

THE NATIONAL SIMULATION LABORATORY: THE UNIFYING TOOL FOR AIR TRAFFIC CONTROL SYSTEM DEVELOPMENT

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ABSTRACT

This paper reports on efforts within the Federal Aviation Administration to develop a National Simulation Laboratory (NSL) for the study of advanced concepts in Air Traffic Control (ATC). The NSL is intended to serve as a resource to developers and managers for studying future ATC concepts in an integrated, multi-system environment. The paper also describes work on the NSL's precursor activity, the Integration and Interaction Laboratory (I-Lab), which is helping to develop the core capabilities necessary for the NSL and to demonstrate the technical feasibility of the program.

1 INTRODUCTION

The National Airspace System (NAS) is a complex amalgamation of airspace, users, and procedures. To safely operate this complex system the Federal Aviation Administration (FAA) operates the Air Traffic Management System (ATMS). The ATMS is the portion of the NAS responsible for regulating the movement and flow of participating aircraft in controlled airspace. It covers the whole of the United States, is remarkably diverse in all its elements, and extraordinarily complicated in its workings. The ATMS has come under increasing stress with the growth in the air transportation industry over the past decade and its concomitant demand for access to the resources which make up the NAS. It is clear that as we enter the 21st Century, the NAS in general, and the Air Traffic Management System in particular, will be unable to meet the demands placed upon them unless changes are made to improve the capacity of the system.

To plan for these future needs, the FAA is using simulation as a tool to study how future components of the ATMS will work and how they will interact with each other. A key element of the FAA's simulation plans will be a National Simulation Laboratory, which will be used to simulate various Air Traffic Control (ATC) components and concepts and

their interaction with each other.

The purpose of this paper is to provide an overview of the plans and scope for the NSL, as well as look at the ongoing precursor activity to NSL, the Integration and Interaction Laboratory, being developed under FAA sponsorship at the MITRE corporation. As a lead-in to this discussion, we provide an overview of some of the key elements of the NAS and the constraints they put on the system and any efforts to model it. At the highest level, we see three categories of components of the NAS: Airspace, Users, and the ATMS.

2 AIRSPACE

There are three major observations which should be noted about airspace. The first is that airspace has a fixed volume which must be allocated in such a way as to reconcile the demands of some users for exclusive access, the demands of most users for equal access, and the demands of all users for safe access. To this end, airspace is divided into three major, mutually exclusive categories: uncontrolled, controlled, and special use.

The second observation is that the structure of the airspace is complex. There are multiple subdivisions within these three categories, each with its own implications for access by users. But beyond that complexity, airspace is characterized by five dimensions of variability. In addition to the three dimensions of spatial variability, airspace is also characterized by variability across time and weather conditions.

The third noteworthy observation is that the designation of airspace has regulatory implications which impact the nature of the operations that can take place in that airspace. In a variety of these airspace types, the FAA must provide ATC services to all aircraft operating in those areas.

The future development of airspace procedures must

balance the needs of all users. There are many claimants to this airspace, each of whom have their own requirements. In many cases, designation of airspace to meet the needs of any one segment results, at worst, in denial of access to others or, more generally, restrictions in the operations of others. The structure of the airspace has implications for the flow of air traffic and the capacity of the system. Finally, when designating airspace where ATC services are required there must be adequate capacity in the Air Traffic Management System to provide for them.

3 USERS

The users are a remarkably diverse group. There are two major groups of "users" of the system: military users and civil users. These users operate aircraft in the entire NAS from sea level to altitudes of 60,000 ft. and at speeds from zero to Mach 2+. Table 1 is a representative list of NAS users. What is key is not the exact list but rather that the list of users is large, their use of the system is different, their demand for services is varied and, in a perfect world, most users would prefer not to have their access to the system limited in order to accommodate other users. In some instances this is possible; in others, it is not.

Many of these aircraft are now equipped with sophisticated navigation, communication, surveillance and flight management systems which provide them with significantly more capability than the present day ATC system can readily accommodate. For example, with area navigation and flight management systems, aircraft can now take-off and fly specific climb profiles, routes, and descent profiles which can be set to minimize fuel burn, minimize time en route, etc. The present day ATC system is geared to standard climb and descent corridors with proscribed airways in between based on the use of VORTACs (Very High Frequency Omnidirectional Range/Tactical Aircraft Control and Navigation) for navigation. The technology enhancements in the aircraft are not limited to any one or two segments of the user population but exist across the strata of users and aircraft types.

The future NAS must be able to accommodate this diversity of user capabilities.

