

DEVELOPMENT OF A REAL-TIME VIRTUAL AIRSPACE SIMULATION CAPABILITY FOR AIR TRAFFIC MANAGEMENT RESEARCH

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ABSTRACT

This paper describes the NASA Ames Research Center's effort to develop a real-time human-in-the-loop Air Traffic Management (ATM) simulation capability that will emulate operations within the National Airspace System. This unique capability will be used to evaluate the human performance impact of ATM concepts at both the systems and local levels with the requisite degrees of fidelity. This new Virtual Airspace Simulation Technology (VAST) will examine critical core component technologies and candidate system level concepts and architectures to meet the requirements of the air transportation system of the future. The goal of this new capability is to provide human-in-the-loop simulations of operations within the NAS to never before achieved levels of fidelity. This capability will also provide a safe, cost effective, common, flexible and accessible platform for evaluating futuristic ATM concepts.

INTRODUCTION

The capacity of the nation's air transportation system has been increasing over the years, and according to some analysts, is expected to double over the next ten years. Much work is being conducted today in developing and fielding new decision support tools to improve the air traffic management (ATM) system. However, these tools are projected to only provide incremental improvements to today's ATM system. In order to meet the demands of the future ATM system, revolutionary changes or technologies have to be developed to meet the envisioned growth. NASA, working with the Federal Aviation Administration (FAA), academia and industry, is currently developing a new research program to develop air traffic management technologies with the hopes of doubling capacity while increasing safety and efficiency. This work will be conducted under the Aviation Systems Technology Advanced Research (AVSTAR) Project. In anticipation of the AVSTAR Project, a new project was initiated under the Aviation Systems Capacity Program in fiscal

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year 2002. This new initiative is known as the Virtual Airspace Modeling and Simulation (VAMS) Project.

One of the critical elements of the VAMS Project is the establishment of a new virtual airspace modeling and simulation capability for evaluating ATM concepts at both the systems and local levels with the requisite degrees of fidelity. This new Virtual Airspace Simulation Technology (VAST) will examine critical core component technologies and candidate system level concepts and architectures to meet the requirements of the air transportation system of the future. The goal of this new capability is to be able to provide a human-in-the-loop simulation of operations within the NAS to never before achieved levels of fidelity. This capability will also provide a safe, cost effective, common, flexible and accessible platform for evaluating human performance issues related to the development and implementation of futuristic ATM concepts.

VAST will leverage existing and future simulation components including software emulations and human-in-the-loop facilities situated across the nation, to utilize today's NAS modeling and systems expertise. In addition, VAST will provide a unique virtual research environment that allows multiple researchers and/or users to collaboratively and interactively participate in NAS simulations from remote locations. This will be accomplished through a flexible and accessible nationwide network infrastructure that links multiple capabilities/facilities together in reconfigurable groupings, allowing a unique variety of research capabilities for human factors studies.

The VAST capability consists of two elements: a non-real-time modeling and simulation capability and a real-time human-in-the-loop simulation capability. The non-real-time system focuses on the development and validation of models and methods for non-real-time assessments of candidate operational concepts. Efforts within this element will produce a suite of tools composed of interoperable models representing the gate-to-gate actions and highly coupled interactions of the key components of the air transportation system. These tools will essentially provide a multi-fidelity simulation environment for primarily conducting fast-

time analyses for determining the benefits of future ATM decision support tools or operational concepts. The assembly of these tools must address a variety of issues including system-level policy assessments, the national economic impact of new technologies, regional flow performance, infrastructure constraints and human performance. This paper however, will only focus on the real-time simulation capability, which is described in the following sections.

The VAST real-time simulation will provide a gate-to-gate NAS-wide human-in-the-loop simulation capability for the assessment of human interactions with airspace operational concepts and their supporting technologies. The real-time simulation will ensure that adequate and credible real-time models, and necessary interfaces to human-in-the-loop laboratories and simulators are available to perform high-fidelity human performance and human factors studies to better understand human/system interactions. VAST will provide a NAS-wide “closed-loop” environment where decisions made at the local level propagate to the system level and vice versa. VAST will also enhance and expand present day human-in-the-loop simulation capabilities to be more flexible and extensible.

