A MULTI-FIDELITY SIMULATION ENVIRONMENT FOR HUMAN-IN-THE-LOOP STUDIES OF DISTRIBUTED AIR GROUND TRAFFIC MANAGEMENT

Thomas Prevot*, Everett Palmer, Nancy Smith and Todd Callantine*
*San Jose State University
NASA Ames Research Center
Mail Stop 262-4
Moffett Field, CA 94035-1000
tprevot, epalmer,nsmith,tcallantine@mail.arc.nasa.gov

ABSTRACT

This paper describes a Distributed Air Ground Traffic Management (DAG-TM) simulation environment created at NASA Ames Research Center for conducting human-in-the-loop evaluations of new concepts for managing and controlling air traffic. The simulation environment combines high fidelity full mission flight simulators with mid-fidelity air traffic controller/manager workstations as well as low to mid-fidelity desktop workstations for additional pilots, controllers, experiment managers and observers. The simulation is distributed amongst different facilities and laboratories at Ames and provides for connecting multiple off-site simulators via the Internet. The Crew Activity Tracking System (CATS) can be attached for real-time tracking and analysis of pilot and controller activities, and intelligent agents can supplant ancillary human participants.

BACKGROUND

Air traffic management research of future concepts needs to address all players including flight crews, air traffic controllers/managers and airline dispatchers adequately. Interactions between the different stakeholders are among the crucial elements for the viability of a given concept. A simulation capable of addressing this type of distributed decision-making needs to meet several requirements in terms of fidelity, operator proficiency and number of participants. Most research facilities and laboratories can provide a sufficient fidelity for one particular aspect, but lack in the other aspects, because of budget, personnel and proprietary constraints.

There are several ways of addressing the problem of sufficient humans in air traffic simulations, two of which are:

- Include many participants (pilots, controllers, dispatchers) in a given air traffic simulation to work all sides of the problem adequately.
- Include automated agents for side aspects and human participants only for the focus area of the research.

The problem of sufficient fidelity is typically addressed by including specialized facilities that often consist of fielded hard- and software and are therefore costly and difficult to adjust to a particular research setup. Full mission flight simulators, air traffic controller RADAR displays are some examples. These facilities are very important for conducting research in operational environments, and need to be included in simulations. During the past years we developed a simulation environment at NASA Ames Research Center that enables conducting these types of heterogeneous multi-fidelity air traffic simulations.

OVERVIEW

We will start this paper by explaining the "open" architecture of the simulation and it's main components. We describe the distributed "simulation hub" design in detail. This architecture enables the integration of many different components at different locations in the simulation.

We will then address the currently operational and the planned components for

- aircraft target generation
- flight deck simulation
- air traffic control/management simulation and decision support tools
- operator activity tracking and automated agents

We will conclude the paper with examples of already conducted demonstrations and experiments using the Distributed Air Ground-Traffic Management (DAG-TM)[1,2] simulation environment. Future expansion of the simulation will include connecting more on- and off-site facilities and making use of additional capabilities that exist at other research and industry sites.

SIMULATION ARCHITECTURE

Figure 1 illustrates the simplified DAG simulation architecture that is currently used locally at NASA

Ames Research Center. The three main NASA Ames facilities that are involved are the:

- Crew Vehicle Systems Research Facility (CVSRF) providing high fidelity full mission flight simulators
- Flight Deck Display Research Lab providing mid-fidelity desktop simulators equipped with Cockpit Displays of Traffic Information (CDTI)[3]
- Airspace Operations Lab (AOL) providing aircraft target generation, Air Traffic Control and Management stations augmented with Center TRACON Automation System (CTAS)[4] decision support tools, Multi Aircraft Control Stations (MACS)[5], additional CDTI stations and experiment control and management facilities.

The AOL controls the overall scenario progress, hosts the Air Traffic Control and Management facilities and pilots the majority of the aircraft throughout the scenario. The research in the AOL focuses on the human factors of ground ATC/ATM operations and decision support tool integration. Other facilities participate in the same traffic environment. The full mission simulators at CVSRF provide the high fidelity environment for realistic flight deck operations research. The Flight Deck Display Research Lab addresses the research, development, design and testing of flight deck-based situational displays in depth and can evaluate advanced concepts before integrating them into a full mission flight simulator. All of these facilities can also run subsets or multiple instances of subsets of the simulation independently. Integrating the different simulation subsets is done simply be connecting the ADRS (Aeronautical Data link and Radar Simulator) hubs to each other which will be explained in detail in the next paragraph.

In addition to these currently used on-site facilities other on- and off-site facilities can be connected to the same simulation. The Research Flight Deck at NASA Langley Research Center participated in studies conducted as part of the Terminal Area Productivity Program[6,7]. Other research labs at NASA Ames and more Universities throughout the country will be connected to the simulation within

