

DISTRIBUTED SIMULATION: A PROPOSED APPROACH FOR AIR TRAFFIC MANAGEMENT RESEARCH

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Abstract

This paper describes the use of distributed human-in-the-loop (HITL) simulation to address complex research questions about human performance requirements of future operational concepts and advanced technologies. Recent events in the Federal Aviation Administration (FAA) and associated research communities that support a move toward distributed simulation are reviewed. The risks of distributed simulation are discussed along with classes of fast time and human-in-the-loop simulation. Specific and candidate architectural requirements to achieve a distributed simulation capability are also described.

Background

Increasing pressure to streamline FAA development, test, evaluation, and deployment of new capabilities is forcing new efficiencies in traditional simulation approaches. As FAA systems become more complex, simulations in support of the acquisition cycle are also becoming more complex and are comprised of individual capabilities linked together in a total environment. Over the years, an increasingly sophisticated simulation capability has been built at several research centers globally. Thus, simulations of a significant number of individual components already exist, developed for other purposes and that could be used in novel ways to enable more simulation opportunities. If existing capabilities were exploited, much of the cost associated with the establishment of a simulation infrastructure could be mitigated.

Two desirable properties that would facilitate the use of existing simulation capability are reuse and interoperability. Reusability refers to component simulation models that can be used in different simulation scenarios. Interoperability refers to the ability to combine component simulation models, including human interaction, on distributed computing platforms. It is the goal of

this paper to describe an approach for achieving a distributed simulation capability between FAA and its research partners. This paper addresses the architectural requirements of a distributed simulation capability, and addresses protocol and interconnectivity issues as well.

Perspective

Distributed simulation is a laboratory without walls. It requires the use of capabilities and laboratories of multiple organizations, such as government-owned labs and commercial sources. In its simplest terms, distributed simulation can be thought of as a telephone conference bridge where actors can join and leave a session once opened by dialing in and entering a pass code. Similarly, a distributed session, once opened, can allow actors to join and leave, provided that a standard set of rules is followed. Simulation capabilities may be dispersed geographically as exemplified by previous FAA-sponsored simulations where interconnected labs were located throughout the US and Europe. Facilities typically use a private network to communicate with one another. Distributed simulations can provide for an integrated representation of the National Airspace System (NAS) by connecting various facilities and laboratories both internal and external to the federal government. Complex simulations can provide the basis for operational hands-on familiarity, procedures development, and training for airspace system users. Distributed simulation can also network computer platforms via the internet as shown in a European study using lower fidelity personal computer-based flight simulators [1].

Research community interest in the use of distributed simulation intends to provide a way to better understand, quantify, and validate NAS capacity enhancements associated with the Operational Evolution Plan (OEP) and the RTCA National Airspace System Concept of Operations and Vision for the Future of Aviation [2]. During

development of the OEP, team members made a proposal to conduct a series of analyses including fast-time modeling and HITL simulations to measure performance of the future NAS with OEP improvements in place [3]. It was envisioned that a gate-to-gate simulation could be conducted to validate operational procedures, identify and mitigate potential human factors issues, resolve integration and interoperability issues, and determine optimal airspace configurations to deliver capacity benefits. It soon became obvious that no single individual laboratory had the financial, infrastructure, or personnel resources to create all of the support structure needed in an airspace simulation or to answer the most complex research questions related to the NAS. As a result, a renewed focus on distributed simulation was established. It was postulated that one way to acquire the number of systems required to emulate the NAS was to link with other research organizations.

The Need for Distributed Simulation

There are many reasons to consider distributed simulation for addressing NAS level research questions. Simulation of gate-to-gate operations provides an integrated view of the NAS that can be used to illustrate the system-wide ripple effect of introducing new capabilities and procedures.

Distributed simulation, by definition, provides the potential for significant research without the attendant increase in cost. Functionality can be combined in various ways, organizational boundaries can be minimized, individual components can be replaced, and the impacts of geographical separation can be minimized. It has been suggested that the NAS needs more emphasis on integrated solutions. Multiple actor simulations provide the mechanism for evaluating integrated solutions.

System level distributed simulation will enable a better understanding of the dynamic nature of the air traffic management (ATM) system and the impact of a new capability or combination of capabilities, procedures, automation, etc. In an environment of multiple systems, FAA's approach to systems engineering and integration must show how capabilities interact prior to fielding them, and must identify integration strategies. We know from

experience that transitioning systems and technology updates to the field has attendant cost and operational impacts including relative to ensuring that personnel are well trained and that effects on sector staffing are well understood. Hence, it is imperative that FAA look more holistically and understand the operational impacts of multiple capabilities and tailor training accordingly.