4 AIR TRAFFIC MANAGEMENT SYSTEM

The Air Traffic Management System is that system which regulates the flow of participating traffic in controlled airspace. It is not a regulatory requirement that all aircraft operating in controlled airspace participate in this system, although, as previously

Table 1. Some of the users of the National Airspace System

Scheduled Air Carriers
 -major airlines
 -national airlines
 -regional airlines
 Small Package Delivery Carriers
 EMS Helicopter Services
 Medical Transfers
 Aerial Application
 (e.g. cropdusters)
 On-Demand Charters
 Aerial Tours/Sightseeing Flights
 Flight Instruction
 Personal Travel
 Business Travel
 Corporate Travel
 Aerial Photography/Surveys
 Aerial Pipeline and Powerline Patrols
 Aerial Firefighting
 Law Enforcement
 (local, state, federal)
 Drug Interdiction
 Search and Rescue
 (e.g. Civil Air Patrol)
 Recreational Flying
 Fish Spotting
 Traffic Reporting
 Air Cargo
 Express Mail
 Military

mentioned, there are subcategories of controlled airspace where participation is mandatory.

The ATMS is composed of two distinct segments. The first segment is the Air Traffic Control system, the primary functions of which are to provide separation between participating aircraft in the controlled airspace volume, sequencing of aircraft for take-offs and landings at controlled airports, and route clearances for participating aircraft. It does this through a network of ground and local controllers in air traffic control towers (of which there are 455), terminal controllers in Terminal Radar Approach Control facilities (TRACONS) and Air Route Traffic Control Centers (ARTCCs, of which there are 21). The division of airspace among these facilities, towers, TRACONS and ARTCCs, does not necessarily align with the regulatory division of airspace discussed earlier.

The second segment of the ATMS is the Traffic Flow Management system. Its primary purpose is to regulate the flow of traffic to avoid unacceptable levels of congestion and to achieve best use of the limited resources of the NAS.

Today, these functions are loosely coupled. Responsibilities of each function are well-defined, and interactions between functions are not highly automated. The Air Traffic Control system of the future envisions tools for both tactical and strategic control which are highly automated and tightly coupled. The interactions will be much more synergistic and less intuitive than ever before.

5 THE NATIONAL SIMULATION LABORATORY

The problem set that can be defined for the future design of the NAS is very large. The initial focus of the NSL will be on a very important subset of that domain, the ATMS. The FAA has a broad vision for this future system and that vision focuses on greater use of automation in both Air Traffic Control and Traffic Flow Management (Federal Aviation Administration 1991). Key features of this vision are highlighted in Table 2. The importance of increasing the capacity of the ATMS is self-evident. We do not wish to unnecessarily restrict users in their access to the NAS, and the airspace volume is fixed.

Table 2. Some key elements of the FAA's vision of the future of air traffic control

- User-Preferred Profiles
- Integrated Traffic Management
- Integration of Aircraft Flight Management System with ATC Automation
- Integration of New Weather Products
- Pilot Involvement in ATC Decision-making
- New Aircraft Mixes and Procedures
- Advanced Automation Strategies
- Satellite-based Navigation

The NSL is a tool the FAA intends to develop for use by both the FAA and the aviation community so that we can achieve that vision of the future. With the anticipated use of sophisticated automated techniques to provide separation between aircraft, accommodate user-preferred flight trajectories, and place greater responsibility for aircraft separation in the cockpit, the traditional tools used to aid in the design of the NAS are no longer adequate. The tight coupling of the future system with the concomitant blurring of boundaries of the functions of the ATMS demand the early use of simulation in the design of the future elements of the ATMS in order to study their interactions with other proposed elements of the system. This includes the interactions within hardware and software components of these systems as well the interactions of these components with their human operators, both pilots and controllers. These interactions must be tested under normal

conditions, under stress, and under failure. The NSL is the place where this will be done.