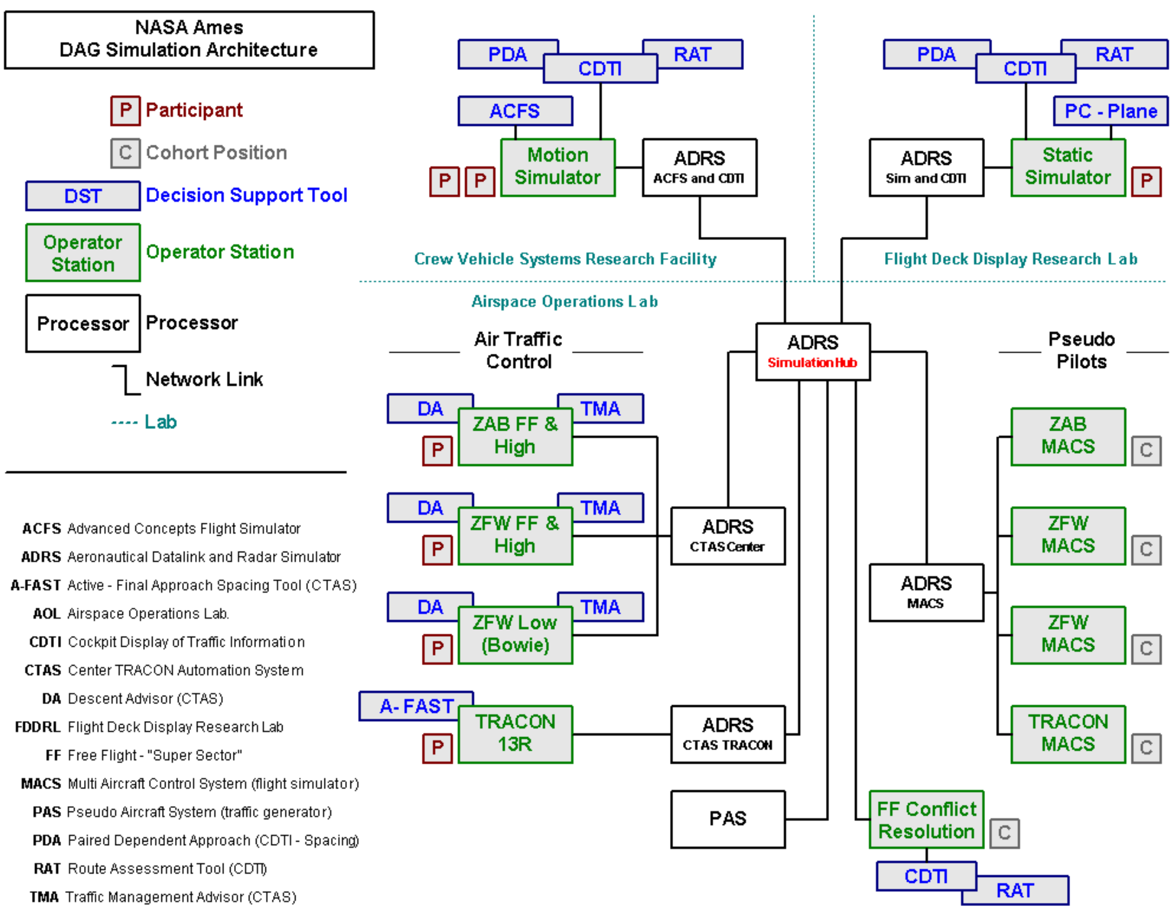

Figure 1 : Current NASA Ames Distributed Air Ground Simulation architecture [1]

this year to increase the pool of participants and facilitate off-site research of additional aspects of Distributed Air Ground Traffic Management (DAG-TM). We will give an outlook of the planned expansion of the simulation network in the final paragraphs of this paper.

ADRS - THE DISTRIBUTED "SIMULATION HUB"

Figure 1 indicates that all major components of the simulation are connected via the Aeronautical Data link and Radar Simulator (ADRS) processes. The ADRS was developed at NASA Ames Research Center originally for CTAS/FMS integration experiments within the TAP project and uses some existing CTAS functions and libraries for its communication and data base management. It is continuously extended for Distributed Air Ground Traffic Management serving more and different client processes that complement the overall simulation progress.

Though used in many different ways each ADRS software program is identical. Each ADRS can serve many additional ADRS clients, which themselves can serve additional clients. There is no limit to the number of servers and clients to be included in the simulation, because adding another ADRS-node can expand each node. All ADRSs share all required information among each other to allow clients to connect to any node and receive the same data quality and quantity. Therefore the number of simulation hubs can be tailored to network loading and real time requirements. If for example one ADRS appears to suffer from delays because of the number of network intensive clients an additional process can be started and half of the clients can be moved to the second one. All processes communicate with the ADRS via TCP/IP socket communication and use custom protocols tailored to the individual process types.

Besides communication management and data distribution the ADRS also simulates and emulates the following functions:

Host Emulation

The ADRS serves as a limited Host emulator. Each process reads the Center adaptation data (using the CTAS adaptation) for a certain facility. If more than one ATC Centers is to be simulated at least one ADRS is used for each Center and the between process communication is used for transmitting the data between Centers and/or TRACON facilities.
The ADRS network maintains and amends the filed flight plans for all aircraft in the simulation. It also generates Host AK routes and Coordination fix information to be distributed to the ATC/ATM clients. Controller inputs like handoff information are maintained and passed along between facilities and different Controller stations.

Radar Simulation

The ADRS adaptation contains information about radar sites, sweep duration and coverage for the different ATC facilities. It also contains means and standard deviations for high- and low frequency radar noise. A radar simulation module inside the ADRS simulates radar sweeps, radar noise, cone of silence areas and alpha beta tracks the radar data.

Data Link Simulation

The ADRS receives data link information from simulated aircraft or ground facilities in different formats. It delays, converts and forwards the information as required. Data link delays can be configured with mean and standard deviations separately for Controller Pilot Data Link Communication (CPDLC) or Automatic Dependent Surveillance (ADS) and ADS-Broadcast (ADS-B) applications[8]. In addition to individual data link assignments the ADRS can also be told to select a certain percentage of aircraft to be data link equipped. This function can be used to compare the effects of different data link equipage percentages on a certain operational concept.
Besides several custom formats some ARINC702[9] standards are supported that can be used with current FANS (Future Air Navigation System) equipped aircraft. In previous studies a slightly modified Honeywell Flight Management System (FMS) was used at Langley Research Center and demonstrated the operational validity of the chosen formats.[10]

Aircraft State and Trajectory Data Harmonization and Maintenance

A complex distributed air ground simulation usually includes many different aircraft target generation sources that can have a wide range of data quality and quantity. Multi aircraft target generation facilities typically only have rudimentary route information and almost no vertical profile information on aircraft trajectories. Advanced flight management system equipped aircraft can have full trajectory and state information, including current winds, temperature, etc. Air traffic research needs to address the issue of mixed equipage, including varying data quantities. However, it is extremely desirable for research and simulation purposes to have the highest level of data available first and then select the amount and mixture of data to be distributed independent of the original data source. This way the individual data recipients do not have to identify the particular data source and can treat all information equally.