The existing airspace operational concept relies primarily on the human element to provide management and control through human skills, knowledge and decision making. Future operational concepts are anticipated to rely more on computer automation processes. The necessity for human interaction in both present and future concepts exists, but roles and responsibilities may not remain the same. The VAST real-time simulation will provide the environment to assess existing and future roles and responsibilities in a safe and cost effective manner enabling refinement in concept development.

Development of the real time simulation environment will be guided by defined operational concepts and culminate in validation experiments. Appropriate multi-fidelity models will be leveraged, modified, developed and integrated with select facilities into a flexible, extensible and reconfigurable architecture. Combined, the models and facilities will provide a gate-to-gate simulation capability allowing human factors studies within any area of the airspace domain.

SYSTEM DESCRIPTION

Conceptually, the VAST Real-Time ATM Simulation System is envisioned to be able to simulate operations within the NAS at both the system and local levels. Much of the ATM simulation work that is done today focuses primarily on a specific region or area and cannot simulate operations of the NAS as a whole. The

intent of the VAST real-time ATM simulation is to provide a simulation environment that extends the current boundaries of simulations by enabling researchers to not only look at what effects a localized simulation may have on the operations of the NAS as a system, but also how operations within the NAS effects that regional area as well.

In order to simulate operations within the NAS, the simulation must provide the ability to emulate the various functions and aspects of the NAS environment. These functions or attributes will include simulation of the various air traffic service providers such as the System Command Center, Air Route Traffic Control Centers (ARTCCs), Terminal Radar Approach Control (TRACONs) centers, towers and ground control, airline business functions such as Airline Operational Centers (AOCs), the various vehicles flying within the simulation environment and weather. Simulations of these functions will be provided primarily through software emulations or through the integration of human-in-the-loop simulation facilities. A proposed architecture for the VAST real-time simulation system is shown in Figure 1, depicting the major elements of the current national airspace system.

VAST ARCHITECTURE

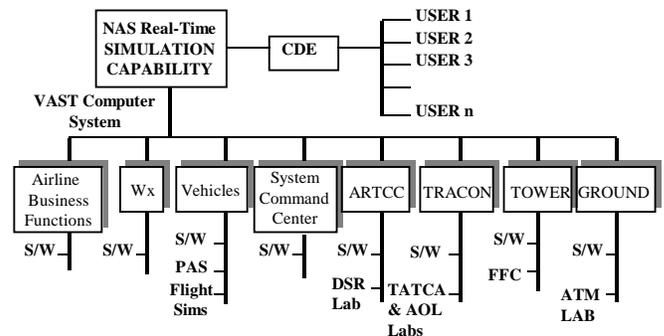


Figure 1 – VAST Real-Time Simulation Architecture

In addition to modeling the current NAS, the VAST real-time simulation must be able to model future air traffic management system concepts. Therefore the VAST real-time simulation architecture must be modular and flexible enough to substitute a new operational concept in place of the current NAS structure today. A depiction of such a concept is provided in Figure 2.

Development of the VAST Real-Time ATM Simulation System is comprised of four major elements. These

elements include the System Architecture, Simulation Modeling, System Integration and the Collaborative Development Environment (CDE). These elements are further described in the following sections.

System Architecture

In order to simulate operations within the NAS, the VAST architecture must be modular and flexible enough to enable the ability to emulate the various functions and aspects of the NAS environment. This element will define the requirements and produce the software infrastructure necessary to produce the VAST Real Time ATM Simulation System architecture. The architecture will be based on the high level architecture (HLA), a current industry standard for large, multi-facility, as well as multi-fidelity, distributed simulation systems. HLA will be leveraged to provide the foundation for incrementally building a next generation, NAS-wide human-in-the-loop simulation system.

