half in the “baseline” condition, half in one of the two experimental conditions. In each condition the controllers experienced high volume traffic problems reflecting approximately 1.3 times current day maximum sector load and weather problems with moderate traffic load at approximately current day non-weather levels. The first group ran the multi-D condition, the second the area flow condition. Each controller was trained for one and a half days on the simulation environment, the new tools and the procedures. Nine out of the ten controllers had no prior exposure to the provided toolset

Simulated Air Traffic Environment

An air traffic environment that was considered possible by 2015 was simulated for all conditions during the study.

All aircraft in the high altitude domain are equipped with controller-pilot data link capabilities (CPDLC) to receive route modification uplinks and frequency transfer messages. All aircraft broadcast their flight state via automatic dependent surveillance-broadcast (ADS-B). The ground system maintains aircraft trajectories based upon flight plan information and amendments, and accurate state information. Conflict probing is available on all positions and controllers can use route and altitude planning functions to data link trajectory changes to eligible aircraft and other ground positions. Information about the current location, shape and trend of convective weather cells is available. The weather information is updated every six minutes, at which point the cell shapes usually change slightly.

Test sectors, traffic flows and test positions

The traffic flows and test sectors are depicted in Figure 1 and consist of three high altitude and transitions sectors that are based on actual Ft. Worth Center (ZFW) sectors managing departing, arriving and crossing traffic. Half the scenarios during the MSP simulations were heavy traffic scenarios, the other half was not as heavy, but several storm cells were moving through the test sectors from the southwest to the northeast.

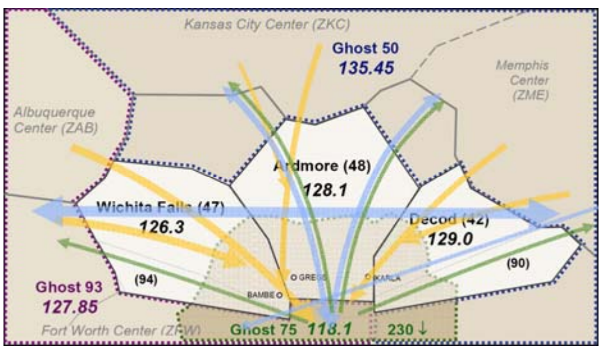

Figure 1: Traffic flows through the experimental test sectors

The multi sector area overlays all three sectors, no individual D-Side was used for the MSP runs. A configuration of one radar controller and one radar associate was used for two test positions in the baseline runs. The R-side tools were integrated into an accurate emulation of the operational controller workstation. A position similar to the R-Side was provided to the D-Side to simulate a future system, in which D-Side capabilities would not be as limited as they are today, and to provide an adequate comparison environment to the highly capable multi sector planning position. The R-Side capabilities were the same throughout all conditions.

R-SIDE OPERATIONS

Task Description

Radar (R-Side) controllers are responsible for maintaining safe separation between all aircraft within their sector, expediting the traffic flow and providing additional services, workload permitting. Air Route Traffic Control Centers (ARTCC) in the USA staff busy air traffic control sectors typically with a team consisting of a radar controller and a radar associate. In a low workload situation only a single Radar controller may work the position, in extremely busy periods other controllers may be added to the sector team.

Experienced air traffic controllers always plan how they manage the sector depending on the traffic patterns and additional constraints like weather. The advanced R-Side prototype toolset was designed to aid controllers in formulating, executing and monitoring their plan.

Heavy traffic in the central test sector Ardmore (see Figure 1) can prompt controllers to formulate and execute a sector plan such as the following; *descend the arrivals early to get them underneath the departures and the crossing traffic. Climb the Departures as soon as possible and route them along the most direct path to their next enroute fix whenever possible. Change flight paths of crossing traffic only if required to maintain safe separation.*

The weather scenarios required a different plan in Ardmore, such as: *reroute the departures heading northwest behind the weather and through Wichita Falls. The early arrivals will be rerouted east of the weather. Once the weather has moved further east arrivals can fly along the west side. Overflights will be routed north or south depending on their current position, their planned route of flight and the weather in Falls and Decod. Route some flights through the gaps between the cells, if the weather appears sufficiently stable and predictable.*

In order to implement their plan the sector controllers periodically scan the traffic and complete a successive set of tasks for each aircraft that include

- Receive track control and communication
- Asses and modify the trajectory if necessary
- Issue clearances as necessary
- Transfer track control and communication.

