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Development of a High-Fidelity Simulation Environment for Shadow-Mode Assessments of Air Traffic Concepts

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This paper describes the Shadow-Mode Assessment Using Realistic Technologies for the National Airspace System (SMART-NAS) Test Bed. The SMART-NAS Test Bed is an air traffic simulation platform being developed by the National Aeronautics and Space Administration (NASA). The SMART-NAS Test Bed's core purpose is to conduct high-fidelity, real-time, human-in-the-loop and automation-in-the-loop simulations of current and proposed future air traffic concepts for the United States' Next Generation Air Transportation System called NextGen. The setup, configuration, coordination, and execution of real-time, human-in-the-loop air traffic management simulations are complex, tedious, time intensive, and expensive. The SMART-NAS Test Bed framework is an alternative to the current approach and will provide services throughout the simulation workflow pipeline to help alleviate these shortcomings. The principle concepts to be simulated include advanced gate-to-gate, trajectory-based operations, widespread integration of novel aircraft such as unmanned vehicles, and real-time safety assurance technologies to enable autonomous operations. To make this possible, SNTB will utilize Web-based technologies, cloud resources, and real-time, scalable, communication middleware. This paper describes the SMART-NAS Test Bed's vision, purpose, its concept of use, and the potential benefits, key capabilities, high-level requirements, architecture, software design, and usage.

I. Introduction

The National Aeronautics and Space Administration (NASA) is developing the Shadow Mode Assessment Using Realistic Technologies for the National Airspace System (SMART-NAS) Test Bed. SMART-NAS Test Bed is an air traffic simulation platform whose overarching purpose is to conduct high-fidelity, real-time, human-in-the-loop and automation-in-the-loop simulations of current and proposed future air traffic concepts for the United States' Next Generation Air Transportation System called NextGen [1]. SMART-NAS Testbed (referred to as SNTB) will enable simulations that are currently impractical or impossible for three major focus areas of NextGen research and development:

- Concepts across multiple operational domains such as gate-to-gate trajectory-based operations (TBO) concepts [2]
- Concepts related to the seamless and widespread integration of new entrants into the National Airspace System (NAS) such as large and small unmanned aerial systems (UAS) [3], on-demand urban air mobility vehicles [4], supersonic aircraft [5], and commercial space operations [6]
- Real-time system-wide safety assurance technologies to allow safe, increasingly autonomous operations in conjunction with traditional manned operations [7]

The vision for SNTB has evolved over time [8] and shaped by the limitations (and strengths) of current research and operational simulation platforms. These limitations can be characterized in three dimensions – scope (how extensive is the simulation), cost (how resource intensive is the simulation), and value (how much is gained from the simulation).

Scope: In general, the simulation tools and systems are developed separately for the different air traffic domains (e.g., surface, terminal, en route, oceanic, etc.). They are usually tailored to the evaluation of specific operational concepts and not easily integrated. Future air traffic concepts are often evaluated using a limited number of air traffic operations due to the complexity of managing large-scale simulations.

Research simulators [9][10][11][12][13] usually model real-world complexities with less fidelity and with fewer interfaces to information than will be encountered in live field demonstrations and operational

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implementation. For example, traffic simulation is typically limited to specific operations (e.g., arrival operations, air carrier operations, etc.) and weather simulation is generally limited to gross atmospheric conditions (e.g., winds and temperature) as a static condition over the course of each simulation run. Most operational data (e.g., nationwide flight plan and surveillance data) has only been available to a select community until fairly recently. Few simulation capabilities have had the ability to incorporate airline information sources.

Training simulator implementations [14][15][16][17][18] typically use operational systems to certify air traffic controllers and traffic managers. Many elements of the training simulators are high-fidelity representations of the current air traffic system. Usually, operational systems are dedicated for a single purpose, do not have extensibility features, and lack the ability to model future air traffic concepts.

Cost: Real-time, high-fidelity simulations are executed in individual brick-and-mortar laboratories by a limited number of research organizations. Smaller organizations do not have the resources to build or maintain sizeable facilities, and thus limited to smaller simulations. Operational systems are proprietary commercial products and restricted government equipment and only available to prominent research institutions with substantial resources. Human-in-the-loop simulation testing is time-consuming, resource intensive, and error-prone. A large amount of undocumented corporate knowledge and manual activities are necessary to achieve successful and useful results.

Value: Simulation tools and infrastructure are not standardized across work-groups and stakeholders. Sharing of simulation capabilities and data is difficult even within the same organization. The configuration management, access and archival of simulation results is often insufficient to reuse during later research activities. As a result, many simulation capabilities are repeatedly redeveloped. Finally, the analysis tools are developed independent from the simulation tools, so today's high-fidelity simulations often generate more data than can be thoroughly analyzed.

This paper describes the vision for the SMART-NAS Test Bed. It begins with a general overview and illustrates the concept of operations. The approach used for development and a more detailed description of the features is then provided. Lastly, the paper briefly describes how SMART-NAS Test Bed has initially been used by other research projects.

II. System Overview

This section describes the set of high-level requirements that were formulated to address the modeling and simulation shortfalls discussed above. It also describes how those high-level requirements are to be used by describing the SNTB conceptual framework and its concept of use.

A. High Level Requirements

The primary SNTB objective is to accelerate transformation of the National Airspace System (NAS) through higher fidelity simulation, testing, and technology transfer of more mature technologies to the Federal Aviation Administration (FAA) and aviation stakeholders.