The RTCA concept describes perhaps the most fundamental change in aircraft separation responsibility to date, creating a shared separation authority environment between air traffic controllers and flight crews. FAA, the National Aeronautics and Space Administration (NASA), and the Volpe National Transportation Systems Center conducted the first integrated, high fidelity, real-time, HITL simulation in September 1999 [4]. During the experiment, researchers examined the effect of shared-separation authority on flight operations when both pilots and controllers had enhanced traffic and conflict alerting systems. The Air-Ground Integration Experiment (AGIE) was conducted using simulation facilities located at the FAA Technical Center on the east coast and NASA Ames Research Center on the west coast. The simulation, conducted over a four week period, included six pilot participants, 12 certified professional controllers, and four operations supervisors as study participants. Technical Center facilities included: the En route Integration and Interoperability facility; Target Generation Facility (TGF); and the pseudo aircraft systems laboratory. At NASA, the Crew-Vehicle Systems Research facility was used, which included the NASA ARC Boeing 747-400 flight simulator, alerting logic, flight crew displays and tools, pseudo aircraft systems laboratory, intruder aircraft simulator, voice communication system, and audio and video recording systems. For the AGIE study, laboratories were linked across the country via a high speed circuit (fractional T1 line) that digitally transmitted data and voice but the T1 line was disconnected after the study. The use of distributed simulation not only helped answer complex research questions but resulted in many lessons learned.

Distributed Simulation: Risks

Perhaps the most significant risk to successfully implementing distributed simulation throughout the US and Europe, using the resources of multiple organizations is, simply stated, cultural. Overcoming institutional and organizational boundaries, managing an effort in a coherent and consistent manner with stable leadership, and providing for resources that will ultimately improve all participants' simulation capabilities requires stability and vision beyond one's immediate organization.

It may be difficult for organizations to sign up for and make their simulation capabilities available because of divergent and potentially conflicting priorities. Even more complex is the use of flight simulators located at commercial training centers. In most cases, commercial operators have their training schedules in place at least a year in advance and research use may be limited to after-hours access only.

Budget needs will have to be identified and resources set aside for simulation runs, including preparatory work to address various network requirements.

Consistent leadership and organizational involvement with stable points of contact in each participating organization is critical to success. Decisions that are made about test parameters, what will be measured and how it will be measured, experimental scenarios, and simulation objectives must be adhered to throughout the conduct of experiments. Changes can result in cost overruns and significant schedule slippages as well as loss of focus on original objectives. Decisions about experimental parameters should be recorded for future use.

Operational changes may identify safety and other issues that require additional analyses, affecting implementation schedules of those capabilities being examined in simulation.

Technical issues, including enhanced security considerations, associated with physically connecting all identified simulation capabilities and

locations due to different architectures, may pose a significant risk.

The logistics of distributed simulation are also difficult to overcome if the simulation network spans several time zones. For example, the west coast of the US and western European time zones are separated by 9 hours rendering a simulation during US west coast working hours cumbersome. Therefore a significant amount of advanced planning is required and once established, schedules become very difficult to change.

Types of Studies

Two types of studies are considered, including inter-process integration (process to process) and HITL. Potential scenario variations are also described. These scenarios are based in part on historical FAA laboratory usage and in part on several excellent definitions contained in reference [5]. Table 1 characterizes these studies, which are summarized in the following sections.

Inter-Process Integration

Inter-process integration describes simulations in which multiple processes are running to distribute processing load, data collection requirements, or various models of airspace activity (e.g., delay model combined with traffic and weather models). In general, the processes run in fast time mode, are comparatively low fidelity, and can involve a portion of, or the entire NAS in scope. Such simulations would be useful to gain an understanding of a new system, process, or procedure in support of alternatives analyses, conceptual studies, or investment analyses.

This class of study is not limited to low fidelity modeling of NAS components. An important characteristic is the ability to imbed a high fidelity model into a simulation, with data feeds from other lower fidelity models. This function facilitates a higher detail of analysis of the effects of a system change on a localized area, while still accounting for downstream effects on the NAS.

Table 1. Summary of Simulation Class Definitions

Simulation Type	Potential Scenarios	Scope	Application
Inter-process Integration	Low Fidelity	Small geographical area	System loading, performance
		Wide geographical area	Downstream effects of perturbation
	Mixed Fidelity	Small geographical area	System stress, system engineering
		Wide geographical area	Alternatives analysis, tradeoff studies
Human-in-the-loop	Actual NAS Equipment	ATC focus	Operational test and evaluation (OT&E)
		Cockpit focus	Procedures development and validation
		End to end	OT&E, validation and verification, procedures
	Development NAS Equipment and R&D Laboratories	ATC focus	New system development
		Cockpit focus	
		End to end	
	Mixed Fielded and Developmental Laboratories	ATC focus	System compatibility studies
Cockpit focus		Safety studies	
End to end		Transition, training, envelope stress	