Automation support

The following automation support was integrated into the R-Side to aid the controllers in conducting these tasks, while keeping controller workload at manageable levels:

- Data link for transfer of communication
- Trial planning of routes and altitudes integrated with data link
- Trajectory-based conflict probing
- Ground to ground coordination of trajectory changes.

Data link for transfer of communication

This automation function is designed to simplify the tasks of receiving and transferring track control and communication. Data link interactions were integrated as an extension to the implementation used for the FAA free flight phase 1 data link trials in Miami Center [8]. The data link for transfer of communications links the frequency change automatically to the aircraft handoff process. Upon handoff acceptance the receiving controller can monitor the progress of the transfer of communication in the data tag and receive the initial contact message from the flight crew promptly without any action by the sending controller.

Trial planning of routes and altitudes integrated with data link and trajectory-based conflict probing

The automation for trajectory planning, communication and conflict probing was designed to support the radar controllers in assessing and modifying the trajectory and issuing clearances as necessary. Particular emphasis in the implementation was given to integrating a highly responsive trial planning function seamlessly into the controller's task sequence to make it useful in high workload situations [9]. Figure 2 depicts an example of a controller assessing and modifying the trajectory of an aircraft according to his/her sector plan.

Before the aircraft enters Ardmore's airspace the controller checks the route of the aircraft. In this example UAL572 is predicted to fly directly through a severe storm, so it will have to be rerouted to the east. (Figure 2 – 1) After scanning the traffic in the sector again and dealing with more urgent tasks the Ardmore controller plans the new routing of UAL572, still before it actually enters Ardmore's airspace. With the trial planning tool, the controller can pre-plan and communicate a route change that will have the first turn inside Ardmore instead of waiting until the aircraft reaches the Ardmore sector or coordinating a radar vector with the upstream controller.

To access trial planning the controller picks a designated data tag item ("portal") and a provisional trajectory is displayed immediately. The automation inserts a point two minutes in front of the aircraft to give the controller and the flight crew time to plan and execute a stable trajectory change. Trajectory points can be inserted, moved or deleted by clicking on the trial plan, or a waypoint on the display. Points can be dragged with the trackball to any desired location. In the process the trajectory is continuously recomputed and checked for potential conflicts, giving the controller rapid feedback about the precise path and potential traffic problems he or she is creating. A potential conflict with another aircraft is indicated by solid circles around the aircraft position symbols. (Figure 2 – 2,3)

The solution can then be uplinked to the aircraft using a "UC" (Uplink Clearance) command that will automatically package the trial plan into a format that can be sent via the data link system into the aircraft's flight management system (FMS) as a loadable "cleared route clearance" (which, for example, is supported by the FANS data link system). The flight plan is automatically amended in the ground system. The controller can incorporate an altitude change into the same trajectory modification or create a new trial plan in a separate step using the data tags altitude fly out menu. The trial plan trajectory will then be generated using the new altitude. The altitude change will be incorporated into the data link message and the new assigned altitude will automatically be sent to the ground system.

After generating and communicating the trajectory change the controller can move on to his or her next task and keep checking the data tag indication for message acknowledgement during the regular scan. The data link status list has provisions to highlight message timeouts and non-positive responses. A detailed description of is available in [9].

Arriving aircraft (like UAL572) as well as departing aircraft in Ardmore require clearances to descend or climb to their next altitude. The automation-supported ground system continuously checks the planned trajectory of all aircraft for potential conflicts. If no conflict indication is given, the system predicts the planned path to be conflict free. Controllers can use this information to help assess whether or not to issue a clearance and update the flight data, as in current day operations without having to make any specific