Therefore, the ADRS harmonizes all received data and estimates missing records. If, for example an aircraft data source only reports it's ground speed, true track and altitude, the ADRS uses it's own wind, atmosphere, and data base models to estimate the wind components, true and magnetic headings and tracks as well as true and indicated air speeds. If an aircraft data source only reports it's waypoints along the route, cruise altitude and ground speed, the ADRS uses crossing restrictions from adaptation data, typical climb and descent profiles for the given aircraft type to estimate full three-dimensional trajectories, as they could have been downlinked from Flight Management Systems. These trajectories can then be used to simulate different levels of data link intent information or to enable FMS-like behavior on pseudo pilot stations. The trajectory functions are not as sophisticated as integration-based trajectory synthesis algorithms like those used in CTAS, but they require only very few computations and provide a sufficient level of fidelity for the majority of aircraft.

Process Control and Monitoring

Each ADRS reports the number, type and status of it's connections to it's ADRS server and clients. This status information includes statistics about number of bytes sent and received, connection delays, and configuration of the connected clients. This information can be used to monitor the health status and activities at any point in the simulation and to assign certain responsibilities to the connected processes. These responsibilities include assignments like the process that provides the state information for a given aircraft and the pilot station in command. This is particularly important, because aircraft can be handed off between pilot stations, taken over by different flight simulators, and can be manipulated from CDTI workstations. We will revisit this point in the paragraph about the Multi Aircraft Control System MACS.

AIRCRAFT TARGET GENERATION

Any air traffic simulation needs a capability to generate scenarios with many aircraft that can be simulated and reproduced in real-time at a sufficient fidelity level. Aircraft target generators typically rely on point mass aircraft models. Several programs have emerged over the past decades providing low- to mid-fidelity air traffic simulations to generate aircraft

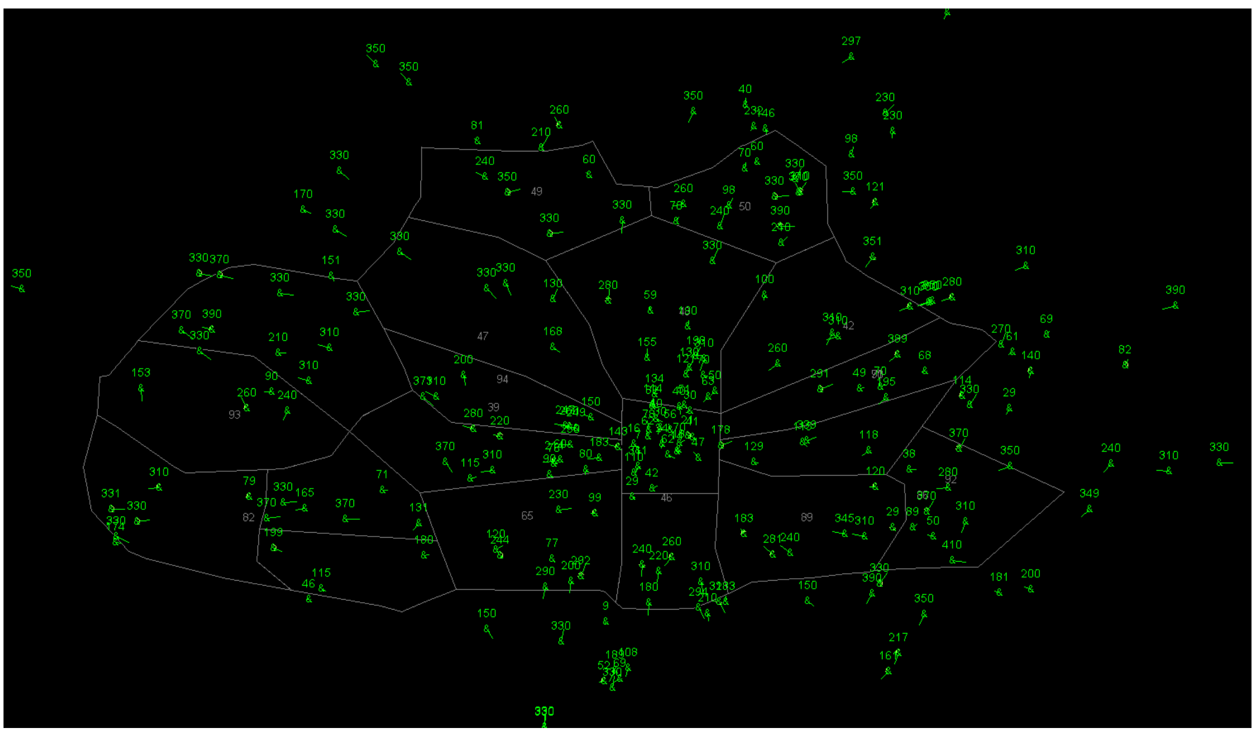

Figure 2: Typical simulated traffic scenario at ZFW. Currently ca 50 aircraft are actively simulated and controlled and 170 prerecorded and played back. During the simulation ca. 800 aircraft will enter and/or exit the run with ca 100 being actively controlled.

targets for controller displays that can be controlled by pseudo pilots. Some of these multi-aircraft simulations are frequently used in air traffic research, such as NASA's Pseudo Aircraft System PAS[11], the FAA's Target Generation Facility[12], NLR's Air Traffic Control research simulator NARSIM[13]. Additionally even the Internet offers free air traffic control software, e.g. [14]. Most of these tools provide custom replicas of ATC displays and relatively simple interfaces for entering pseudo pilot commands. The aircraft dynamics is generated by an internal simulation module and typically permits entering autopilot commands to change heading, altitude and speed of an aircraft. Currently we are using the PAS system for generating actively piloted aircraft mixed with replaying prerecorded data. One planned ADRS expansion involves creating an interface to the FAA's target Generation Facility.

Typical DAG-TM scenarios running for 60 -90 minutes involve 70 -120 active and 500 to 1000 prerecorded aircraft. Typically 200 -300 aircraft are in the air across the simulated Center at any given time. Figure 2 shows a Dallas Ft Worth example which is a screen snapshot from a MACS overview display during a simulation.