One example of this application comes from the Controller Pilot Data Link Communications (CPDLC) benefit studies where a high fidelity model of an en route sector was equipped with CPDLC, and traffic flow through the sector was compared in two conditions of communication between aircraft and air traffic control. One condition used CPDLC as the primary communications medium, and another condition used voice as the primary medium. Aircraft feeding through the sector were provided by a lower fidelity traffic flow model surrounding the high fidelity sector simulation. The sector was a feeder for a major airport in the southeast, and the effect of sector flows on the airport and on down stream sectors was assessed. This model was executed in

fast time and real time for demonstration purposes, illustrating an additional characteristic of this class of simulation [6].

Inter-process integration studies are useful when needed modeling capability resides at more than one laboratory or center, or when large amounts of data must be collected and analyzed, and this data load can be distributed among several locations. In each of these scenarios, the general data flow is sequential, i.e., one process feeds another process with data; the second process operates on the data and feeds it to the next, and so forth. However, as the scope of simulations get larger, extending to NAS-wide with thousands of concurrent flights, the processing load for any one

model may exceed normal computer capacity and so the processing load may be distributed among several locations. That is, a single model may be processed concurrently among several laboratories.

Human in the Loop (HITL) Studies

In this important class of studies, there are two distinctions: HITL using actual fielded NAS equipment, and HITL using developmental research and development (R&D) NAS systems. Once the R&D capabilities are prototyped, a hybrid case emerges where R&D tools can be integrated with fielded NAS systems for HITL simulations. The applications of a hybrid configuration include performance studies of new systems against a realistic NAS baseline, system stress testing, integration of new systems, transition studies, and training requirements development. There is an additional application of this capability that is critical. This capability allows validation of human factors and system performance requirements of new systems at the design stage prior to the development and hardening cycles. Once a new system reaches operational test readiness, changes are expensive, and historically have threatened the viability of new systems. The capability to evaluate new systems, processes, or procedures in an actual NAS context, yet still prior to deployment is critical to the success of new system deployment. For this reason, this type of simulation is widely used. Accordingly, the architecture should facilitate rapid experimental setup and execution.

Fielded NAS systems are maintained under strict standards of configuration control. Therefore, use of these systems in a test environment requires specialized interface equipment that enables connection and operation, without disturbing operational certification. A similar situation exists with cockpit simulators that are certified as training devices. Whether certified as a flight training device or a full flight simulator any changes to a cockpit simulator will nullify FAA certification, and the simulator can no longer be used for pilot training until it has undergone re-certification by the FAA. For this reason, operators of commercial training simulators generally do not allow use of their simulators for R&D activities, unless the simulator is used 'dry' (without modification).

There is a tradeoff in the use of actual NAS equipment or training cockpit simulators, that is, flexibility is traded off for fidelity. When certificated systems are used, the applicability and transferability of simulation study results to 'real world' problems are generally inscrutable. However, the types of simulations that can be done with these systems are somewhat limited. R&D NAS emulations and engineering (non-certified) cockpit simulators offer greater flexibility for developmental simulations and can fill research needs where system modifications are required. Also, these systems can be modified at greatly reduced cost and risk, compared to their certified counterparts. R&D systems and cockpits are generally 'backwards engineered' from the actual system and typically lack the full functionality of the real system. Decisions regarding the use of these devices versus certified equipment are usually made on a study by study basis.

Network Capacity Requirements – Real Time Simulation

Audio Response Delay

In HITL studies, controllers exchange clearances and responses with pilots/flight crews. Two types of voice communication are required: air to ground radio-telephony (RT) and interfacility air traffic control (ATC) communications. The bandwidth of the RT channel is approximately 3 kHz and the dynamic range is compressed to approximately 30 Decibels (dB). This performance is usually adequate for the interfacility communications channels. If the voice transmissions are digitized at 6 kHz to avoid aliasing, and 8 bits of sampling are used, the resulting data rate is 48k bits per second. Widely used telephony compression such as μ -law (mu law) encoding achieves compression ratios of 4:1, which means that an audio signaling rate of 16.5 kHz¹ would be capable of meeting most capacity and delay requirements. A study of transport lag [6] showed that delays in voice transmissions greater than 200 ms were noticeable to the study subjects, and delays greater than 250 ms were objectionable.

¹ This data rate is a standard among portable telephones, and has been adopted in voice and data multiplexing systems.

Thus, for most purposes, the 200 ms threshold should be chosen.