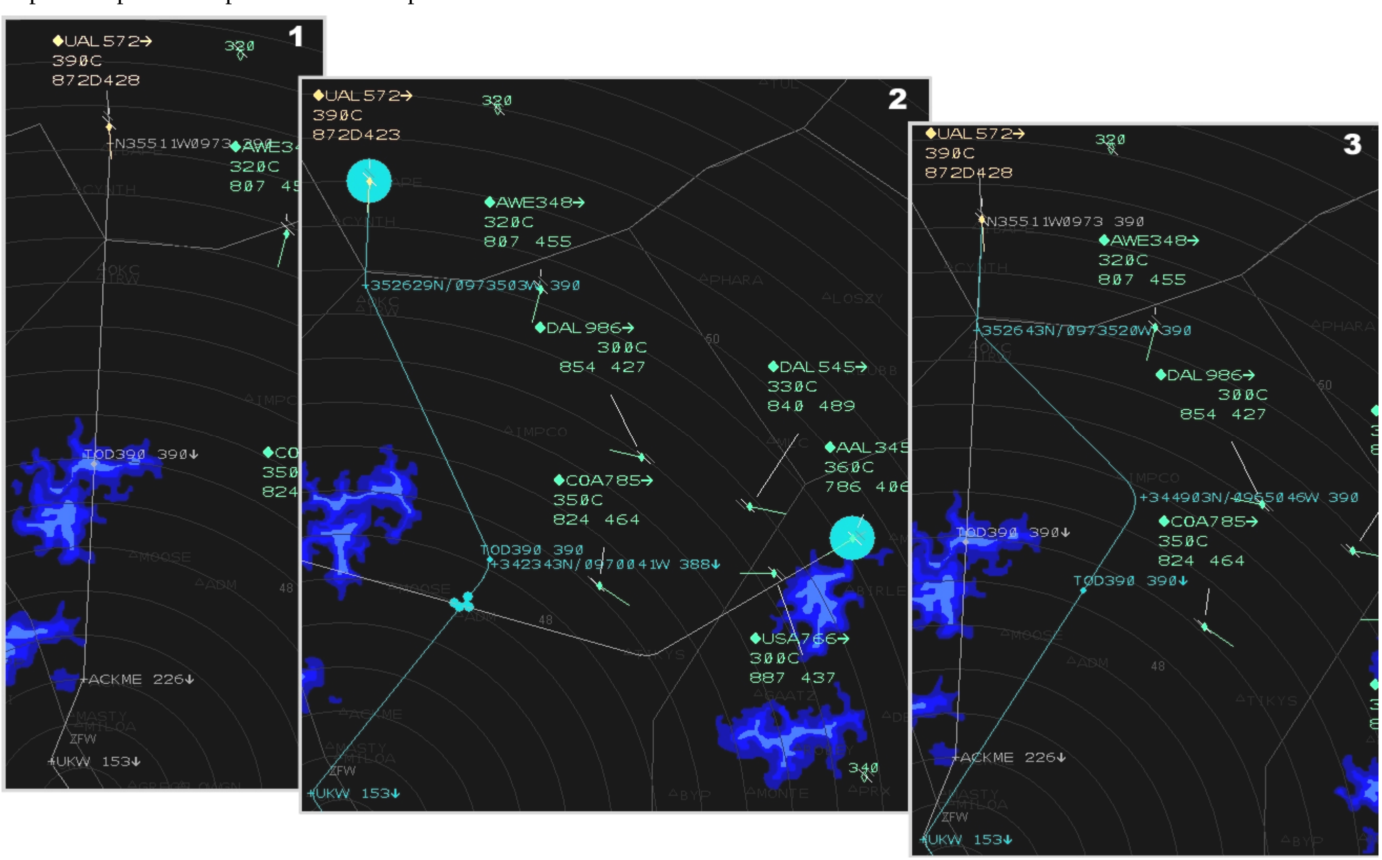

Figure 2: Route trial planning in Ardmore with conflict feedback around weather.

entries for updating the automation. The tools are designed to support strategic trajectory changes by data link and tactical changes (heading vectors, speed changes, interim altitudes) by voice. Whenever an aircraft diverts from its predicted trajectory the system creates short-term trajectories using the current state values and flight data entries available.

MULTI SECTOR PLANNER OPERATIONS: MULTI-D

Task Description

A "Multi-D" position was evaluated in one of the experimental conditions. The role of the Multi Sector Planner (MSP) in the multi-D condition was to act like a radar associate (D-Side) for multiple R-Sides. In this case the Multi-D assisted the Falls, Ardmore and Decod sectors (see Figure 1). The Multi-D position was located in the same room as the R-Sides, but not directly behind or next to them. Therefore, verbal coordination was only possible via the ground-ground communication system, or by walking to the R-Side controllers.