The eight primary SNTB requirements are:

1. SNTB shall simulate both current and alternative air traffic operations, architectures, technologies, roles and responsibilities, and business strategies.
2. SNTB shall integrate operational and prototype systems using standardized interfaces defined by stakeholders.
3. SNTB shall include any combination of live (i.e., real people operating real systems), virtual (i.e., real people operating simulated systems), and constructive (i.e., simulated people operating simulated systems) air traffic operations.
4. SNTB shall execute concurrent air traffic simulations by multiple, independent users.
5. SNTB shall execute geographically distributed air traffic simulations.
6. SNTB shall provide a set of core services for simulation design (both architecture and scenario), execution, and configuration management.

7. SNTB shall allow users to augment the existing set of SNTB capabilities with their own capabilities.
8. SNTB shall allow users to share their individual simulation components and simulation results with other users.

B. Concept Framework

The SNTB platform is comprised of six primary elements shown in Figure 1. A set of secure support services (shown in the top-left portion of the diagram) are provided to simplify all aspects of real-time, human-in-the-loop and automation-in-the-loop simulations from design (i.e., prior to execution) through analysis (i.e., after execution). These services are primarily web-based. They include authentication, authorization and accounting; scenario generation; simulation architecture and asset configuration; command, control and monitoring; real-time visualization; and data analysis support.

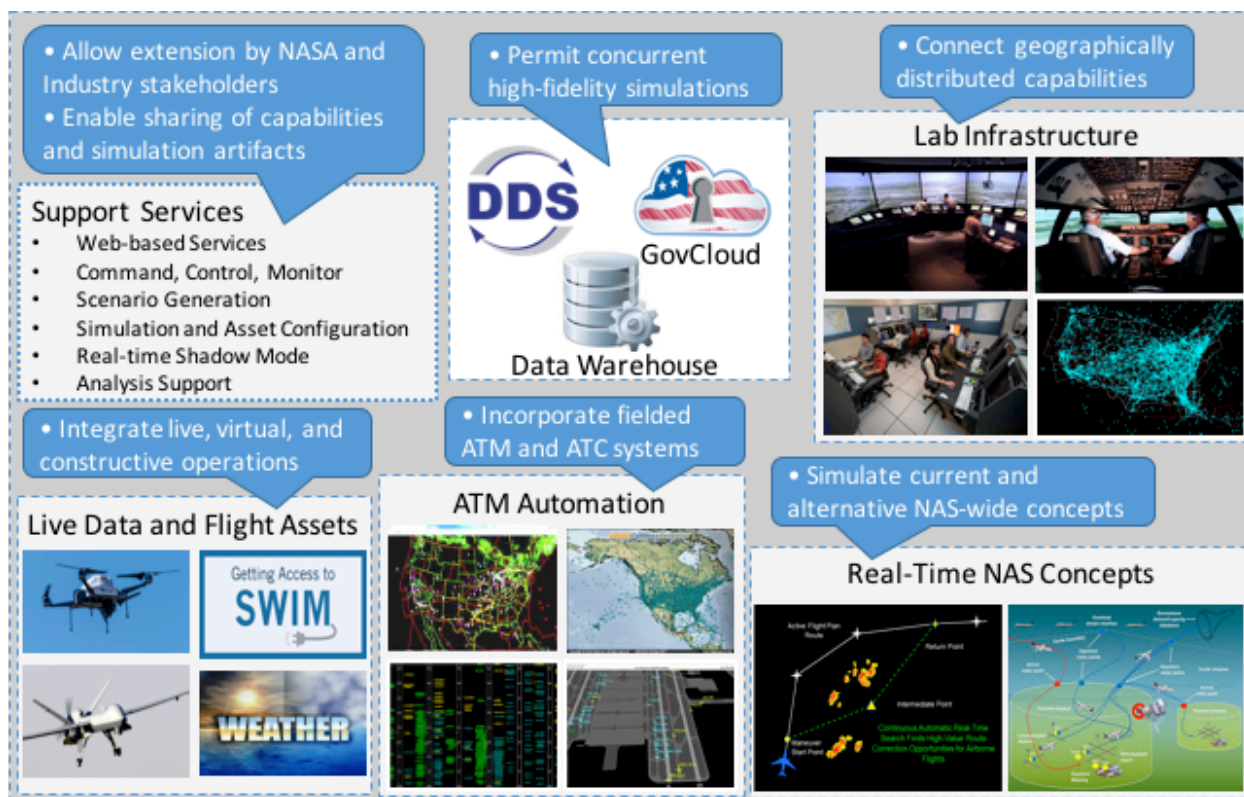


Figure 1 SNTB Platform Elements and Capabilities

There are three foundational infrastructure elements shown in the upper middle portion of Figure 1, that underlie SNTB. The GovCloud [19] (cloud service) allows SNTB to execute multiple simultaneous large-scale air traffic management (ATM) and air traffic control (ATC) simulations by utilizing its on-demand compute resources. NASA's ATM Data Warehouse [20] provides access to an extensive archive of historical air traffic, weather and airspace data, as well as the ability to use Big Data analytics (process of collecting, organizing, and examining large data sets). Finally, Data Distribution Service (DDS) [21], a middleware standard, enables scalable, real-time, dependable, high-performance, and interoperable data exchanges between both legacy and emerging technologies.