Data Loading: Cockpit Simulator to Air Traffic Control

A de-facto standard has emerged in the simulation environment at the FAA Technical Center. The Center's TGF developed an interface specification that has been used in several airspace simulations since the late 1980's including for cockpit simulators in NAS simulations. From the cockpit to NAS, the datagram contains about 150 bytes of data and is transmitted from one to ten times per second depending on study requirements. TGF can also provide traffic data from other aircraft in the simulation to drive the target aircraft traffic collision and avoidance system (TCAS) and

window visual systems. The uplink message is slightly smaller, about 100 bytes of data, and is sent once per second to correspond to TCAS interrogation rates. If the cockpit simulator uses this data to drive the visual system traffic models, data filtering is required for smooth motion of the target image. Higher data rates could be broadcast, but in the absence of any data filtering, 30 uplinks per second (minimum, per target) would be required to render smooth target motion if the simulator visual system is driven directly.

Number of Participating Systems Required: A Potential Scenario

A representative simulation of gate to gate airspace between city pairs is shown in Figure 1.

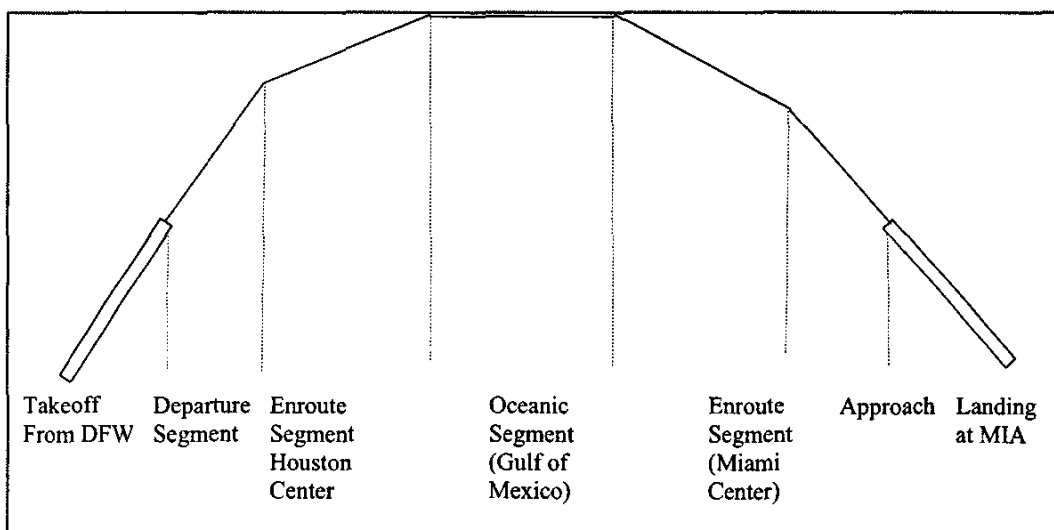


Figure 1. Gate to Gate Scenario for Network Loading Analysis

Each flight of a cockpit simulator would depart in 5 minute intervals from Dallas/Fort Worth. Each handoff at a control authority boundary would generate audio and inter-facility messages among the air traffic control entities. With 6 control region boundaries, the worst case scenario would occur if 6 aircraft positions happened to coincide with control boundaries simultaneously. Voice transmissions could be accomplished using simplex transmissions so the load for voice RT would be additive in only one dimension (uplink or

downlink). The summation of data transmission would be:

1. Voice RT: $6 * 16.5 \text{ kHz} = 99 \text{ kbps}^2$
2. Aircraft Position Data:
 $7 * 150 \text{ bytes-sec}^{-1} * 8 \text{ bits} = 8400 \text{ bps}$
3. Aircraft TCAS Data:
 $7 * 100 \text{ bytes-sec}^{-1} * 8 \text{ bits} = 5600 \text{ bps}$
4. Inter-facility Data:
 $6 * 200 \text{ bytes-sec}^{-1} * 8 \text{ bits} = 9600 \text{ bps}$

Thus, the design capacity for the proposed distributed network is 122.6 kpbs. Coincidentally, this is the approximate capacity of a single channel, fractional T-1 telephone circuit (DS0). For a simulation of 7 air traffic domains, and 7 aircraft simulators, a DS0 capacity of a T-1 telephone circuit should be adequate for the network traffic.

Note that some protocols use data compaction techniques, and the actual data transmission requirement may be less. Voice inter-facility communications are for the purpose of coordination and are not likely to occur coincident with air to ground communications transactions.

FAA Technical Center Capabilities

The FAA Technical Center operates extensive laboratories of NAS systems maintained in field equipment configuration. Processors and display systems for all ATC domains reside at the Center. In addition, developmental systems exist in the Enroute Integration and Interoperability Facility (EI²F), Research and Development Human Factors

Lab (RDHFL), and TGF. A network of support systems exists in the laboratories to support operation of each of the systems. Brief descriptions of several of the capabilities follow.