Many tasks of the regular D-Side depend on the R-Sides' requests for assistance and are possible because the D-Side can have great situation awareness sitting right next to the R-Side. The multi-D position, in contrast, does not offer the same awareness, because the data controller has to monitor multiple sectors, is not able to monitor all radio transmission, cannot listen or talk to the R-side as easily, and cannot interpret the individual R-Sides' body language as well as if he or she were in close proximity. Therefore, the multi-D's tasks had to be different from the regular D-Side. More specifically, the Multi-D was not able to help with all the handoffs, or flight data entries. When specifying the Multi-D's duties it also became obvious that monitoring the large amount of traffic for short-term conflicts was less suitable with the additional difficulty in communicating urgent information to the R-Side.

The main multi-D task that was a priori specified consisted in reducing sector complexity via medium-term conflict management. The Multi-D was supposed to remove some of the traffic complexity, so that radar controllers could handle the traffic without the assistance of individual D-Sides. Specifically, the multi-D was asked to evaluate the traffic for potential conflicts that were predicted to occur within the next 8 to 15 minutes, plan a solution and communicate the solution to the respective R-Side for approval and execution.

A typical conflict resolution task sequence for the multi D includes:

- Detect medium-term conflict
- Plan a trajectory that resolves the conflict
- Coordinate the solution with the R-Side
- Monitor the execution of the trajectory change

In addition the multi-D was supposed to assist R-Sides upon request or when they appeared to have excessive workload.

Automation support

The automation at the Multi-D position was designed to provide additional situation awareness about sector complexities and conflicts, and tools to easily generate and communicate trajectory changes. The following functions were integrated into the multi-D controller's workstation, which was configured like a sector controller position zoomed out to show all three sectors:

- Trial planning of routes and altitudes integrated with data link
- Trajectory-based conflict probing
- Ground to ground coordination of trajectory changes
- "See-all" repeater of the R-Side displays
- Electronic flight strips
- Sector quick look
- Graphs and tables showing the predicted sector loads.

The set of base tools for trial planning, conflict probing and coordination was the same for the Multi-D as for the sector controllers. A "See-all" R-side repeater allowed the MSP to view an exact replication of any of the three R-Side displays. The Sector quicklook allowed the MSP to switch his or her display to a view centered on a particular R-Side display. Electronic flight strips (EFS) were modeled after the EFS currently operational in the Oceanic ATOP system, and not specifically tailored to support the Multi-D tasks. Graphs and tables were provided indicating the predicted sector loads. These tools were intended to provide general situation awareness to the MSP acting as multi-D. Since they were crucial to the MSP in the area flow planner role they will be described in more detail in the next section. The most important automation functions for the Multi-D position are Conflict detection, trial planning and coordination of trial plans described below:

Conflict detection, trial planning and coordination

The prototype automation monitors all aircraft continuously for potential conflicts in and around the multi sector airspace. When a conflict is detected the conflict is depicted in a conflict list and the time to the predicted initial loss of separation (LOS) is indicated as a number in the first line of the data tag. Clicking on this number displays the trajectories of the involved aircraft, highlights the aircraft with solid red circles around the position symbols, and highlights the conflict region. The MSP assesses whether this conflict is appropriate for him or her to resolve. This is determined for example by a priori verbal coordination with the R-Sides, such as "The Multi-D resolves all conflicts with more than 8 minutes to LOS" or, "the Multi-D resolves all conflicts for aircraft that are not yet controlled by the R-Side". Additionally the Multi-D can use the "See-all" to determine whether the radar controller is already working on a resolution.

Once the Multi-D has decided to resolve the conflict, s/he can use the trial planning tool described in the previous section to plan an appropriate trajectory change. The extended traffic display and the sector load graphs provide additional information for the Multi-D during the trajectory planning process to balance the workload resulting from the trajectory change.