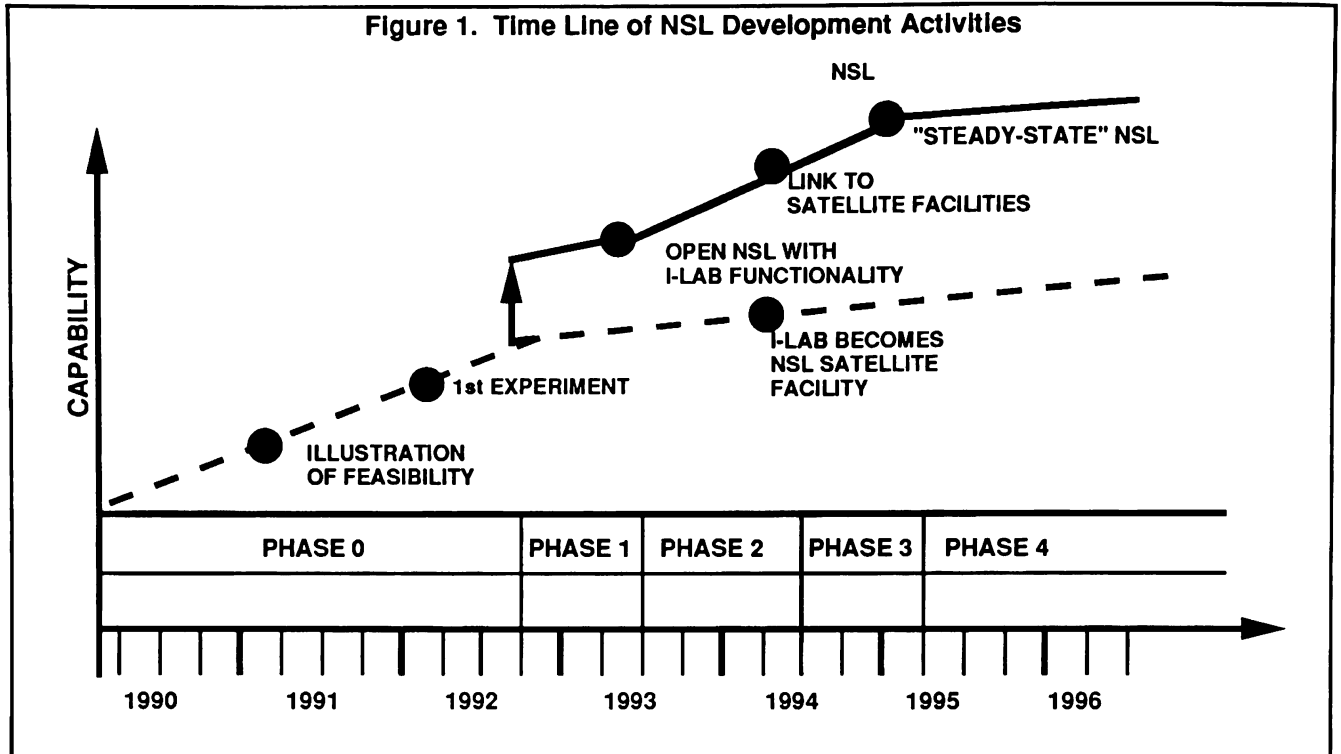
The NSL is intended to be a place where researchers will come; a focus for activities related to the design of the future ATMS. It will be a place where ideas can be tested. It will be a repository for simulation models, and prototype operational software, of ATMS elements for use by others.

The NSL will not be a monolithic entity existing in isolation. It is not intended to duplicate or replace those research facilities currently in operation. Examples include facilities at the FAA's Technical Center, facilities at NASA Ames, and facilities at the Volpe National Transportation System Center. Rather it is intended that the NSL will establish electronic links with those facilities and others as necessary to be used in simulations of the NAS. The linkages will be two-way. The NSL will avail itself of other facilities when it is necessary for the NSL to conduct its own experiments and we anticipate that other facilities will link to the NSL when necessary for the conduct of their own experiments.

The NSL is intended to be an evolutionary development. However, we can adequately describe pieces of that system and have done so with an preliminary *Object-Oriented Analysis* of the Air Traffic system. (Ball and Kim, 1991). This is not a complete figure. The initial NSL will encompass those elements and it will grow, over time, to encompass the remaining ones. The rate of growth and its ultimate end state will be governed largely by demand for its services tempered by the realities of the budget table. Growth will also be governed to the extent that activities external to the NSL perform their own research, develop their own simulation models and contribute those to the infrastructure of the NSL. Figure 1 represents these growth stages of the NSL.

The NSL needs to be responsive to the demands for change in the NAS. It needs to provide experimentation results in a timely manner, the validity of the experimentation process should be proven and respected, and the experiments should address issues that are of concern and importance to the aviation community.

To ensure that the NSL is responsive to the needs of the aviation community in general, and the FAA in particular, its operations will be governed by two groups: an Operations Review Board composed of members of the system development organizations within the FAA and a Steering Committee composed of members from senior FAA management, other government organizations, academia and industry.