Target Generation Facility

TGF is a crosscutting infrastructure resource capability that is capable of generating aircraft targets, and driving the Terminal and Enroute laboratories at the Center. In addition, TGF can also drive the developmental system laboratories. TGF is capable of generating up to 800 aircraft simultaneously (600 piloted), and can simulate up to 50 radars simultaneously. It can emulate radar channel data signaling and formats (e.g. common digitizer [CD] formats) and is therefore able to drive actual NAS systems at their radar interfaces. In this manner, TGF can drive fielded NAS systems while maintaining the configuration integrity of the system. Figure 2 shows the interface between TGF and the en route and terminal system laboratories at the Technical Center.

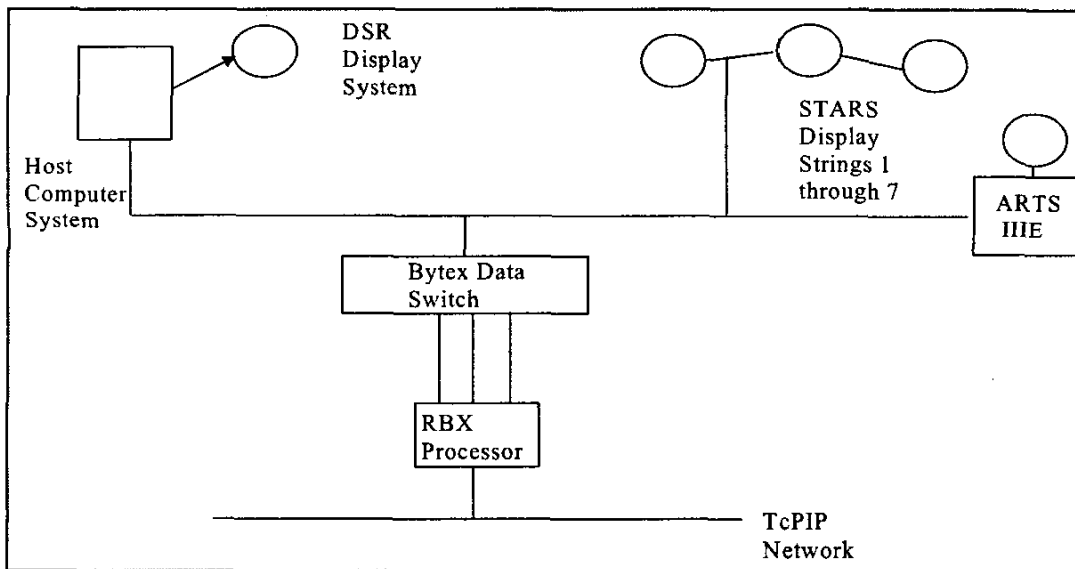


Figure 2. TGF – NAS LAB Interface Configuration

Two systems are shown in Figure 2 that perform conversion between TGF and radar data. RBX is the function that generates the radar data including all timing signals (azimuth reference and change pulses), and can also generate weather and inter-facility messages to drive the ATC systems.

BYTEX is a laboratory switch that routes data from the RBX to the particular system under test. It should be noted that the laboratory capability includes the provision of live radar feeds, and permits playback of recorded radar data. BYTEX

switches radar from the appropriate source to the appropriate laboratory.

RBX interfaces with TGF through a TcPIP network. TGF can generate aircraft target data internally, or can accept data streams from cockpit simulators which can then be converted into radar data. TGF also has the capability to merge data from an external cockpit simulator with an internally generated aircraft target. This capability has proven useful in track initiation and in maintaining experimental continuity if the external cockpit simulator fails to join the simulation.

En Route System Laboratories

This capability is comprised of a fully functional Host Computer System, and Display System Replacement (DSR) display laboratories. In actuality, there are several laboratories with display systems; each laboratory is configured as an air route traffic control center (ARTCC). Data from the BYTEX switch can be routed to any of the laboratories.

Any ATC position may tune to any frequency in the VHF communications band; any position tuned to a given frequency will hear all communications, and be able to talk to all other positions, and pilots, tuned to the same frequency. The resultant 'party line' effect provides a high fidelity simulation of actual air to ground RT communications. Lastly, squelch break on transmit key release and heterodyne tones when two transmitters are keyed simultaneously are included in the audio system.