Even though the Multi-D has access to air/ground data link, radar controllers and the Multi-D agreed that all changes would be coordinated with the R-Side. The procedure to send the trajectory change to the R-Side is similar and just as easy as sending it to the aircraft. Instead of using the "UC" (Uplink Clearance) command described previously, the controller uses the "CC" (Coordinate Clearance) command. This will automatically send a coordination request with the trial planned trajectory to the R-Side who currently has track control. In case track control changes while the coordination request is pending, the request "travels along" with the aircraft's ownership and can therefore be handled by the next controller. A message in the data link status list of both controllers indicates the presence of a coordination request and the trial planning portal is highlighted. The receiving R-Side can click on the portal to get a graphical display of the new trajectory, which is automatically conflict probed. If the controller decides to accommodate the request, he or she can use the "UC" command to send it to the aircraft. At the same time, a coordination response is relayed to the Multi-D indicating the request was accepted. If the radar controller cannot execute the request he or she can us the "CN" (Coordination: No) command that sends an UNABLE message to the Multi-D. During the coordination process, or at any other time, the Multi-D can use the "See-All" or his or her own display to monitor the status of the coordination request. The data link status and the trial planning portal provide the necessary indications. Once a coordination response has been received the trial planning portal is no longer highlighted and the task sequence is complete.

MULTI SECTOR PLANNER OPERATIONS: AREA FLOW

Task Description

In the second experimental condition the MSP served as area flow planner. The area flow planner was located in a different room and had a workstation very similar to the Multi-D described before. The tasks for the area flow planner however were very different. One of the main area flow planner tasks in high traffic was to balance the predicted traffic load such that none of the sectors in the MSP area were predicted to exceed the Monitor Alert Parameter (MAP) value specified for this sector. This organization reflects the idea that individual radar controllers can handle a certain number of aircraft without D-Side assistance and as long as this number is not exceeded traffic remains manageable. The area flow planner has no duties with regard to conflict detection and resolution. In addition to sector load balancing the area flow planner was also responsible for managing requests from adjacent area flow positions. The general sequence for balancing the sector load at the area flow planner position includes the following tasks.

- Assess the predicted sector load and determine problems
- Identify candidate flights for rerouting
- Coordinate with other area flow planner
- Plan route changes for candidate flights
- Coordinate route changes with sector controllers
- Monitor plan execution

Automation support

The area flow planner's toolset was almost identical to the one provided to the multi-D, except conflict probing was only available for trial plans. In addition, specific flights can be color coded at the area flow position by different criteria (e.g., direction of flight, destination, altitude, etc.) The load graphs and load tables were interactive and particularly important for the area flow position as described hereafter.

Interactive load graphs and load tables

In order to help the MSP assess the predicted sector load the prototyped system predicts the number of aircraft that will be present in the sectors of interest and displays the counts in a table and a graphical format. (Figure 3) The indication changes color whenever a predicted load exceeds a pre-set value similar to a monitor alert parameter (MAP). The value can be adjusted for additional complexities like weather.

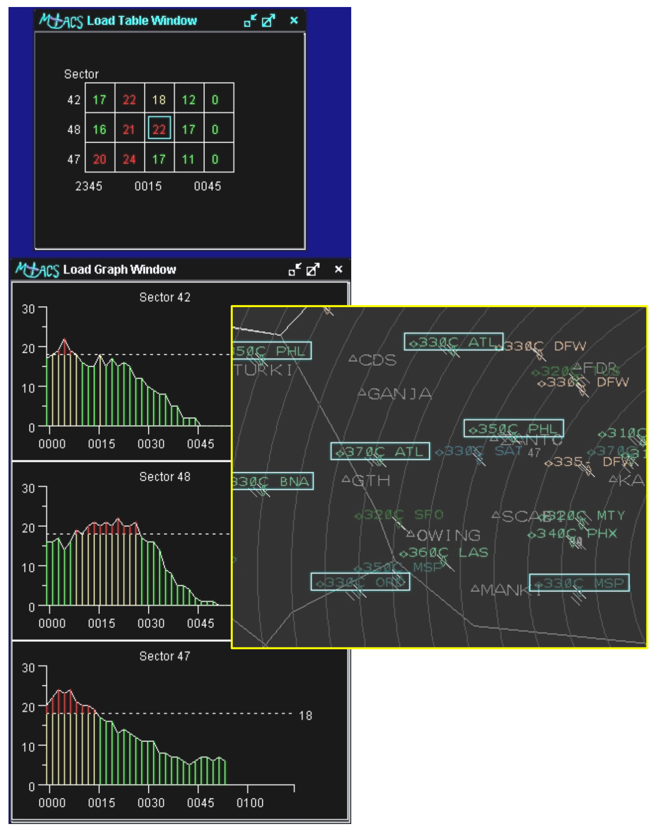

Figure 3: Interaction between load table and graph and traffic display

When the MSP recognizes excessive sector load s/he can determine the specific flights that are contributing to this load by selecting the cells within the load table or a vertical bar in the load graphs. This highlights all aircraft that are contributing to the load with rectangular boxes around the data tag on the traffic display. A typical goal of the area flow planner is to reroute as few aircraft as possible and therefore find those that create multiple problems. Therefore, the load table has been designed to accept selecting multiple cells to display those aircraft that are a factor only for all selected cells.