SNTB will connect geographically distributed air traffic simulation and flight simulator facilities inside and outside of NASA (shown in the top-right portion of Figure 1). The resulting combination of real and virtual facilities have an unparalleled simulation capacity spanning all phases of an aircraft's operation from start (e.g., gate pushback) to finish (e.g., gate arrival). These facilities have the ability to simulate key actors in the National Airspace System (NAS) including the air navigation service providers (ANSP), the airline operations centers (AOC), and the flight deck.

Live, virtual, and constructive (LVC) flight operations [22] (shown in the bottom-left portion of Figure 1) are used to support a broad array of tests from traditional human-in-the-loop research simulations to shadow tests and flight demonstrations. Live and recorded air traffic data from the FAA are combined with data from non-FAA sources (e.g. NOAA, airlines) to form the SNTB data store. Actual flight operations can be combined with simulated air traffic generated by NASA and industry flight simulators and traffic generators.

Sophisticated ATM and ATC systems (shown in the bottom-middle portion of Figure 1) will be incorporated as pluggable extensions to SNTB. They will be used to construct realistic, high-fidelity emulations of both current and proposed air traffic operational concepts. Examples of these systems include operational automation platforms (e.g., FAA systems), research prototypes of future advanced capabilities (e.g., NASA prototypes), and commercial air traffic solutions (e.g., industry applications).

Lastly, the capability to perform human-in-the-loop real-time NAS wide simulations (bottom-right portion of Figure 1) is used to research alternative concepts and compare with current operations. SNTB will help facilitate the setup and execution of these simulations.

In addition to the elements described in the diagram, SNTB allows the augmentation and extension of its capabilities with both NASA and non-NASA components. It promotes the sharing of both simulation capabilities and simulation data among its users. Three distinct libraries are provided by SNTB: a component library of the pluggable extensions to SNTB, a scenario library of traffic, weather and airspace scenarios previously simulated, and a simulation library of the results of previous SNTB simulations.

C. Simplified Concept of Use

The simplified SNTB Concept of Use is illustrated in the Figure 2. The user's interactions with SNTB are organized into five color-coded categories numbered one through five.

Step 1 (brown): The user logs into the SNTB web portal from an ordinary web browser. The user may initiate their session from both NASA and non-NASA domains (i.e., internal and external networks). The user's credentials are verified by the Authentication, Authorization, and Accounting service. The user may provide NASA or third-party credentials (i.e., third-party identification).

Step 2 (blue): A secure user session is established to guarantee the confidentiality of the user's activity and data. SNTB allows concurrent sessions by different users as well as the same individual user. All web traffic associated with the user's session includes the user's credentials. The Authentication, Authorization, and Accounting service ensures that web content and data is only provided to authenticated and authorized users.

Step 3 (green): The user's web browser receives SNTB content from the User Account, Component Library, Scenario Library, and Simulation Library services. The User Account maintains the user's personal settings; the Component Library contains the set of supported simulation components; the Scenario Library contains scenario playbooks available for execution; and the Simulation Library contains the results of previously executed simulations. The Authentication, Authorization, and Accounting service ensures that SNTB content and data is appropriate for the user's identity, role and authorization level.

Step 4 (orange): The user interacts with several core services to manage the creation and execution of SNTB simulations. First, the Simulation Architect is used to define the components of the simulation and their configuration. Second, the Scenario Generator is used to define the traffic, weather, and airspace configurations for the simulation, if a predefined scenario from the library is not used. Lastly, the Command, Control and Monitoring services are used to start, stop, and monitor the simulation. Each of these services provides additional SNTB content to the user's web browser.

Step 5 (purple): Using the Command, Control and Monitoring services, simulations defined by Simulation Architect and Scenario Generator are executed by SNTB. Simulation components may be run on physical and virtual, NASA and non-NASA compute resources. All of the elements of a simulation are integrated using the DDS communication middleware. Simulations are comprised of several primary types of components. Simulated (i.e., virtual and constructive) air traffic is provided by traffic generators and flight simulators (initially, NASA systems, but eventually external systems will be available). Live air traffic is provided by the FAA System Wide Information Management (SWIM) [23] digital data-sharing network. If needed the ATM Data Warehouse provides recorded air traffic, weather, and airspace configuration

information. Specific current and proposed operational concepts can be tested in SNTB by using their associated NextGen applications (both prototype and operational) in conjunction with the live, virtual and constructive traffic, weather and airspace configuration information. Finally, a wide range of support tools allow the simulation to be observed, recorded, replayed, and analyzed by the user.