FLIGHT DECK SIMULATION

The current DAG-TM simulation gives researches access to three different levels of fidelity for flight deck research:

- Full mission flight simulation
- Desktop based single aircraft flight simulation
- Desktop-based multi aircraft control stations

Each of these can be equipped with CDTI and data link interfaces.

Full Mission Flight Simulation

Figure 3 shows the Advanced Concepts Flight Simulator that is currently used in the DAG-TM simulation environment. This 6 degree of freedom full mission flight simulator is equipped with FANS-type data link capabilities, custom Boeing 777 like data link interfaces developed for the TAP program[15] a Vertical Situation Display[16] and Cockpit Display of Traffic Information (CDTI) on both the Captain's and the First Officer's position.

Cockpit Display of Traffic Information CDTI

The CDTIs communicate to the Flight Management System via the ADRS using ACARS formats to facilitate loading of route changes that are graphically generated on the CDTI. The Flight Management System is capable of autoloading data linked forecast winds, route modifications, cruise and descent speeds. Route change requests can be generated on the CDTI and downlinked to ATC for review. Therefore the ACFS is capable of participating as a free flying aircraft as well as an aircraft fully equipped for trajectory negotiation tasks. Figure 4 depicts a route modification created on the CDTI. This modified route can be directly sent to the Flight Management System or to Air Traffic Control.

The CDTI also contains a self-spacing module that allows flight crews to select a lead aircraft and a time or distance to follow. The appropriate speed to achieve/maintain the desired spacing is computed and displayed. Flight crews can manually select the speed or use a specific autopilot mode that closes the loop and commands the computed speeds automatically. More details on the CDTI can be found for example in [3]

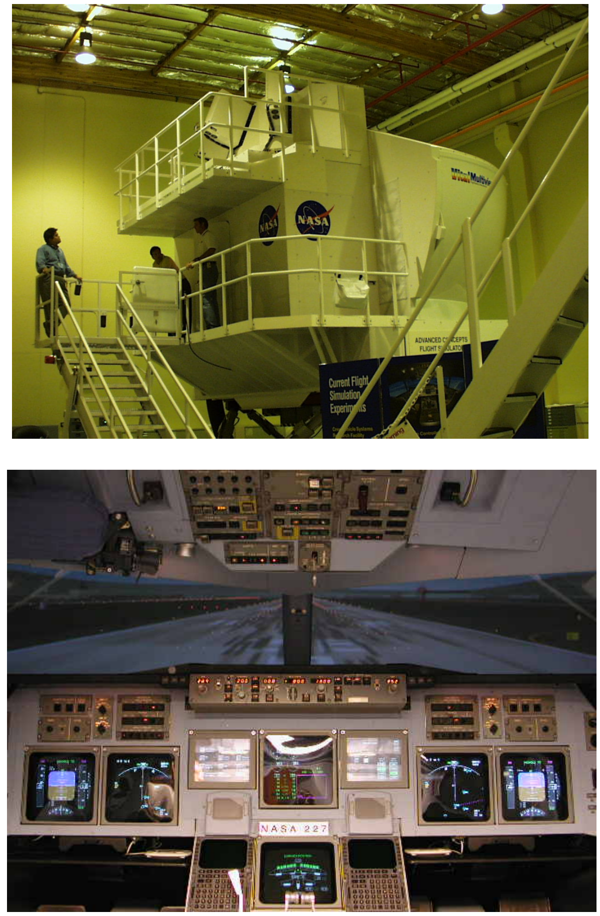

Figure 3: Advanced Concepts Flight Simulator

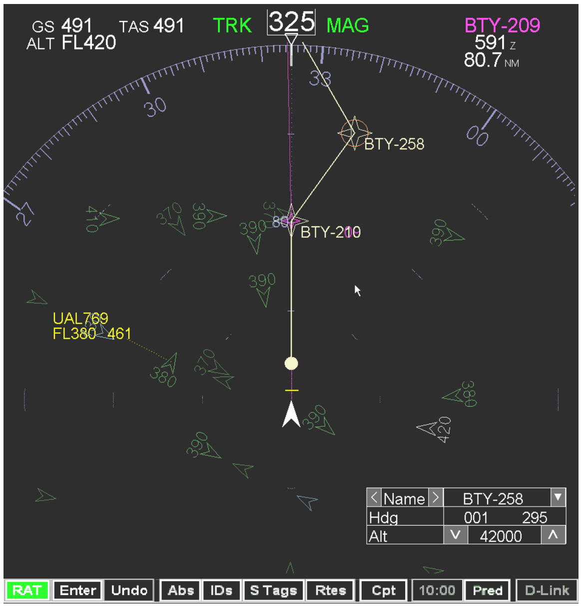

Figure 4: CDTI with Route Modification

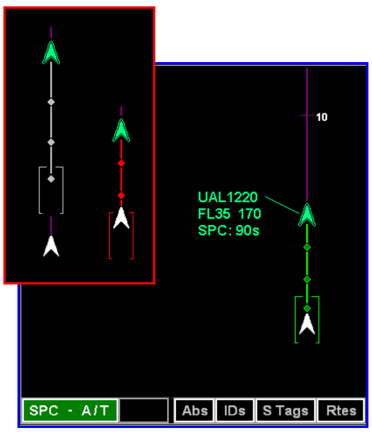

Figure 5: CDTI in self -spacing mode

Desktop-based Single Aircraft Flight Simulation

In order to increase the number of realistic flight deck responses desktop-based single aircraft simulators can be attached to the air traffic simulation. The "miniACFS" is a desktop-based version of the ACFS that provides the same capabilities and interfaces as the ACFS discussed in the previous chapter. The "PC-Plane" developed at Langley Research Center is a PC-based simulator of a Boeing 757 flight deck using the same interfaces to the ADRS as the Research Flight Deck at LaRC. The Flight Deck Display Research Lab at Ames Research Center developed a combination of the Pc-Plane with a CDTI display and custom data link interfaces that can be distributed to many simulation sites to participate as additional flight decks in traffic scenarios. This increases the number of well-equipped aircraft participants as required for DAG-TM research.