Before rerouting the flights the area flow planner has to make sure that the new routes will be acceptable to all impacted regions. Two adjacent area flow planners can communicate verbally, adjust the plan, and decide who will implement the reroutes. Either MSP can construct new trajectories using the trial planning functions as described before and send the coordination requests to the sector controllers. As the plan is being executed and the route changes are implemented the load graphs and tables reflect the newly predicted sector loads. Upon successful implementation none of the sectors should be predicted to exceed the pre-set maximum.

TOOL RELATED RESULTS

The general results regarding the operational concepts and additional metrics can be found in [7]. This section focuses on tool related results. First subjective assessments by the participants are presented. Second, objective measurements collected during the four area flow planner runs of the study are examined with respect to how the trajectory-oriented tools impact air traffic control operations.

Subjective ratings

Information regarding participants' subjective impressions of the study tools was collected in three ways. After each study run, participants completed a short questionnaire where they noted the adequacy of the simulation. At the end of all the simulation runs, participants completed a short questionnaire, of a dozen questions, focused on the simulation tools and events. Some of the questions required responses on a Likert-style scale where a higher rating was more positive; others were free-form and required written responses. Questions asked about tool usability, usefulness, adequacy, clutter and improvements. Due to the low number of participants, only descriptive calculations were undertaken to analyze these data. Table 1 lists the subjective ratings.

Base tools

Usability ratings for the base tools were generally high. Five of the six tools, were rated by all groups, on average, as having a usability of 4 ("easy to use") or above The only exception to this was the DSR emulation that participants rated as "usable" (average 3.2). All six base tools were rated as "useful" or "very useful", although not all participants filled in this portion of the questionnaire.

Sector tools

The four sector tools were rated as "easy to use" on average, although the sector positions rated the conflict list as "usable" (average 3.5) and the multi-D positions gave the same "usable" rating to the conflict alert tool. Three of the four sector tools also had a usefulness rating above 4 ("useful"), but the conflict list was rated as only having "some uses" (average 2.9). This lower-than-median usefulness rating for the conflict list is due mainly to low ratings given by the multi-D participants. However, sector participants only rated the conflict list just above scale median (3.1).

Table 1: Tool suite for participants and average ratings for usability and usefulness

	Area Flow		Multi-D Position		Sector Positions		All positions mean	
	Usable	Useful	Usable	Useful	Usable	Useful.	Usable	Useful
Base tools								
Ground/ground DL	5	5 *	4.5	4 *	3.5	4.2	4	4 . 2
DL status list	5	5 *	3	4 *	4.3	3.8	4.2	4 . 1
Route trial plan	4	5 *	4	5 *	4.8	4.8	4.5	4 . 9
Altitude trial plan	4.5	5 *	4	4 *	4.5	4.6	4.4	4 . 6
Color coding of information	4	5 *	5	5 *	4	4.5	4.2	4 . 4
DSR emulation	3.5	4 *	2.5	4 *	3.3	3.8	3.2	4
Sector								
Medium term conflict probe	X	X	4.5	3 *	4.7	4.6	4.2	4.4
Medium term conflict list	X	X	4.5	1 *	3.5	3.1	4.1	2.9
Conflict Alert	X	X	3.5	5 *	4	4.3	3.9	4.4
Air/ground DL	X	X	4	4 *	4.8	4.4	4.6	4.4
MSP								
Sector load graph	5	5 *	4.5	4 *	X	X	4.7	4.5
Sector load table	4.5	5 *	4.5	4 *	X	X	4.7	4.5
Predicted a/c in sector	4.5	5 *	4	5 *	X	X	4.2	4.5
See all repeater	3	5 *	5	5 *	X	X	4	4.5
Quick look function	3	4 *	3.5	4 *	X	X	3.2	4.5
Traffic display	4	5 *	4	3 *	X	X	4	4
Electronic flight strips	1	1 *	1.5	1 *	X	X	1.2	2.5