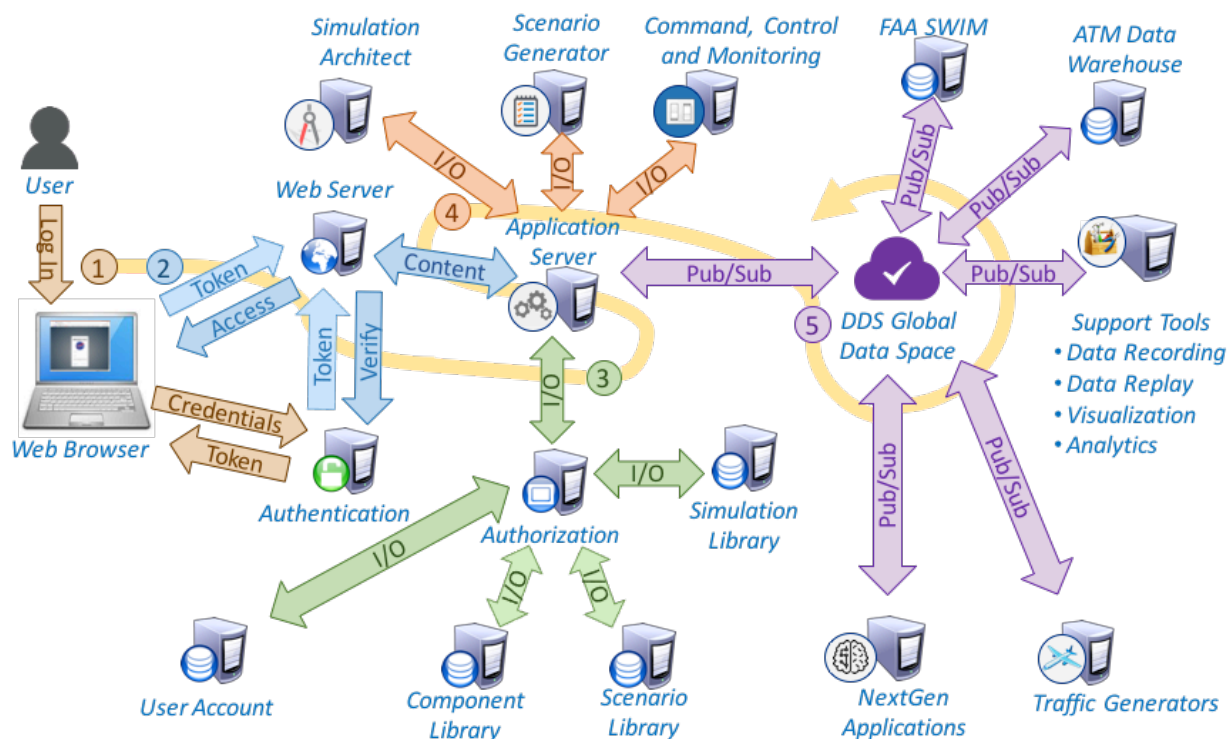


Figure 2 Simplified SNTB Concept of Use

III. Development Approach

The SNTB development is described in terms of a set of nominal use cases each of which comprised of a set of major capabilities. These nominal use cases are realized through the implementation of four major SNTB software builds. Each software build, has a set of system-level functional requirements that are used to guide the software development.

A. Nominal Use Cases

The nine nominal use cases are listed in Table 3. The SNTB nominal use cases are representative of potential SNTB configurations and inform SNTB system-level and functional requirements. These nominal use cases were chosen to encompass the initial major representative capabilities that together span the entire set of SNTB capabilities. Additional nominal use cases may be added in the future to support a broader range of capabilities. Various combinations of these capabilities will be used to compose individual customer use cases. They will have varying degrees of maturity with the objective to provide initial benefit to users and demonstrate capability.

B. Software Builds

During its planned five-year development period that started in 2016, SNTB will mature through a series of software builds as shown in the Appendix. New core services and components will be added with each build to support the increasing set of nominal use cases. One of the benefits of the incremental approach is it allows leveraging lessons learned during development to make more informed decisions and mitigate risk. Additionally, it allows for requirement changes during development.

Table 3 Nominal Use Cases

Use Case	ID	Summary
Automatic Scenario Generation	1	Representative air traffic simulation scenarios are automatically generated and validated by using offline Big Data analytics and historical data from the ATM Data Warehouse
Automated Air Traffic Control	2a	Automated air traffic control algorithms are endurance-tested using closed-loop shadow mode capabilities with realistic NAS configurations, traffic demand, and weather conditions
Integrated UAS Traffic Management	2b	Integrated traffic management, scheduling, separation management, and collision avoidance algorithms are investigated for small unmanned operations with realistic NAS configurations, traffic demand and weather conditions
Airborne Weather Rerouting	3	Collaborative decision-making algorithms are tested using mixed real-time and fast-time capabilities with realistic NAS configurations, traffic demand, and weather conditions
Integrated Arrival, Departure, and Surface Operations	4	An operational integration assessment is conducted using distributed late stage prototypes of the integrated arrival/departure/surface scheduling technologies
Terminal Sequencing and Spacing	5	In-situ terminal automation training is performed using on-demand human-in-the-loop simulation capabilities with realistic NAS configurations, traffic demand, and weather conditions
What-if Planning	6	What-if testing is conducted with operational technologies to compare the outcomes of several different traffic management decisions using scaled real-time simulation capabilities
Adaptation Update Validation	7	Regression testing is conducted to verify the adaptation consistency of simulation components and to certify a prescribed traffic scenario
ATM Data Provider	8	Airspace, weather and traffic data from the ATM Data Warehouse is available via a standardized interface with customizable formats to internal and external customers

C. System-Level Functional Requirements

Each SNTB build will contain an incremental set of capabilities that are reflected in a set of system-level functional requirements. All of these SNTB requirements are contained in the SNTB Specifications Tree (SST). The current hierarchy of the SNTB specifications is shown in Figure 3. The SST will grow as new SNTB capabilities are added. The SST traces from the project goals and nominal use cases to system requirements to major subsystem requirements and lower level software requirements. The system-level functional requirements shared among the subsequent builds are repeatedly verified during SNTB system integration prior to use by customers.