The second major advantage of including these types of simulators lies in the early cost-effective evaluation of new display and human machine interaction concepts before taking the expensive step of a full mission flight simulation. Therefore these types of simulators play a vital and increasingly important role in DAG-TM simulations.

Desktop-based Multi Aircraft Control Stations (MACS)

Starting this year (2002) we have integrated the Multi Aircraft Control System (MACS)[5] into our simulation. MACS is a powerful research tool that is being developed at NASA Ames Research Center to increase the overall realism and flexibility of human-in-the-loop air traffic simulations. MACS is designed to enable many participants to be included in the same simulation, on- or off-site. Each MACS station is a platform independent JAVA program that provides user interfaces and views for pilots, air traffic controllers/managers, airline dispatchers, experiment managers, and observers. Any station can serve as a mid-fidelity input device, an autonomous agent or a display for any perspective of a distributed air traffic management simulation.

Figure 6 depicts an example of a MACS pilot view. In this example this MACS station gives access to 66 active aircraft, of which this station controls 11 and 55 additional aircraft can be viewed. Two aircraft require the operator's attention and are displayed in the To Do List. The operator can select any aircraft displayed in any of the aircraft list windows or by clicking on the aircraft symbol on the MAP display. He or she can enter basic autopilot commands on the Mode Control Panel and can enter LNAV and VNAV commands on the "FMS Route Panel" and "FMS VNAV Panel". The "Pilot Handoff" panel allows the operator to hand the aircraft to the MACS pilot controlling aircraft on a different frequency.

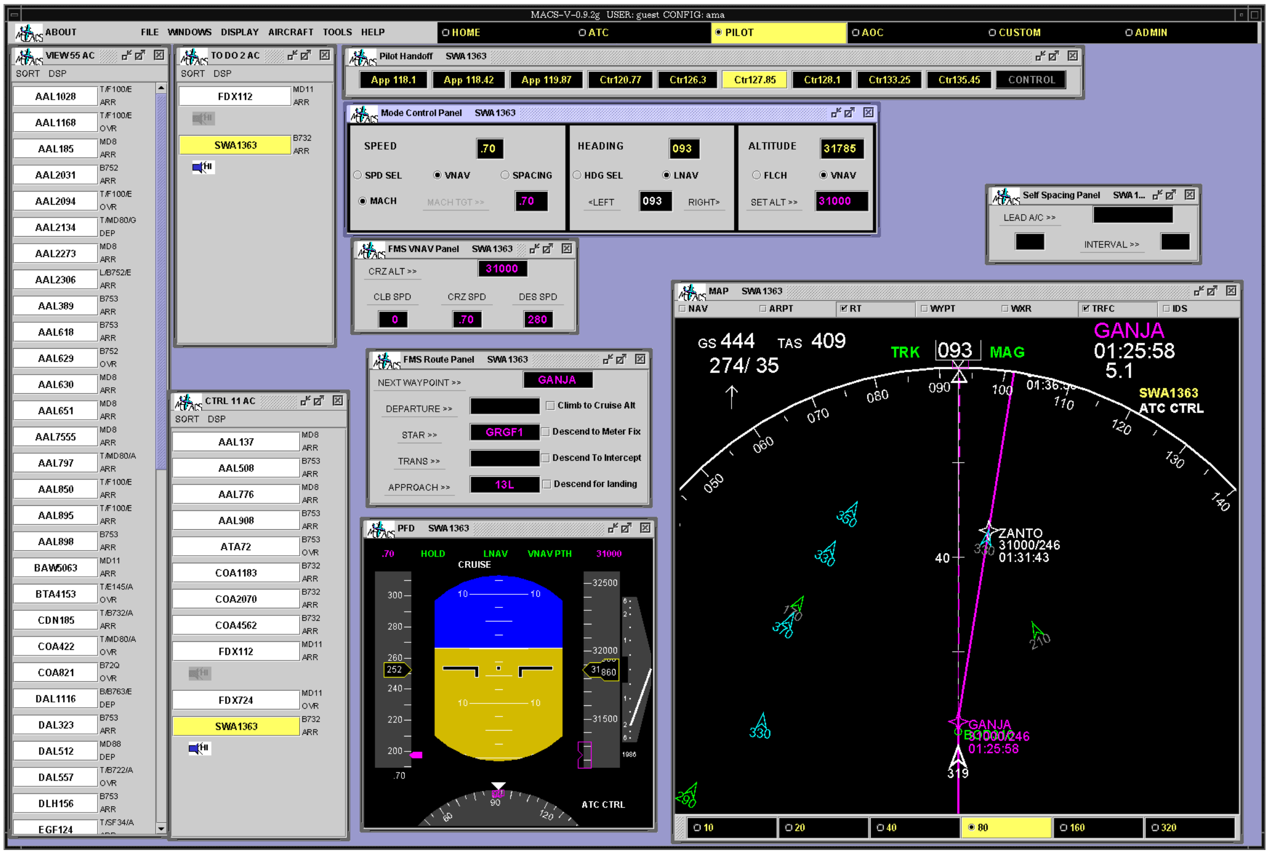

Figure 6: MACS pilot view

MACS can provide reminders to the operators when actions must be taken. The icons in the aircraft lists in figure 1 are examples for those reminders prompting the operator to check in. Other reminders include lowering the MCP altitude or entering a STAR transition or an approach routing. A MACS station can also be run in an automatic mode where, instead of reminding the operator, the actions are performed automatically. This function allows us to run prototype concepts with automatic pilot-agents for controller display development, scenario development and controller training, or to automate those parts of the airspace that are outside the immediate subject area.

A CDTI can also be displayed on top of a MACS station instead of the generic MAP display in Figure 6. When linked to this particular MACS station, all aircraft controlled by this MACS station can act as fully equipped aircraft in a given simulation.