The heart of the real-time simulation system will be a widely distributed computational system. This capability denoted by the box representing the NAS Real Time Simulation Capability in Figure 1, will serve as the run-time host executive and as a portal to the different simulation attributes or models supporting the simulation. It will also serve as a portal to the development environments supporting the simulation system and to the Collaborative Development Environment (CDE), providing system interfaces and utilities for users and researchers for a given experiment. The architecture must also provide the scalability to add and the flexibility to replace models as required with other models conforming to interface requirements specifications to support simulations evaluating future operational concepts as depicted in Figure 2.

Initial efforts will define the broad expectations of the system to arrive at the necessary functional and performance requirements for the architecture. This includes requirements for the real-time environment, the command and control environment, and the mechanisms for communicating data and commands between simulation attributes. Concurrently, an initial prototype design of the architecture will be developed. These high-level expectations will then be refined with the selection of the Run Time Infrastructure (RTI), the definition of the Federation Object Model (FOM), and the development of a working architecture prototype. Later efforts within the VAMS/AVSTAR projects will direct the implementation of the architectural requirements and design for execution of a defined human-in-the-loop experiment. This experiment will validate the capabilities of the VAST Real Time ATM Simulation System including the architecture. It is

anticipated the development of the architecture will be completed at this point.

Simulation Modeling

An essential aspect of the VAST Real Time ATM Simulation System is the ability to model current and future attributes of the NAS for human-in-the-loop experiments. Since the intent of the VAST real-time ATM simulation is to provide an environment that extends the current boundaries of ATM simulations conducted today, it will be necessary to develop models or agents that can emulate the various functions or attributes of the NAS. This may include developing models or agents that emulate functions of a specific ARTCC or TRACON through the use of software as opposed to having to integrate a large number of facilities which could prove to be cost prohibitive in most cases.

Real-time models for the various simulation attributes will be developed, validated and maintained during the life of the project. These models will be leveraged and modified from existing capabilities, or developed where no adequate models exist.

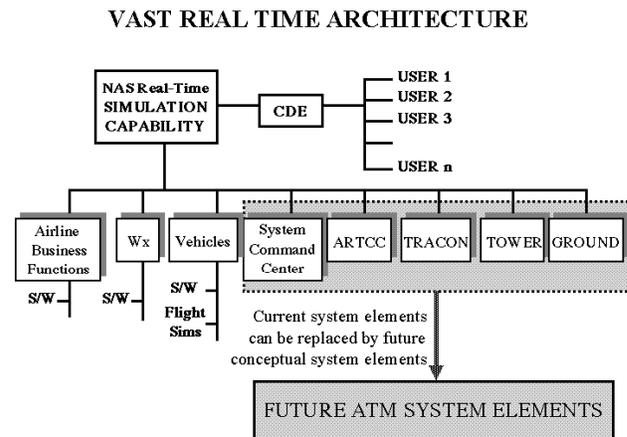


Figure 2 – VAST Real-Time Simulation Architecture for Future Concept Evaluation

This element will define and produce the necessary models to create the real-time, human-in-the-loop simulation environment. The types of models and their fidelities will be derived from the operational scenarios developed by researcher requirements. Additional efforts will support the integration of approved models provided to the project for inclusion to the system. Models to be integrated within the VAST ATM simulation system shall emulate operations of the System Command Center, the various ARTCC's, TRACONS and other air traffic services. In addition, a

target generation capability will generate the various vehicles resident within the simulation environment. It is envisioned that some type of tool such as the NASA Ames developed Pseudo-Aircraft System (PAS) or a similar tool will provide the means to perform this function. In addition, the ability to feed live traffic data or other flight simulators (high fidelity motion based or lower fidelity desktop simulators) into the environment will also be included as part of the system design. In addition, a central weather model will be integrated as part of the simulation as well as the provision to include any airline business functions such as an Airline Operations Center (AOC).