IV. System Description

Four teams consisting of 13 organizations were contracted with the task of developing architecture alternatives for the test bed [8]. Recommendations from this study influenced the design of the system architecture. The envisioned SNTB high-level system architecture is shown in Figure 4. The architecture diagram is used to communicate the scope of the system, develop requirements, and identify interfaces.

SNTB has a flexible, scalable and extensible publish-and-subscribe design. The specific components included in the architecture diagram are examples of the most relevant and highest-priority customer needs for early SNTB users. As SNTB development progresses, additional components and additional types of components will be added to support the increasing portfolio of use cases.

Overall, SNTB will integrate an extensive set of real-time, high-fidelity simulation systems supported by a sophisticated set of support services. Examples of the simulation systems include advanced air traffic management decision support tools and automation platforms; several traffic generators and flight

simulators; and visualization and analytics frameworks. Examples of the support services include authentication, authorization and accounting; simulation architecture; scenario generation; data warehouse services; and cloud provisioning services.

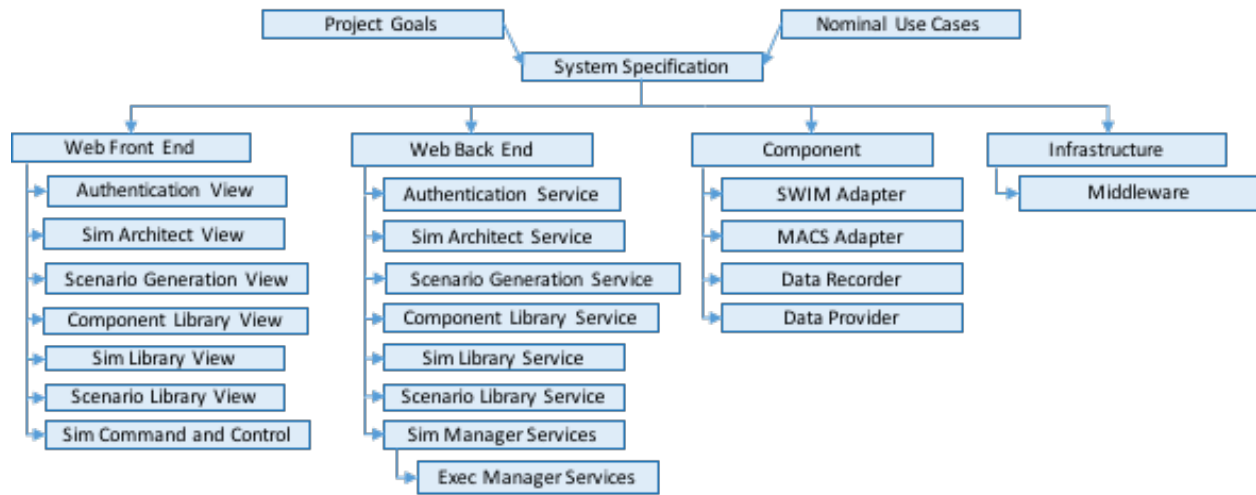


Figure 3 SNTB Specifications Tree

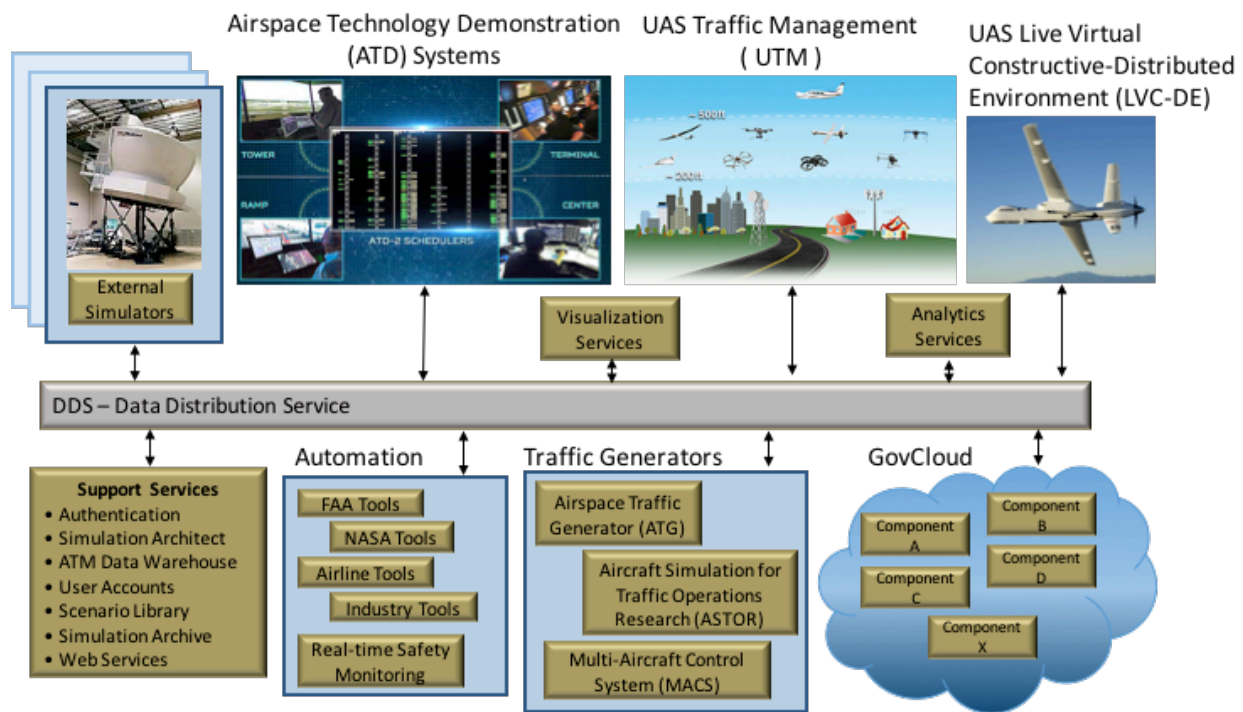


Figure 4 High-Level System Description

A. High-Level Architectural Features

i. Publish-and-Subscribe

The SMART-NAS Test Bed uses a publish and subscribe communications architecture. The Publishers and Subscribers are associated by common message topics but are unaware of each other or the network topology. This scalable architecture allows for components in the system to communicate with one another in a loosely coupled fashion and promotes a desired “plug-and-play” feature for components

integrating into SNTB. The architecture is decentralized and does not have single points of failure or performance bottlenecks that are seen in architectures using centralized message brokers.

ii. Cloud-Based

SNTB will be able to leverage cloud resources and allow a lab to scale beyond its resident computing capabilities. Cloud compute resources can be used as needed and released when they are not to enable simulations that are currently impractical or impossible. Additional compute resources may also be used when processing data pre and post-simulation.

iii. Distributed Execution

Different labs and simulation facilities have unique characteristics that focus on providing realism toward simulating specific operational domains of the NAS such as airport control towers, aircraft flight decks, and airline operation centers. Live, virtual, and constructive flight operations are also used to perform simulations. Currently, these facilities each conduct simulations independently from one another. To help enable the research of concepts across multiple operational domains, SNTB was designed with an architectural feature of the capability to connect these facilities and have them interact within the same simulation. This enables leveraging each facility's unique simulation fidelity characteristics, leverage shared resources, and support the ability to conduct simulations that examine complex interactions involving multiple ATM operational domains.

B. High-Level Design

i. Data Distribution Service

Data Distribution Service (DDS) is the communications middleware used in SNTB that follows the publish-and-subscribe architecture. The use of DDS is a recommendation from the studies that examined alternative Test Bed architectures mentioned in Section IV. Using a middleware communications layer allows applications developer to focus on the business logic of the application with less concern about the low-level communications implementation. DDS provides an application programming interface (API) to Quality of Service settings that have a number of options to specify communication behavior and performance. DDS is an open standard from the Object Management Group (OMG). Since DDS is a standard and has interoperability between vendor implementations, the use of DDS does not restrict SNTB to a particular DDS vendor. DDS can be run on major operating systems (Linux, Windows, Mac OSX) and with a number of programming language implementations (Java, C/C++, Scala, Ruby, and others) heterogeneously.