*Note: all ratings for usability and usefulness were given on a Likert-style scale with a higher rating indicating a more positive response. * only one rating available*

Multi-sector position predictive tools

Five of the seven multi-sector position (MSP) tools received high usability and usefulness ratings, multi-sector participants rated them, on average, as having a usability of 4 ("easy to use") or above and a usefulness of 4 ("useful") or above. There were two exceptions to this. All MSP participants rated the quick look function as "usable" (average rating of 3.2) and the electronic flight strips (EFS) as "very difficult to use" (average rating of 1.2) and "not that useful" (average rating of 2.5), which could be expected since the EFS were not designed to specifically support the MSP task.

General observations

Participants made numerous suggestions to observers about how to complete tasks with fewer keyboard and mouse steps.

Participants *thought* the advanced tools had a positive effect on workload, responding that they "reduced workload" (average 2.2). The information presented on the displays during the simulation was rated as creating "very little" (average 4) clutter. However, one participant rated clutter as "very unacceptable" although most other participants said clutter was "no problem".

Apart from the interfaces, where participants gave tools ratings on usability and usefulness that were two scale steps apart on average, the area flow participants thought the tools were better (gave higher ratings) than the multi-D and sector participants.

Suggested improvements and additions

Participants were asked to give suggestions about ways to reduce clutter, what aspects of the tools should be improved and additional support tools they would like to see. Four suggestions were made to reduce clutter on the screens – change the range out function, the trial plan function, the data block function and the color scheme. Of these, the data block function was mentioned most often (3 times) and the problem cited was that data blocks became unreadable when they overlapped. Participants suggested placement of the data block close to the target but not over lapping the data blocks of other targets that were close by. Other requested improvements included the communications link with the MSP, and the conflict alert. Some controllers cited occasions when "the conflict alert didn't show and it should have". It should be noted that the conflict alert logic for the study was not identical to the fielded conflict alert. It used more accurate state information and a slightly improved logic, which might have contributed to the controllers' impression. Additional analysis is underway to determine whether the prototype conflict alert could have malfunctioned.

More weather tools were the most often mentioned new type of tool (5 times). Other changes/augmentations to already existing tools in the system were suggested for flight strips, color coding, load graphs, and the quick look function. The comments about augmenting color coding functions were to reduce the need for verbal explanation between positions, so there was a procedural reason for this suggested addition. Other suggestions were received from participants and observers after the study. These included a multi aircraft trial planning function that would allow an MSP to plan the same routing for multiple aircraft at once. Another suggestion was an MSP function that would link the traffic display to the load graphs by indicating all sectors a selected aircraft would transition.

In sum, tools were judged to be usable, useful and helpful by participants, and there was no lack of suggestions for additional tools and features.

Trajectory-based air traffic operations

The following preliminary analysis has been conducted based upon the data collected at the sector controller positions during four area flow planner runs (second group). The data reflects two weather scenarios and two high traffic volume scenarios in the area flow condition. The primary tools added to the sector positions were trial planning, data link and medium term conflict probe.

Trial Planning and Data link vs. Radar Vectors

It was anticipated that a *well integrated* and *responsive* trial plan function [10] would help transitioning the air traffic system from mostly tactical operations to a trajectory-based system as envisioned for the NGATS. The data presented in figures 4-6 support this expectation on two levels. 1. Radar Vectoring was practically eliminated. 2. The trial planning function was responsive and integrated enough to uplink trajectory changes within 5 to 10 seconds after initiating the trial plan.