The Operations Review Board will approve annually the Operating Plan for the NSL. This plan will include the prioritized list of experimental questions to be addressed in the upcoming year, growth/changes to be made in the NSL infrastructure in the same period as well as general plans for experiments and infrastructure changes in the 2-5 year period beyond the upcoming year. This "out year" period will be developed based upon the broad policy guidance from the Steering Committee. The Steering Committee will consider the broad aviation community needs versus NSL capabilities when identifying future direction for the NSL.

6 THE INTEGRATION AND INTERACTION LABORATORY

The development of the NSL is seen as a multi-year effort which will require a number of significant problems in distributed simulation and reuse of existing (*legacy*) simulation elements to be addressed. With these challenges in mind, the FAA established the I-Lab project at MITRE in February of 1990 as a precursor activity to the NSL. The goal of the I-Lab project has been to serve as the test bed for the NSL, and in particular to address three areas of concern:

- To begin to develop and test an architectural framework for the NSL, including core

capabilities in networking, computer graphics, data management, and other areas necessary for integrating diverse ATC simulation systems.

- To begin to address the problems of reuse of legacy ATC simulations and prototypes.
- To demonstrate a substantially complete, integrated network of ATC simulation systems being used to conduct meaningful experiments on interoperability of proposed ATC systems.

The I-Lab project is planned as a four phase effort, proceeding as follows:

- Phase I: Illustration of Technical Feasibility (ITF) and lab development
- Phase II: Initial Experimental Capability (IEC) development
- Phase III: I-Lab experimentation and NSL baseline development
- Phase IV: Technology transfer/Federally Funded Research and Development Center (FFRDC) NSL satellite operations

Phase I, now completed, involved the establishment and equipping of the I-Lab facility and the

development of an "illustration of technical feasibility." The facility consists of a 2,700 ft.² laboratory located at MITRE's Washington D. C. facilities in McLean, VA. This lab includes a raised-floor computer room approximately 750 ft.² in size with the balance of the space devoted to the experimental test and development area. The laboratory was outfitted with a suite of computer systems and peripherals to support the anticipated ITF and IEC baseline experimental needs.

The Illustration of Technical Feasibility, completed in August, 1990, was designed to demonstrate the NSL concept and to show on a small scale how a group of legacy ATC simulations and prototypes could be integrated in a laboratory setting to produce a useful demonstration of interoperability (Kim, 1991).

The Phase II Initial Experimental Capability baseline, scheduled for completion in March 1992, will go significantly beyond the proof-of-concept work done in the ITF phase of the project, and will put in place many of the core capabilities needed for the NSL. The software development and integration for this IEC capability is nearing completion and work is focusing on development of experiments and experimental procedures for laboratory use.

In Phase III the I-Lab will begin to be used for performing ATC experimentation. These experiments will be designed to exercise the unique features of the laboratory, most importantly the lab's ability to study impacts of changes across the broad spectrum of components of the ATMS. Architectural work will also continue during Phase III with the goal of defining the baseline NSL architecture.

Phase IV of the I-Lab work coincides with the onset of operation of the NSL. During this phase, the I-Lab will serve as a satellite facility to the NSL, further refining the tools, techniques and procedures for its operation.

7 I-LAB ARCHITECTURE

The structure of the I-Lab Simulation Architecture has been driven by the project goals outlined in the previous section. The project, now in its Phase II build for the Initial Experimental Capability, has developed a strong, flexible architecture for conducting ATC experiments (Roberts, 1991). Key features of this IEC architecture include:

- A "layered" software model including core capabilities for message handling, data management and graphical display.

- A central simulation manager to orchestrate simulations and coordinate data collection.
- Representation of most major elements of the air traffic control system, including: Airport operations (ground movement and gate control), the terminal area, en route - including the capabilities of the Automated En Route Air Traffic Control (AERA) system, traffic management (metering and departure sequencing), and the cockpit.
- The ability to realistically simulate an operational environment and perform meaningful experiments using air traffic controllers and other ATC professionals.
- Simulation support elements to cover pre- and post-processing requirements including analysis and display of experimental results.