ii. Authentication, Authorization and Accounting

The Simplified Concept of Use section II. C. describes how each user is required to log in to the SNTB System. The user's credentials will be authenticated and then allow access to SNTB content that is appropriate for the user's identity, role and authorization level and conversely restrict access to content for which the user is not authorized for. SNTB will be able to accommodate various usage and confidentiality use cases (e.g. sharing or restricting access or visibility of proprietary components). Another benefit of requiring a user to log in is the ability to track usage and storage for accounting purposes.

iii. Web Services

Users access all SMART-NAS Test Bed functionality through a web browser. By using a web interface, SNTB can be accessed by any machine independent of platform as long as it is connected to the network and supports a web browser. Web enabled accessibility will allow the use of SNTB Core Services (described in sub section v.) to be performed remotely outside the confines of the lab. For tasks that may require a long processing time, a user can start the process, log off, and return later to SNTB when the process is completed.

iv. Component Adapters

Components integrated into the SNTB framework are treated as "black boxes" (i.e., no knowledge of the component's internal workings). Component Adapters function as bridges between the Component and the SNTB system, by translating component input and output messages and mapping data to

communicate with the SNTB DDS architecture. Currently, the SNTB Development team is creating the Component Adapters to provide some initial capability to SNTB. The SNTB Development team will use the lessons learned from this task to develop templates and instructions that will enable developer partners to create adapters for their own components to contribute into SNTB.

v. Core Services (Scenario Generation; Architecture Generation; Command, Control and Monitoring)

SMART-NAS Test Bed provides a number of Core Services that support the lifecycle of a simulation. These services are intended to be used “a la carte” (to permit users to use their own tools where appropriate) or with the other SNTB services, because the SNTB framework cannot anticipate all the specific needs of the users. Furthermore, SNTB will provide integration points to allow users to add custom code and later contribute to enhance the Test Bed. The following is a description of three primary Core Services.

The first SNTB Core Service is Scenario Generation. Generating a scenario that will run in a simulation is largely done manually today. The task can be tedious, time consuming, and error prone. SNTB currently provides an early version of the Scenario Generation service to assist in automating this task that contains filtering and pre-processing routines for the input traffic data and can accommodate user defined routines. A drag-and-drop graphic user interface (GUI) is used to assemble the data sources (traffic, weather, airspace definitions), specify filtering and preprocessing, and assign the simulation software tool(s) that will use the output files of this service as scenario input (Figure 5). This approach provides ease of use and allows a user without a coding background to perform this task. A record of the data source and processing used to produce the scenario is also generated for use in an audit trail of the simulation. A future version will integrate with NASA’s ATM Data Warehouse for access to the latter’s archive of historical air traffic, weather and airspace data, as well as Big Data analytics.