Terminal System Laboratories

This capability includes Standard Terminal Automation System (STARS) displays and processors, and vestiges of the Automated Radar Tracking System (ARTS) IIIIE systems, maintained in fielded system status. In the STARS laboratory (see also figure 2), 7 systems or 'Strings' comprise the laboratory structure. In the ARTS III lab, the predominant system is ARTS IIIIE, although older systems are still supported. STARS can run independently of, or in tandem with ARTS IIIIE in a co-located system (e.g., Philadelphia) operational configuration. There are approximately 30 radar displays in the ARTS laboratory. Interconnectivity

is similar to the en route laboratories in that radar and interfacility data are routed to the terminal laboratories via the Bytex data switch from live, simulated, or playback sources. From the simulation perspective, the primary difference between enroute and terminal configurations lies in the radar update rates. There are also differences in the interfacility interface data protocols. All of these differences are handled in the RBX function of TGF, so from the user perspective, a common interface is provided to drive the en route, STARS, and ARTS capabilities.

The audio system in the terminal laboratories is identical to the Enroute laboratories; thus the capability sets are the same. There is a portal into the laboratory audio system for external users that conforms to the Voice over Internet Protocol (VoIP).

En Route Integration and Interoperability Facility (E²F)

This facility is a hybrid that is based on actual fielded equipment, but does retain the flexibility for developmental or R&D projects. It is capable of being driven by TGF with radar inputs, but has a unique audio system for the controller positions. Recently, the facility adopted a DSP-based audio system that can support a VoIP interface facilitating outside interconnectivity to the laboratory.

Research and Development Human Factors Laboratory (RDHFL)

The RDHFL uses an ATC emulation called Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE), a developmental tool used for R&D projects. The laboratory maintains 4 controller positions with a comprehensive data collection capability. DESIREE can be driven from the TGF. The laboratory audio system is not conformant to the other facility audio systems, but can support a VoIP interface for external users.

Airways Facilities Tower Integration Laboratory (AFTIL)

AFTIL is a tower simulator with 360 degree field of view visual system. The system is based

upon the Addacel target generation and projection architecture, and has a unidirectional High Level Architecture (HLA) interface currently installed. AFTIL can transmit target data to the TGF via a HLA interface. However, the capability of receiving targets is currently under development.

Cockpit Simulation Facility

The FAA Technical Center is developing the capability to address all NAS domains for a variety

of aircraft types as shown in Table 2. The cockpit simulation facility (CSF) has, in various stages of development, cockpit simulators of four classes of aircraft types including: general aviation, commuter class, business jet, and transport category aircraft including classic, second generation, and next generation. The aircraft simulators are either development (e.g., engineering simulators) or training devices.

Table 2. Technical Center Cockpit Simulation Capabilities

Aircraft Type	Simulator Type	% Complete	Aircraft Class
Beech-1900	Developmental	20%	Commuter
Cessna-421	Level II Flight Training Device	100%	General Aviation
SATS	Developmental	100%	Micro-Jet (Research)
EMB-175	Developmental	25%	Business Jet
B-747-400	Developmental	85%	Second Generation Jet Transport
B-767-231	Flight Management System Trainer (FMST)	100%	Second Generation Jet Transport
B767-231	Cockpit Procedures Trainer (CPT)	100%	Second Generation Jet Transport
B-767-231	Full Flight Simulator Level C Certification	In Procurement	Second Generation Jet Transport
B-737-800	FMST	80%	Next Generation Jet Transport
B-727-200	CPT	80%	Classic (Analog) Jet Transport

Proposed Architecture

FAA Intra-Center Simulation Architecture

The approach described in this paper is based upon a fundamental assumption of the HLA as the network protocol underlying its distributed simulation architecture. As outlined in [5], HLA has been developed for real time simulation, and can be adapted to fast time applications. It is therefore particularly suited for HITL studies which form the bulk of FAA simulations.

The structure of the Technical Center laboratories employs the TGF as the common element to provide NAS system stimulus at the system boundary interface. Therefore, bringing

TGF to HLA compliance provides access to the preponderance of the laboratories on the Center. Figure 3 shows the proposed architecture within the confines of the Technical Center. As shown in Figure 3, connectivity would be established through the Center's Local Area Network (LAN) backbone, using a subnetwork dedicated to the simulation traffic. A HLA server would be installed for simulation management. Initially, a separate data collection system would also be included. One sub-network would be defined for the Technical Center, and network monitoring would be applied to tally the data load during a simulation trial. If multiple sub-networks are required, each network would require a HLA server that would synchronize data between the networks.