AIR TRAFFIC CONTROL AND DECISION SUPPORT TOOLS

The air traffic control and management facilities for DAG-TM simulations are currently hosted in the Airspace Operations Laboratory (AOL) at NASA Ames Research Center. The AOL can currently provide 3 (being expanded to 6) full size sector controller RADAR positions and 5 to 8 desktop based sector controller positions. Additional traffic manager positions can be simulated. All positions can be configured for Center or TRACON operations and tailored to the particular research needs. Future plans include connecting to the CTAS development laboratories[17] and the Future Flight Central tower simulation[18] at NASA Ames.

Controller Displays

Our present setup uses modified Planview Graphical User Interfaces (PGUI) that are part of the Center TRACON Automation System (CTAS) as the primary ATC displays. MACS ATC views that provide the look and feel of DSR (Display System Replacement) and STARS displays will soon replace some of the CTAS PGUIs and the architecture will be modified accordingly. We expect this major modification to reduce controller training time and unfamiliarity effects in the simulation and to provide a more realistic interaction between controller displays and decision support tools.

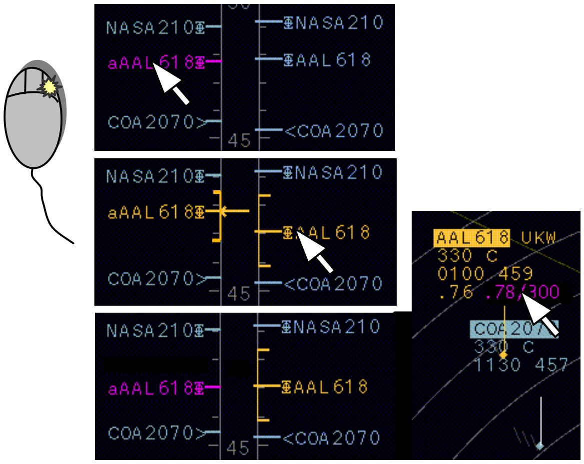

Figure 7: Scheduling and speed planning

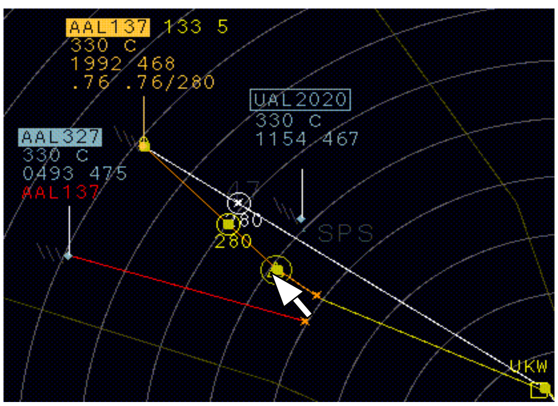

Figure 8: Route trial planning

All controller displays can display aircraft track symbols and data tag information as radar targets retrieved from the ADRS radar simulation or data link augmented precise information. Data tags can be displayed in limited, full and expanded modes. The displays enable entry of typical flight data like altitudes, handoff information, and flight plan amendments. The displays also provide access to specific decision support functions and trajectory assessment tools that are mostly gained from CTAS decision support automation. Figure 7 depicts an example of scheduling and speed planning, figure 8 shows route trial planning on a controllers display that complements the airborne route modification capability explained previously.

Decision Support Tools

The decision support tools that can be accessed from the controllers currently comprise a variety of CTAS tools:

The CTAS Traffic Management Advisor (TMA) is used to aid traffic managers and planners in arrival scheduling. The Descent Advisor (DA) can be accessed to compute speed advisories and assist in manual route planning for generating conflict free aircraft trajectories that meet the scheduled time of arrival. Additional Enroute Descent Advisor (EDA) functions will be integrated into the simulation as they become available.

In the TRACON airspace the passive Final Approach Spacing Tool (FAST) can be used for runway balancing and sequencing. New active FAST research prototypes can be included and evaluated to support advanced decision support automation in the TRACON airspace.

In support of the DAG-TM concept of aircraft self-merging and self-spacing additional functionality has been added to the TRACON displays. Actual and advised spacing intervals are presented to TRACON controllers. History circles indicate the desired position of a trailing aircraft behind a lead aircraft. This function represents controller support of the airborne self-spacing function depicted in figure 5.

OPERATOR TRACKING AND AUTOMATED AGENTS

The simulation environment also supports connections to the Crew Activity Tracking System (CATS), a model-based tool capable of analyzing subject activities in real time.[19] CATS compares actual operator actions to a model of the procedures required for a new operational concept, and detects any deviations. It also produces visualizations of salient operator-automation interactions.[20]

This technique is valuable in fast-paced, iterative design environments, because it drastically reduces the time and effort needed to analyze human operator performance data by focusing traditional analysis techniques (e.g., videotape) on those portions of the data that warrant in-depth examination. CATS also supports participatory design, because it can replay data immediately in post-trial debriefings, enabling the experimenter to directly query subjects about detected deviations. For example, CATS has been used to replay salient segments of a simulation run for ACFS subject crews and, with its visualization capabilities, immediately get their ‘take’ on events.[21]

The simulation environment also enables model-based agents to supplant ancillary human operators. This capability is important for reducing the number of human participants required for a simulation. In addition, because such agents use models of specific operational procedures to perform consistently within and between trials, variability is limited to those human subjects that are the focus of the experiment. CATS models have been used as the basis for flight crew and TRACON controller agents,[22] and preliminary efforts have been made to track the activities of en route controllers.[23] Current research continues these efforts, and seeks to develop agents capable of handling en route traffic in sectors adjacent to those staffed by human subject controllers.