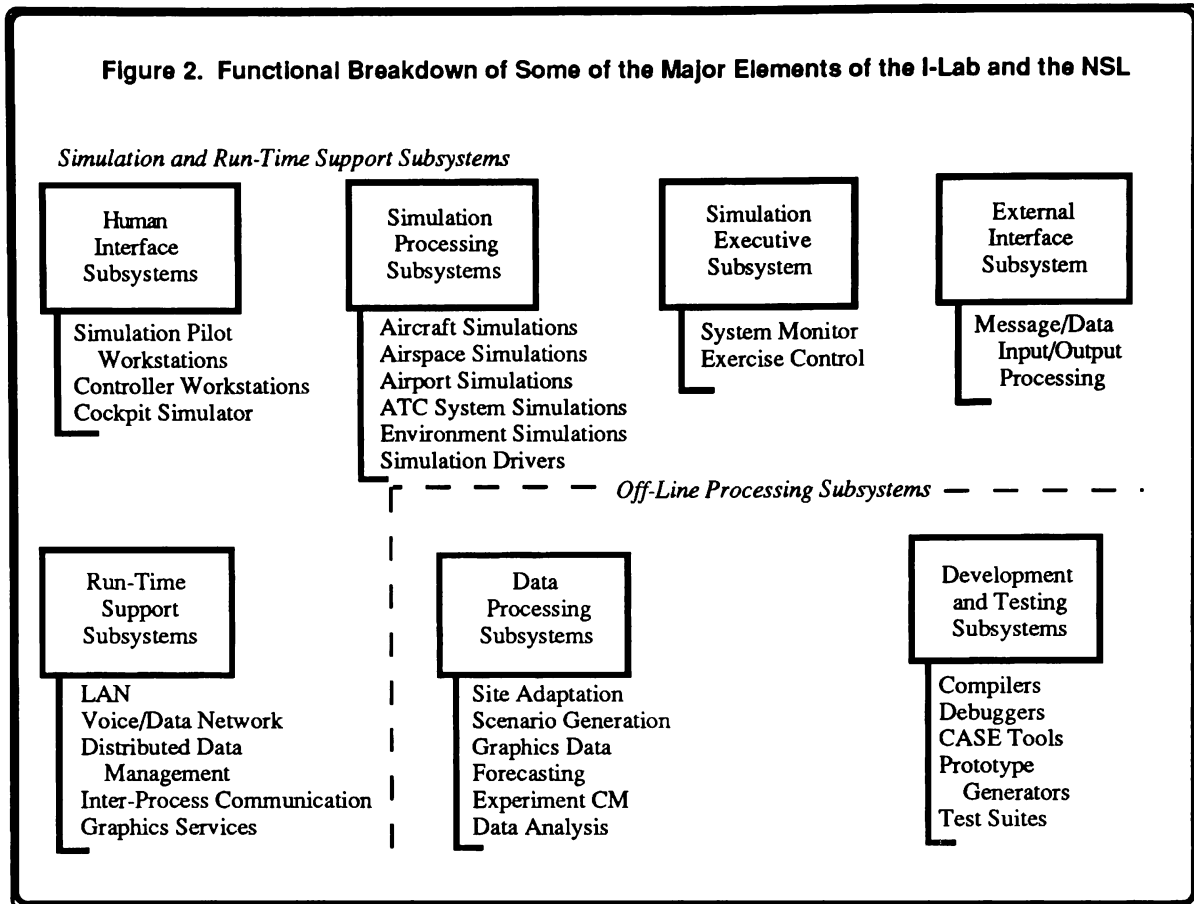
As currently envisioned, the NSL will need to support a collection of interoperating simulation elements including computer simulations, human interaction subsystems such as cockpit simulators and ATC consoles, and possibly "real world" elements such as experimental radars, sensors and other elements of the NAS. With this in mind, the I-Lab was designed as a fundamentally distributed simulation environment, using a network of commercial off-the-shelf workstations and minicomputers. This represents a logical way to allow existing simulation platforms to be brought into a laboratory setting with minimal redesign and rehosting of code. This approach also has a useful parallel to the real world ATC environment, where major operating environments, such as en route centers, TRACON facilities, and airport towers, interoperate through voice and data interchange networks.

In order to provide this capability, the NSL will need to have a flexible, general purpose architecture designed to handle data sharing and data collection, inter-process communication, and shared ATC functionality (e.g., in handling of weather, aircraft target generation, flight plan processing, etc.) Figure 2 depicts, at a functional level, key architectural components of the I-Lab and the NSL.

8 SUMMARY

This paper has presented an overview of the FAA's plans for building a National Simulation Laboratory and a brief overview of a precursor activity known as the Integration and Interaction Laboratory (I-Lab). The technical and programmatic challenges of the NSL effort are substantial. Envisioned as a research

Figure 2. Functional Breakdown of Some of the Major Elements of the I-Lab and the NSL



facility to meet the needs of planners, engineers, researchers and other ATC professionals, the NSL must provide a flexible, broad-range platform on which to refine the design and operating concepts of the future national air traffic management system.

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AUTHOR BIOGRAPHIES

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