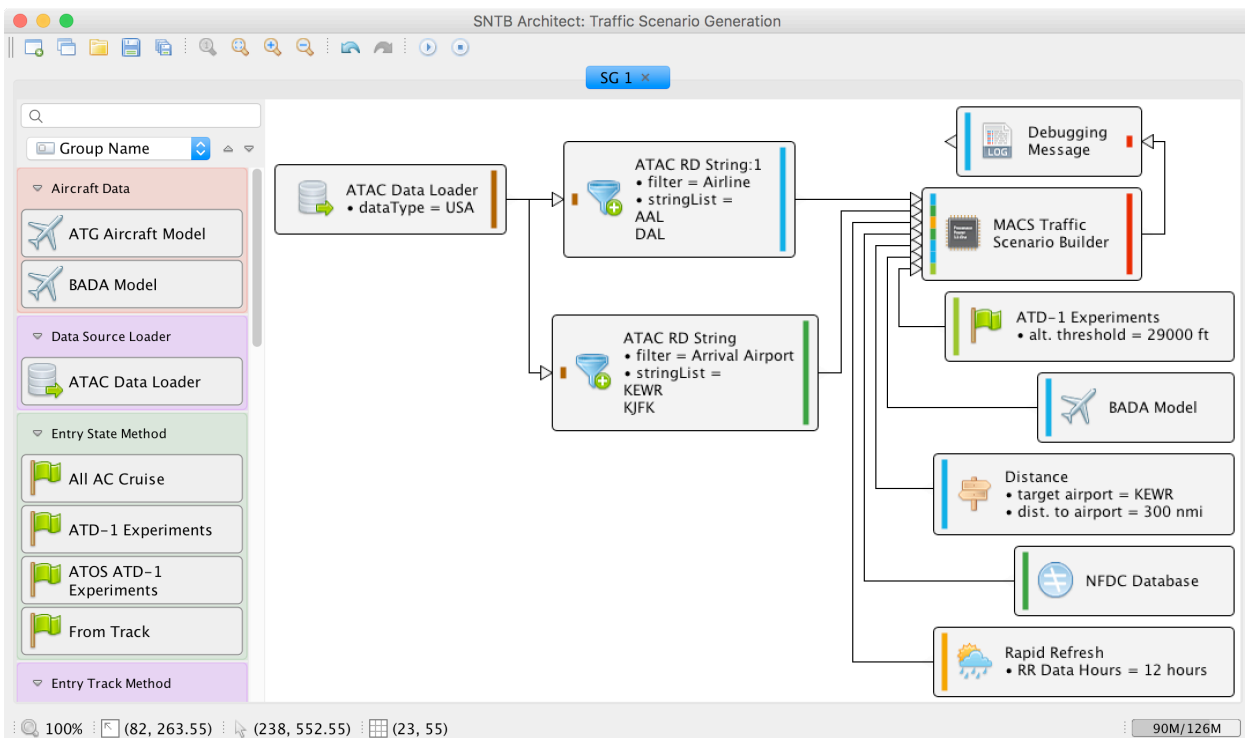


Figure 5 Scenario Architect GUI

Architecture Generation is the second SNTB Core Service. It uses a drag-and-drop GUI similar to the one used for Scenario Generation, to define a simulation’s components, their runtime configuration, and their interconnectivity. Only Components that are authorized for the user will be available for the user to include in their Architecture. A benefit of this approach is that the layout can be visualized and the configuration details are recorded into an Architecture file.

Command, Control, and Monitoring is the third Core service that provides the user the ability to control and execute simulations. The status and health of infrastructure elements, simulations, and Simulation Components will be displayed on the Simulation Command and Control View. To run a simulation, a user will specify the scenario from the Scenario Generation service or uploaded by the user and the Architecture generated from the Architecture Generation service. The typical usage envisioned is for a given architecture to be paired with different scenarios that follow a researcher’s simulation test matrix. As this service evolves, users will have runtime controls that allow simulations to be paused, resumed and operated at non-real-time rates if supported by the Simulation Component. Additional health status information will be provided to monitor the performance of individual infrastructure elements and Simulation Components.

vi. Core Libraries

The many services, SNTB also contains a set of Core libraries. The Component Library contains the available simulation components; the Scenario Library contains scenario playbooks available for execution; and the Simulation Library contains the results of previously executed simulations. These libraries are more than just storage locations because they are combined with SNTB features and services for access control and file sharing, remote access via the web, simulation and architecture configuration files, scenarios files, pluggable components to provide a place for SNTB users to contribute, share, reuse, and collaborate with one another. All the elements to rerun a previous simulation are stored in the SNTB libraries. A simulation run on SNTB by one user can be re-run by a different user with caveats regarding access privileges and hardware accessibility. This enables reproducible research for simulations where research results can be verified and/or be extended. It also reduces a single point of failure risk related to a single expert with knowledge of how to operate the entire simulation. Another benefit made possible by these features is the ease of advancing a concept’s Technical Readiness Level (TRL) by initially using the low fidelity components (available in the library) and later using more realistic ones.