USE OF THE SIMULATION ENVIRONMENT

The simulation environment described in this paper has been used for a number of different research activities. For the TAP program we ran a serious of flight deck, ground-side and integrated studies:

A flight deck centered full mission study of the human factors of flying CTAS descents in the Terminal Area[18] using the ACFS at Ames Research Center was conducted in 1998 to evaluate

- Use of data link interfaces in the Terminal Area
- Use of Flight Management Automation in the Terminal Area
- The impact of a Vertical Situation

The initial demonstration of CTAS/FMS operations with controllers in the loop at NASA Ames Research Center was conducted in the AOL and investigated:

- Acceptance and Usability of operational concept
- Controller interaction with advanced automation tools and pseudo pilots

CTAS/FMS operations with pilots in the ACFS at Ames, pilots in the Research Flight Deck at Langley Research Center and controllers in the AOL were demonstrated in 2000 and evaluated:

- Acceptance and Usability of operational concept
- Controller interaction with improved automation tools
- Pilot controller interactions in a strategic ATM environment
- Flight crew factors for CTAS/FMS operations

Based on the promising results, a CTAS/FMS integration experiment is currently conducted in the AOL with more complex traffic scenarios and higher fidelity controller positions.

One main use of the simulation environment is to serve as test bed for the ongoing DAG-TM workshops and focus meetings that are taking place at NASA Ames Research Center to test, further refine, and evaluate different aspects of DAG-TM operational concepts. In this context a series of workshops has already been conducted in 2001 and continues to be conducted over the next years at a regular basis. These demonstrations and simulations have their major focus on distributed concepts that investigate free-flight concepts with airborne and ground-based concept resolution techniques, new separation responsibilities and airspace restructuring.

UPGRADING AND EXPANDING

Because of the complex nature of the distributed air ground concepts many flight crew and controller participants are required to test any mature operational concept with an appropriate degree of fidelity. The human machine interfaces and the air/ground system architecture need to be realistic enough to make a clear assessment of the envisioned technologies, even if the target time frame may be some 15 to 20 years later. Therefore, we continuously expand and upgrade our simulation to replicate the look and feel of currently available and envisioned flight deck and controller interfaces and use a simulation architecture that can simulate all relevant potential bottlenecks and information flow requirements. Some of these changes have been mentioned throughout this paper. Figure 9 shows the planned simulation environment.

The decision support tools will no longer provide the ATC displays; instead they will be connected to the ADRS host emulation similar to their fielded version. MACS ATC views will provide the primary Center and TRACON controller displays. More facilities will be connected to the simulation by hosting their own ADRS servers that can provide the data management for several PC-Plane, CDTI and MACS stations. It is planned to build an interface between the ADRS and the Future Flight Central simulation facility at Ames to integrate the two facilities and enable simulation of uninterrupted gate-to-gate operations. Airline dispatchers get access to the simulation by adding an AOC component that includes MACS stations and CTAS traffic management tools like the Collaborative Arrival Planner CAP. These additions are on their way and will mostly become available in the upcoming months.