The process of model development will begin in the early phases of the project with the creation of a high-level exhaustive list of NAS components that require modeling. The list will include decision-making agents, and operational and procedural functions of facilities, vehicles and equipment. Surveys of existing models will be made to map the available capabilities against the items on the list. This will provide an overall scope of the modeling effort and establish the gaps where significant development efforts may be required. The model development list will then be prioritized, and detailed information added for each item to establish specific modeling requirements. Software design and coding of the models supporting an initial baseline experiment will then be initiated. Prototyped models will be demonstrated operating within the developing system architecture. Model development for the initial baseline experiment will continue throughout the project. A process will be defined to ensure consistent model development practices. This process will include:

- Defining requirements for the models
- Documenting functionality of the models
- Leveraging, modifying or developing source code
- Validating model code and functionality
- Integrating models into system
- Validating integrated system
- Documenting model information for users

Model development will continue to the end of the project in support of multi-facility experiments of the baseline NAS and future airspace operational concepts.

System Integration

The VAST real-time simulation capability will make use of existing and future simulation components including software models or emulations and human-in-the-loop simulation facilities situated across the nation, leveraging today's NAS modeling and simulation expertise. Such facilities will include NASA's FutureFlight Central (FFC), a unique Air Traffic

Control tower simulation facility, other ATC laboratories at NASA Ames, and flight simulators such as the Crew Vehicle Systems Research Facility's Boeing 747-400 and Advanced Concepts Flight Simulator (ACFS). In addition, it is envisioned to link VAST to other laboratories including the Federal Aviation Administration's Traffic Flow Management (TFM) Laboratory, and it's Target Generation Facility (TGF) at the William J. Hughes Technical Center in Atlantic City, New Jersey. The emphasis behind VAST is not to create new facilities but to create a new ATM simulation capability which leverages existing facilities to simulate NAS operations on a larger scale.

The System Integration element is responsible for coordinating internal and external task efforts, and integrating all products developed for the VAST real-time ATM simulation. This will include:

- Coordinating experimental requirements with the researchers
- Translating requirements into simulation designs
- Implementing simulation designs
- Training system users and research subjects on system functionality
- Supporting simulation experiments with appropriate staff
- Providing coordination between elements and participants of the simulation experiments
- Delivering validated data to the research and user community
- Acquiring constructive feedback for system refinement
- Documenting system capabilities and limitations

A laboratory will be established in the early phases of this project to support development and testing of the system architecture, models and networking infrastructure. This laboratory will be upgraded as needed and maintained through the life of the project. During the initial phase of the project, the System Integration element will also create and maintain a list of potential simulation facilities and laboratories that may be integrated with the architecture and software models supporting designated experiments. The list will include the attributes of the facilities, their associated specifications, and points of contact.

Collaborative Development Environment (CDE)

Another key aspect of this virtual research environment is to provide the ability for multiple researchers or users to collaborative and interactively participate in NAS simulations from remote locations using a virtual reality interface. This interface is being leveraged through another Ames developed product known as the Virtual Laboratory or VLAB. This tool has been successfully

demonstrated for several projects including numerous Space Shuttle simulations at Johnson Space Center and most recently at Marshall Space Flight Center in support of the Space Launch Initiative Program.

The CDE will provide users the ability to interactively monitor and observe simulations in real-time, and will allow the primary investigators to manipulate characteristics of simulation parameters such as turbulence levels, visual scene depictions, communications to name a few. The CDE will also include an expandable set of tools for data collection, data management and data analyses (digital, audio, video) and performance management. This effort includes the development of interfaces and utilities for simulation set-up, and command and control; database management; scenario generation; data collection, reduction, analysis and storage; and virtual environments supporting collaborative and interactive participation. Development of the CDE capabilities will be driven by requirements established in the early phases of the project. Prototypes will be created during the project supporting the necessary needs of the system.

TECHNICAL APPROACH

The VAST Real-Time ATM Simulation System will be produced using a multi-phased spiral development process defining and generating requirements for software and hardware architectures, developing working prototypes, and validating system capabilities. System prototypes will be designed, implemented and tested in each phase. Requirements definition and development efforts in successive phases will build and expand upon the capabilities developed in prior phases. A gap analysis will be conducted in each phase establishing differences between requirements and known capabilities, and highlighting areas where technology is deficient and necessary development efforts will be required.