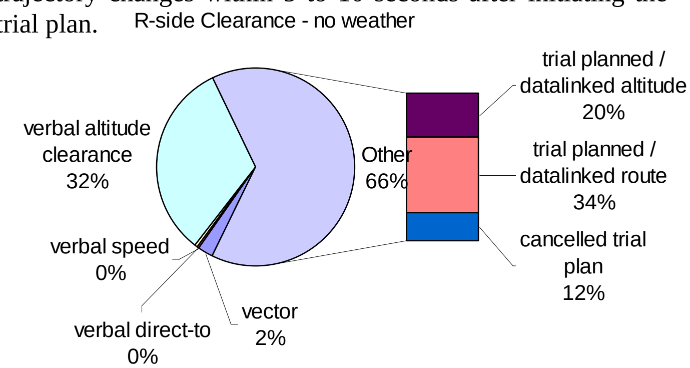

Figure 4: R-Side clearances in high traffic scenario

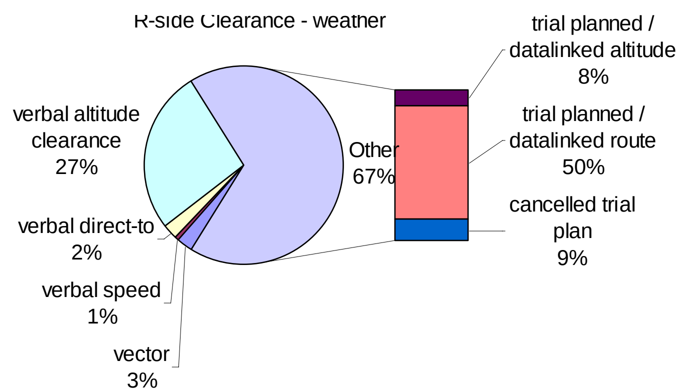

Figure 5: R-Side clearances in weather scenario

Figures 4 and 5 summarize the control instructions issued from the sector positions for the high traffic and the weather scenario. Heading vectors are used far less frequently than route trial plans. This means that even in high density traffic arriving, departing and crossing traffic can stay predominantly on trajectories, which greatly enhances the integrity of trajectory prediction based functions like scheduling, conflict probing, and traffic load computations. Similar reductions in heading vectors have also been reported in research on using airborne spacing [11, 12]. However airborne spacing operations are currently only applicable to arrivals and would therefore only impact a small subset of the total route change instructions issued in the current simulation. Regular altitude change instructions along the planned trajectories were intended to be issued by voice, while only cruise altitude changes were supposed to be issued by data link. Therefore the percentage of verbally issued altitude changes was still very high. Approximately 10 % of all trial plans were cancelled. There can be a number of reasons for this including using the trial plan to determine the aircraft's route.

Figure 6 shows the duration of the trial planning activities from when the controller first started the trial plan until the data link message was uplinked. It shows that most altitude trial plans were completed within 5 seconds while route modifications typically required 5 – 25 seconds. The high number of trial plan issued modifications indicates that this total trial planning and implementation time is sufficient for using trial planning in high workload situations.

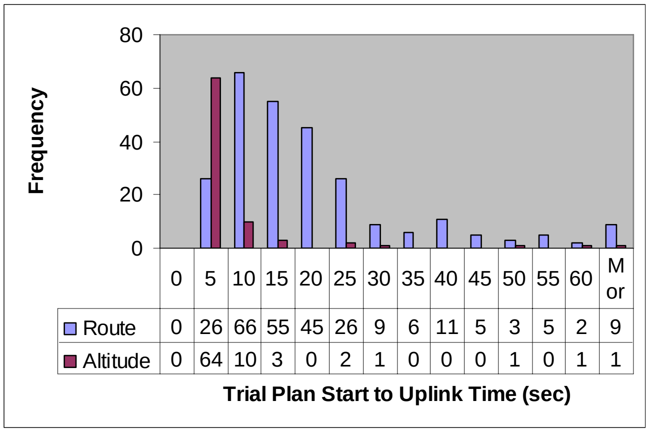

Figure 6: Duration of trial planning activities

Future directions

Many tools used in this study were the result of several iterations during earlier studies with similar toolsets in the airspace operations laboratory. As before, the feedback gathered from this study will be used to make further improvements and refinements. All capabilities complete the suite of tools and function available in MACS and the airspace operations laboratory, which therefore provides a powerful test bed for NGATS research.

CONCLUDING REMARKS

The prototyped tools for trajectory-based air traffic control and multi sector planning have proven to be adequate for the multi sector planner concept evaluation. Moreover, the sector controller tools have demonstrated their usability and usefulness for the tested environments. Tools with similar specifications could be implemented into the next generation ground automation. The MSP tools represent a very good initial set that with further improvements can provide a powerful environment for advanced NGATS concepts.

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