C. Measures of Performance and Progress Indicators

SNTB will use Measures of Performances (MOP) and Key Performance Parameters (KPP) to monitor and evaluate the development of its technologies. MOPs quantitatively characterize the extent of SNTB development maturity. KPPs are a subset of the MOPs that are of particular interest to the SNTB users and are used in communication with them. The SNTB MOPs and KPPs are listed in Table 4 below:

Table 4 Progress Indicators

<p><u>Capability Metrics</u></p> <p>Quantify the breadth of capabilities in regard to the scope of air traffic simulations that can be conducted.</p> <ul style="list-style-type: none"> • Number of Simulation Components [KPP] • Maximum Sustained Duration of High-Fidelity Simulation
<p><u>Utility Metrics</u></p> <p>Quantify the utility in regard to supporting the high-fidelity simulation and testing activities of other users.</p> <ul style="list-style-type: none"> • Number of Activities Using SNTB [KPP] • Total User Account Activity
<p><u>Usability Metric</u></p> <p>Quantify the usability in regard to providing a user-acceptable simulation and testing environment.</p> <ul style="list-style-type: none"> • Mean User Experience Rating
<p><u>Performance Metrics</u></p> <p>Quantify the performance in regard to the number, size, and speed of simulations that can be conducted</p> <ul style="list-style-type: none"> • Number of Concurrent Simulations • Number of High-Fidelity Simulated Aircraft [KPP] • Maximum Simulation Time Rate

V. SNTB Utilization

Although SNTB is still in an early state, some capabilities are already in a sufficiently mature state to provide benefits to other projects. The Airspace Technology Demonstration 3 (ATD-3): Dynamic Routes for Arrivals in Weather (DRAW) project [24] has used the SNTB Scenario Generation service for their Human-in-the-Loop (HITL) simulation #1 (May 16-25 2017) and in a portion of HITL #2 (Oct 4-13 2017). The SNTB Scenario Generation service was used to automatically generate scenarios with air traffic for the entire DFW Center. This scenario consists of approximately 400-500 flights and weather conditions from an actual day. Generating a scenario of this scale would have been extremely difficult or near impossible if done manually. Using actual historical data provides a basis of realism for the scenario and allows a baseline to compare against.

The Real-Time Safety Monitoring (RTSM) framework was developed for monitoring and predicting the state of safety as well as predict unsafe events in the NAS. This project completed a study where live FAA SWIM traffic data was provided by SNTB to the RTSM framework [25]. By demonstrating the framework's use of real flight data from an operational source, the RTSM project anticipates that the acceptance for deployment will be accelerated.

Future work involving using SNTB to assist other NASA projects has been planned. Some examples are: Airspace Technology Demonstration 2 (ATD-2), Low Boom Flight Demonstrator (LBFD), and New York Trajectory Based Operations (NYTBO). Furthermore, the Integrated Demand Management (IDM) project intends to integrate a simulation capability into SNTB that automates both the human components and collaboration between operational systems [26].

VI. Conclusion

This paper described the current state and vision for the SMART-NAS Test Bed, an air traffic simulation platform that will enable real-time simulations that are currently impractical or impossible. SNTB has the ability to scale, connect, share, leverage other simulation assets, and reduce the complexity involved in setting up and running simulations. The combination of these features can permit additional benefits including, reproducible research, distributing the expertise related to the setup and execution of a simulation, and increasing the TRL development pace. This ambitious vision has crystalized over time and holds much promise, but much work remains. SNTB will continue to develop incrementally, adding new capabilities and maturing the existing ones.

VII. Appendix

Table 5 Build Summary

Build Identifier (User Type)	Release Date	Use Case IDs	Key Capabilities
Alpha (Developer)	December 2016	Use Case 1 Use Case 8	<ul style="list-style-type: none"> • Initial user management and web front end • Static (i.e., pre-defined) Component Library • Recorded data driven scenario generation • Predefined physical computing resource allocation • FAA SWIM live data access • Simulation architecture • Distribution over NASA local area network • Basic real-time support • Limited traffic and weather visualization • Single traffic generator component • Real-time System-Wide Safety component
Beta (Invited NASA Users)	September 2017	Use Case 2a Use Case 5	<ul style="list-style-type: none"> • Big Data interface for scenario generation • Time-invariant atmospheric conditions (winds) • User-defined physical computing resource allocation • Deploy and startup components • ATM Data Warehouse recorded data access • Integrated traffic and airspace visualization • Multiple traffic generator components • Arrival scheduler component • Conflict detection component
Version 1.0 (NASA Users)	September 2018	Use Case 2b Use Case 4	<ul style="list-style-type: none"> • Live data driven scenario generation • Dynamic (i.e., user-defined) Component Library • Dynamic atmospheric conditions (winds) • Dynamic virtual computing resource allocation • Simulation command, control and monitoring • Distribution over NASA wide area network • Integrated traffic, airspace, and weather visualization • Scaled real-time support • Flight simulator components • Arrival, departure, and surface scheduler components • Conflict resolution component • En route and terminal controller display components • Airport tower controller display components • Ramp tower controller display components • Simulation Archival Support
Version 2.0 (non-NASA Users)	September 2019	Use Case 3 Use Case 6 Use Case 7	<ul style="list-style-type: none"> • Secure Component Library • Dynamic weather conditions (convective) • Distribution of non-NASA wide area network • Participant voice communication • Participant DataComm communication • Fast-time support • Live aircraft operations • Traffic flow management component • Airline Operations Center display components • Oceanic controller display components • UAS ground control station components

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