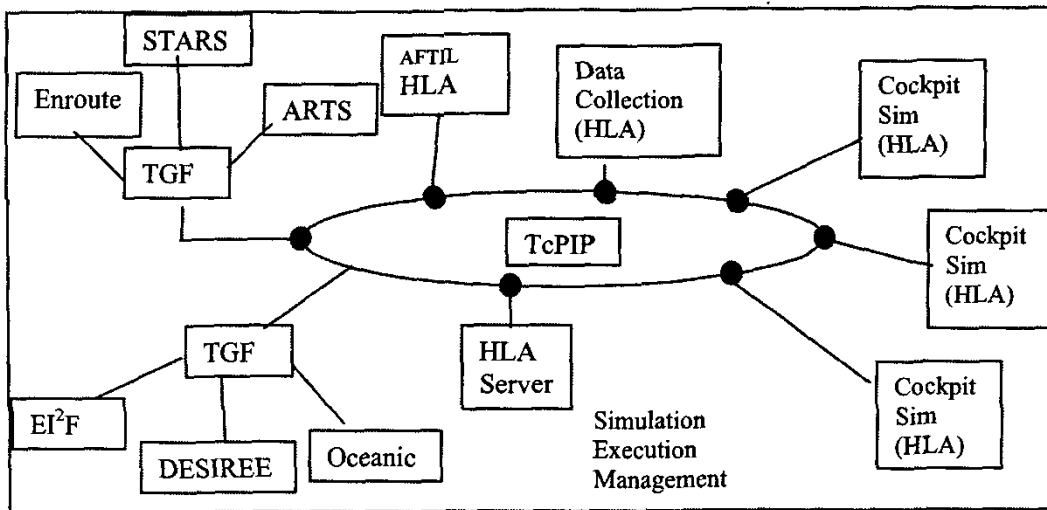


Figure 3. Proposed Interconnectivity for Principle Laboratory Functions at the FAA Technical Center

Inter-Center Simulation Architecture

To fully realize the simulation potential available to the FAA, interconnectivity to research centers globally must be established. However, this capability must be contrasted with the ground rule that simulations must be able to be organized and conducted relatively quickly and with little cost associated with connectivity establishment. Historically, when FAA has collaborated with other major research centers to combine resources in major simulations, the participating laboratories relied on high speed telephone circuits to provide connectivity. Although effective, these circuits often required several months lead time for establishment, and involved coordination with long distance and local carriers.

Presently, FAA, NASA, MITRE, and other major research organizations maintain high speed networks to provide interconnectivity between their regions and centers. Our approach proposes to employ these networks in the provision of connectivity among the laboratories in each organization. Connectivity between organizations would be by means of high speed networks between servers at selected locations. For example, if the FAA located a server at the Technical Center, NASA at Langley Air Force Base, and MITRE at McLean, T-1 lines would be routed between these locations. Data routing within the organization

would be the responsibility of the organization. Thus, for the cost of two full T-1 lines and one fractional T-1 (*f*T-1), the simulation capability of each entire organization would be made available.

The strategy has several advantages. For example, if the network gateway for an organization were located outside of the network firewall of that organization, security measures consistent with the local philosophy could be implemented in the gateway so that data passed across the firewall would be secure. Another advantage to this approach is speed and economy of experimental setup. Above the cost of the high speed telephone circuits, there is no appreciable cost for the use of the facilities. Once connectivity within an organization is established, simulations could be established with very little lead preparation.

Should the internet adopts a priority system (or permits data tunneling between users), it may suffice as a conduit to connect organizational gateways in lieu of the T-1 circuits. However, in the present configuration, the amount of traffic versus capacity renders the transport lag across the internet variable and non-deterministic. In trails between the East and West Coast, lag time in packet transfer varied from a few milliseconds to several seconds. This variable delay violates the 200 ms delay requirement voice traffic, and renders voice

communications for domestic simulation inadequate when transmitted across the internet [5].

Proposed Initial Steps

To better understand the costs and advantages of gaining a distributed simulation capability for the FAA Technical Center using HLA as the backbone, we recommend building a subset of a distributed simulation capability. In particular, the following steps are being undertaken:

1. Select a Real Time Infrastructure (RTI).

Discussions have been initiated between TGF personnel, and cognizant project leads at NASA and MITRE. There are several versions of RTI available, either free-ware or licensed versions, and each offers security and performance features. However, the RTI must be consistent among participating laboratories.

2. Establish HLA Server. It is suggested that TGF host the server because of its commonality to the laboratories at the Technical Center.

3. Establish a LAN Subnetwork. In conjunction with personnel in the Technical Center Office of Operations, Technology, and Acquisition, establish a secure subnetwork on the Technical Center's Local Area Network dedicated to simulation support. TGF will manage connectivity to the FAA laboratories for external users through its HLA server.

4. Incorporate Federates. In HLA terms, a federate is a cooperating simulation. This plan recommends incorporation of FAA Technical Center laboratories including cockpit simulator, tower simulator, and terminal and en route laboratories. External facilities including the tower simulator, and one or more cockpit simulators located at NASA Ames Research Center could also be included. Initially, and recognizing the delay problem, the Internet could be used to establish connectivity between the two Centers. Internet connectivity will be referred to as Phase 1. Full capability over a high speed telephone circuit would be accomplished in Phase 2. Ultimately, a high speed circuit can be installed to permit real time HITL simulation.