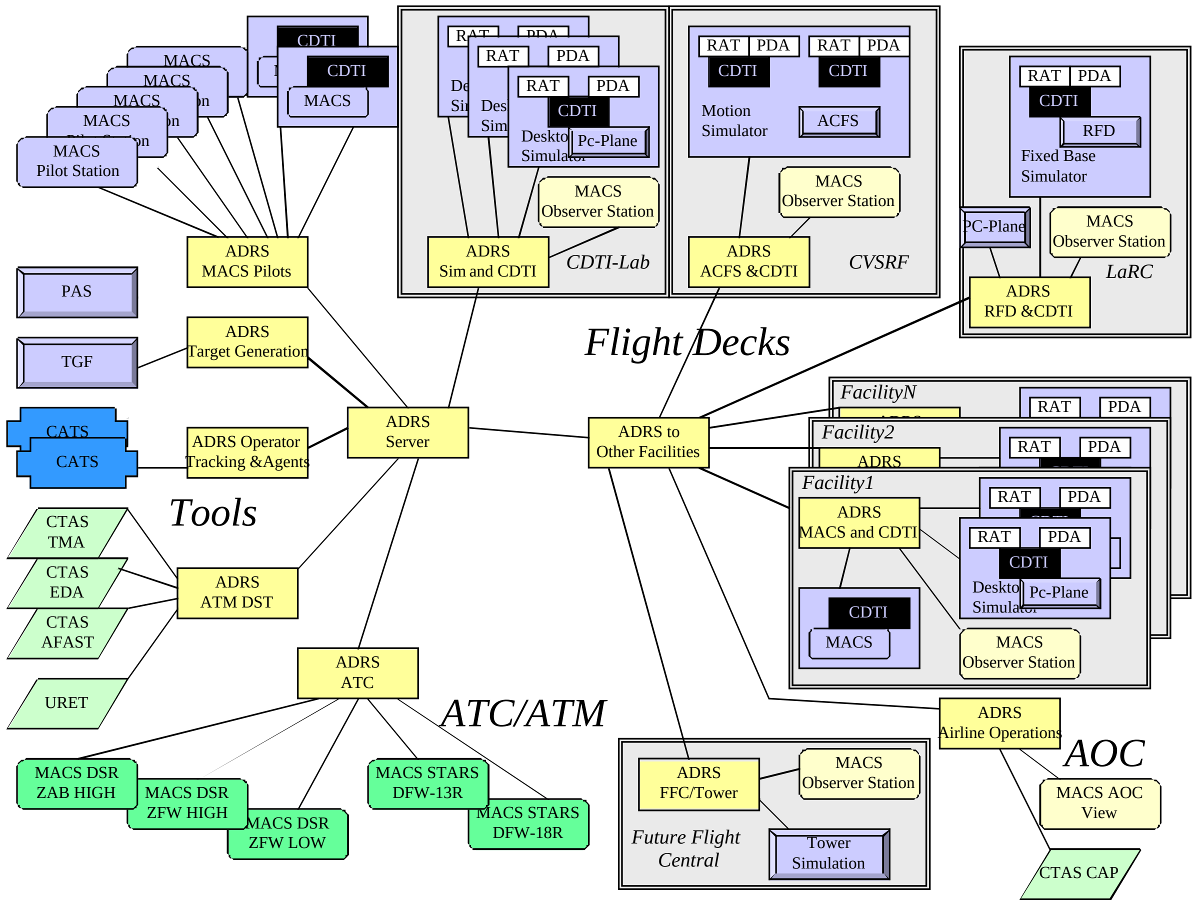

Figure 7: Planned simulation environment

CONCLUDING REMARKS

Realistic human-in-the-loop simulations of future distributed air traffic management will require participation of numerous pilots, controllers, airline dispatchers, researchers and the operational community alike in order to gain an early solid understanding of the important issues involved in implementing new distributed ATM concepts. A simulation environment was created at NASA Ames Research Center that covers the majority of these requirements for all appropriate fidelity levels. This environment has been successfully used in many research studies and demonstrations. It will be expanded to include more research facilities on and off-site as active participants, observers, or data analysts. There are no architectural limitations on the number of involved facilities in any given simulation. We plan to demonstrate distributed air ground test scenarios in a simulation that combines the Airspace Operations Lab, the Advanced Concepts Flight Simulator, the Flight Deck Display Research Lab (all at NASA Ames Research Center) and desktop based CDTI-equipped flight simulators at three different research facilities in the US by September 2002.

ACKNOWLEDGEMENTS

Creating the initial simulation environment for TAP required the professional help of many dedicated individuals including, at NASA Ames Research Center, Stephan Romahn, David Encisco and the ACFS staff and, at NASA Langley Research Center, David Williams and Rosa Oseguera-Lohr.

For expanding the simulation environment towards it's current and future DAG-TM capabilities the "CDTI-Group" headed up by Walter Johnson and Vernol Battiste with their research and development staff made major contributions as well as the "MACS development team" and the AOL support staff.

REFERENCES

1.NASA(1999), *Concept Definition for Distributed Air/Ground Traffic Management (DAG-TM)*, NASA Ames, Moffett Field, CA http://www.asc.nasa.gov/aatt/dag.hmtl (see also http://human-factors.arc.nasa.gov/ihh/cdti/DAG_TM_WEB)

2.Green, S. M., Bilimoria, K.D. and Balin M.G (2001) *Distributed Air/Ground Traffic Management for En Route Flight Operations* in *Air Traffic Control Quarterly Vol. 9 No. 4.*

3.Johnson, W.W., Battiste, V., and Holland, S. (1999) *A cockpit display designed to enable limited flight deck separation responsibility*. Proceeding of the 1999 World Aviation Conference, Anaheim, CA. http://human-factors.arc.nasa.gov/ihh/cdti/publications.html

4.Erzberger, H., Davis, T.J, and Green, S. (1993) "Design of the Center-TRACON Automation System", *Proceedings of the AGRD Guidance and Control Symposium on Machine Intelligence in Air Traffic Management*, Berlin, Germany

5.Prevot, T. (2002 in preparation). *Exploring the Many Perspectives of Distributed Air Traffic Management: The Multi Aircraft Control System MACS* HCI-Aero 2002, Boston, October 2002

6.Prevôt, T., Crane, B, Palmer, E., and Smith, N. (2000). Efficient arrival management using ATC and aircraft automation, in Abbot, K., Speyer, J., and Boy, G. (Eds.). *HCI-Aero 2000 International Conference on Human-Computer Interaction in Aeronautics*, Toulouse: EURISCO, 183-188.

7.NASA Ames Research Center (2000) *Aviation System Capacity - Terminal Area* Productivity http://www.asc.nasa.gov

8.RTCA (1998*) Minimum Aviation Standards Performance Specification for Automatic Dependent Surveillance-Broadcast*, RTCA-DO242, February

9.Aeronautical Radio Inc (2000) "*702A-1 Advanced Flight Management Computer System*" ARINC Standard.

10.Callantine, T.J., Prevot, T., Smith, N. and Palmer E.A. (2001) *Simulation of CTAS/FMS Air Traffic Management.* 4th USA/Europe Air Traffic Management R&D Seminar Santa Fe, 3-7 December, 2001

11.*Pseudo Aircraft Systems (PAS) an ATC Simulation Tool.* http://www.ctas.arc.nasa.gov/project_description/pas.html

12.*Target Generation Facility*. URL: http://www.tc.faa.gov/act-500/nsb/tgf

13.*The NLR Air Traffic Control research simulator (NARSIM)* http://www.nlr.nl/public/facilities/f75-05

14.*ATC interactive for the future of Air Traffic Control*. http://users.skynet.be/atcsim

15.Prevot, T. Crane, B, and Palmer.E.A. (1997) Flight Crew Support for Automated Negotiation of Descent and Arrival Clearances OSU 97, Columbus. OH

16.Prevot. T. and Palmer.E.A. (2002) *Staying Ahead of the Automation:A Vertical Situation Display Can Help* SAE2000-01-5614 World Aviation Congress 2000, San Diego, CA.

17. NASA Ames Research Center (2002) *Center TRACON Automation System - Facilities* http://www.ctas.arc.nasa.gov/facilities/index.html

18. NASA Ames Research Center (2002) *Future Flight Central* http://ffc.arc.nasa.gov

19. Callantine, T., Mitchell, C., and Palmer, E. (1999). *GT-CATS: Tracking operator activities in complex systems.* NASA Technical Memorandum 208788. Moffett Field, CA: NASA Ames Research Center.

20. Callantine, T. (2000). Online analysis of high-fidelity simulation data. *Proceedings of the 2000 Conference on Cognitive Systems Engineering in Process Control*, Taejon, Korea, November, 175-181.

21. Callantine, T., and Crane, B. (2000). Visualizing pilot-automation interaction. Abbot, K., Speyer, J., and Boy, G. (Eds). *HCI-Aero 2000 International Conference on Human-Computer Interaction in Aeronautics*, Toulouse: EURISCO, 87-92.

22. Callantine, T. (2001). Agents for analysis and design of complex systems. *Proceedings of the 2001 International Conference on Systems, Man, and Cybernetics*, Tuscon, AZ, October, 567-573.

23. Callantine, T. (2001). *Air traffic controller intent inference*. In B. Bell and E. Santos (Eds.) Intent Inference for Collaborative Tasks, Technical Report FS-01-05, Menlo Park, CA: AAAI Press, 25-32.