Programmatically, the work will be carried out in five phases, beginning in fiscal year 2002. Phase 1 will produce a preliminary System Description Document (SDD) containing the system requirements specifications, the system design, the interface requirements specifications, and the supporting documentation necessary to give a complete system description. The preliminary SDD will be delivered at the end of fiscal year 2002. During phase 1, a Simulation Development Laboratory will be created to support the requirements and interface definition process through prototyping efforts. The lab will be sustained throughout the life of the Project.

Phase 2 expands the preliminary SDD into a complete requirements document by refining the efforts of Phase 1 and prioritizing the requirements to successfully meet the needs of the baseline validation experiment in year three (fiscal year 2004) of the project. This phase will also characterize system development supporting the multi-facility and advanced airspace operational concepts experiments in the out-years of the project. Deliverables include a completed SDD and a demonstration simulation. Phase 2 will be completed in fiscal year 2003.

Phase 3 integrates models that have been developed and the necessary facilities into the real-time system architecture to perform a baseline validation experiment in fiscal year 2004. The VAMS project office will select the concept for the experiment in fiscal year 2002. Researchers supporting the VAMS Project will define the experiment's scenarios, validation metrics and verification methodologies. Working together, the researchers and the VAST simulation support staff will define the models and facilities that support the experiment. Phase 3 will be completed in fiscal year 2004.

Phases 4 and 5 support continued development of the VAST Real Time ATM Simulation System for multi-facility integration and the evaluation of advanced airspace operational concepts. Phase 4 supports the multi-facility real-time simulation experiment associated with project milestone to be completed at the end of fiscal year 2005. Phase 5 extends the real time system for evaluations of advanced airspace operational concepts developed within the research part of the VAMS Project. This phase supports a project milestone that is to be completed by the end of fiscal year 2006. VAST Real Time operational efforts will continue through fiscal year 2007 to support later project milestones within the AVSTAR Project. These milestones complete the simulation and evaluation of the most beneficial advanced operational concept identified by the project.

The subtasks of this effort will:

- Design and develop a flexible, distributed system architecture
- Leverage, modify and develop the necessary real time simulation models
- Integrate the models with the architecture and provide the ability to link human-in-the-loop simulation facilities to the system for real time, human-in-the-loop experiments
- Provide appropriate user interfaces for system set-up, command and control, data management, and virtual environments

SUMMARY

The VAST real-time human-in-the-loop ATM simulation capability will provide NASA with a unique tool to research and evaluate ATM concepts in the national airspace system at both the system and local levels to never before achieved levels of fidelity. It will provide a safe alternative to conduct research in complex NAS environments by providing a simulation environment that extends the current boundaries of the simulations that can be done today which are generally very localized to a specific region or area. This will enable researchers to not only look at what effects a localized simulation may have on the operations of the NAS as a system, but also how operations within the NAS effects that regional area as well. Also, the VAST real-time simulation will provide a cost effective solution to developing a NAS-wide "gate-to-gate" simulation capability by leveraging existing simulation capabilities and/or facilities that currently exist, instead of building a new capability from the ground up. This will be achieved by the further development of state-of-the-art networks and enhanced information technology interfaces, establishing a flexible and accessible nationwide network infrastructure that links multiple capabilities and/or facilities together in reconfigurable groupings. Additionally, the VAST real-time simulation will provide a unique virtual research environment that allows multiple researchers and/or users to collaboratively and interactively participate in VAST simulations from remote locations, providing a variety of research capabilities for human factors studies.

The VAST real-time ATM simulation system will play a major role in designing new air traffic management concepts for the future by supporting AVSTAR as well as other follow-on projects within the Aviation Systems Capacity Program. It will also support other FAA safety and capacity initiatives. This capability will play a vital role in enhancing aviation safety and capacity in the years to come.

REFERENCES

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