Actions Necessary to Achieve HLA Compliance

This section describes suggested steps to achieve HLA compliance for the FAA Technical Center.

1. Adopt RTI. After an assessment of security concerns at each of the various research centers, a decision to adopt one of the available versions of RTI will be made. A consideration of the network type and connectivity should be included in this decision so that each organization may assess its vulnerability to malicious attack from the network.

2. Define the Object Models in the Object Model Template. These include the Federate Object Model (FOM), Simulation Object Model (SOM), and Management Object Model (MOM). Attributes and parameters of the aircraft federates may be based on the existing Technical Center's Interface Control Document (ICD) for the remote interface between cockpit/flight simulators and the TGF. Since 1981, several studies have been performed where cockpit simulators have been linked to the Technical Center, and have participated in ATC simulations as a real time player. TCAS, voice, and weather effects have also been enabled in the remote simulators so the data and transmission rate requirements are well understood.

3. Define Data Management Services. This service is based on the proposed scenario. The effort in this task is the establishment of an HLA simulation, and then monitoring the network traffic for loading, expressed as a percentage of the total capacity. This data is expected to serve as guidance in sizing future simulation requirements. Based on network traffic loading as a function of the number of federates, future simulations may add network capacity, or elect to use DMM services.

Current Research Using Distributed Simulation

FAA and NASA Langley

The FAA and NASA are collaborating on an impact assessment of Small Aircraft Transportation System (SATS) aircraft to assess existing air traffic control procedures, processes,

and methods. Measured in units of subjective workload, acceptability, and situation awareness, the impact assessment will focus on increased traffic operating out of non-towered, non radar (feeder) airports, transitioning Class B airspace around major hub airports. NASA Langley Research Center developed the airport management module (AMM), a process designed to facilitate arrivals and departures at the feeder airports. The HLA compliant AMM is being integrated into the FAA Technical Center's TGF to drive the en route and terminal ATC simulation laboratories at the FAA Technical Center to replicate forecast levels of SATS traffic against a NAS baseline. To accomplish this integration, the TGF was also brought into HLA compliance. In the near term, the AMM will reside at the Technical Center for the duration of the ATC impact assessment; follow-on plans include the integration of the two centers. Langley's AMM capability and their flight simulation capability will be integrated with the FAA's air traffic control simulation capability. The successful integration of the AMM via the HLA interface has established the basis for long term integration.

NASA Langley and NASA Ames

In June 2004, research teams at NASA Langley Research Center and NASA Ames Research Center conducted a joint HITL simulation investigating the feasibility and operational benefits of en route free maneuvering [7]. The simulation is assessing pilot and controller performance during mixed operations involving autonomous and managed aircraft, and how the number of autonomous aircraft can be increased while ensuring safe operations. En route free metering is a concept element under NASA's Distributed Air Ground Integration-Traffic Management (DAG-TM) program. DAG-TM is a proposed solution for expanding airspace capacity limits that alters the roles and responsibilities of stakeholders. Its objectives include more user-preferred routing, increased flexibility, increased system capacity, and improved operational efficiency.

NASA Ames

At NASA Ames, the Airspace Operations Laboratory, the Air Traffic Control Simulator, the Advanced Concepts Flight Simulator, and the tower simulator (Future Flight Central) were joined together this summer for a demonstration using HLA.

Conclusions

The use of distributed simulation to address complex NAS level research questions has been proven. Its value has been documented in various sources and studies and includes examples in which FAA, NASA, selected airlines, and others have collaborated. FAA has participated in many studies in which distributed simulation has been used successfully to model the NAS. The approach described in this paper proposes to build upon the lessons learned in previous studies to help identify future potential risks, and increase functionality by creating a reusable and interoperable distributed simulation capability. While we have come a long way, much work still needs to be done. Security concerns and attendant heightened security protocols in the US and around the globe add yet another layer of complexity for establishing a distributed simulation capability. At the same time, FAA has been called upon to collaborate with NASA, Department of Defense, Department of Homeland Security, Department of Commerce, and others to establish a next generation air transportation system. Spearheading the effort is a Joint Program Office, resident in FAA. Here, teams are working actively to define a National Aviation Transportation Program that includes a unified, interagency R&D program. One of the goals, among others, is to align various organizations to support a national research program to evaluate concepts, develop alternative solutions, assess the NAS air/ground infrastructure design and relationships, and support integrated planning. Distributed simulation supports this intent and others. In a time of diminishing R&D resources, it is easy to make a business case for leveraging the capabilities of multiple organizations, including people and infrastructure.

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Disclaimer

The opinions expressed are those of the authors and not of the FAA.