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# High Level Architecture (HLA) as a Research Tool for Advanced Air Mobility (AAM)

*Terence McClain, Jason Prince, and Saeideh Samani*
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August 2024

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Space Administration

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# Executive Summary

In this document, a NASA investigation into the High-Level Architecture (HLA) standard for distributed simulation as a means of furthering Advanced Air Mobility (AAM) research is illustrated along with a description of the evolution of distributed simulation leading to the HLA standard. HLA enables efficient definition and insertion of components and participants in simulation sessions. Novel concepts can be added or removed as the work evolves. A general history of the HLA standard is described to show past needs for improved methods of distributed simulation, particularly among participating laboratories in separate locations, as well as previous applications of HLA simulation to airspace research. These examples from the past illustrate how new and emerging concepts can be simulated by layering notional ideas over simulated current-day systems and capabilities in a controlled environment for examination.

In the 1990s, the Federal Aviation Administration (FAA) and the MITRE Corporation performed joint research into then-emergent capabilities in the National Airspace System (NAS). In the early 2000s, the MITRE Corporation developed an open, extendable set of objects and protocols designed for global and collaborative aviation research called AviationSimNet, which has HLA as its foundation. This led to NASA and the FAA using AviationSimNet to connect laboratories for AAM research, resulting in the NASA/FAA Laboratory Integrated Test Environment (NFLITE). The underlying capabilities of HLA enabled testing a notional interaction between AAM and legacy ATC systems that resulted in AAM vehicles receiving beacon codes for identification on ATC screens in Class C airspace. The potential next steps in this work include defining and examining notional interactions between AAM and legacy ATC systems within Class B airspace.

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# List of Acronyms

| | |
|---|---|
| 4DT | 4-Dimensional Trajectory |
| AAM | Advanced Air Mobility |
| ADS-B | Automatic Dependent Surveillance Broadcast |
| ALSP | Aggregate Level Simulation Protocol |
| API | Application Programming Interface |
| ARTCC | Air Route Traffic Control Center |
| ASTOR | Aircraft Simulation Capability for Traffic Operations Research |
| ATC | Air Traffic Control |
| ATOL | Air Traffic Operations Laboratory |
| ATOS | Air Traffic Operations Simulation |
| ATS | Air Traffic Services |
| ATS-TIGAR | Advanced Trajectory Services Toolkit for Integrated Ground/Air Research |
| CAASD | Center for Advanced Aviation System Development |
| CAVS | CDTI Assisted Visual Separation |
| CDTI | Cockpit Display of Traffic Information |
| COTS | Commercial Off-The-Shelf |
| CRCT | Collaborative Routing Coordination Tool |
| CSAOB | Crew Systems and Aviation Operations Branch |
| CSF | Cockpit Simulation Facility |
| DARPA | Defense Advanced Research Projects Agency |
| DDS | Data Distribution Service |
| DIS | Distributed Interactive Simulation |
| DoD | Department of Defense |
| EDDS | En Route Data Distribution Service |
| ERAM | En-Route Automation Modernization |
| eVTOL | electric Vertical Takeoff and Landing |
| FAA | Federal Aviation Administration |
| FMS | Flight Management System |
| FOM | Federation Object Model |
| HLA | High-Level Architecture |
| JFAN | Joint FAA, ARMY NASA Federation |
| LAN | Local Area Network |
| LaRC | Langley Research Center |
| LMTSS | Lockheed Martin Corporation's Transportation and Security Solutions |
| MITRE | MITRE Corporation |
| MMAC | Mike Monroney Aeronautical Center |
| NACCL | NASA ATM Common Communication Library |
| NAS | National Airspace System |
| NASA | National Aeronautics and Space Administration |
| NextGen | Next Generation Air Transportation System |
| NFLITE | NASA/FAA Laboratory Integrated Test Environment |

| | |
|---|---|
| NIEC | NAS Innovation and Emerging Concepts |
| NSC | National Simulation Capability |
| OMT | Object Management Template |
| RTI | Run-Time Infrastructure |
| RUC | Rapid Update Cycle |
| SDRR | Simulation Driver Radar Recorders |
| SFDPS | SWIM Flight Data Publication Service |
| SIMNET | SIMulator NETworking |
| SOM | Simulation Object Model |
| STARS | Standard Terminal Automation Replacement System |
| SWIM | System Wide Information Management |
| TFM | Traffic Flow Management |
| TGF | Target Generation Facility |
| UAM | Urban Air Mobility |
| UAS | Uncrewed Aircraft Systems |
| URET | User Request Evaluation Tool |
| VFR | Visual Flight Rules |
| WAN | Wide Area Network |
| WJHTC | William J Hughes Technical Center |

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# 1. Introduction

NASA Langley Research Center's (LaRC) Crew Systems and Aviation Operations Branch (CSAOB) is studying the impacts of AAM operations on the National Airspace System (NAS), specifically Urban Air Mobility (UAM) Operations reaching Midterm Operations. Midterm UAM Operations remain at low tempo but may increase to a level requiring changes to the existing regulatory framework and procedures [1]. Pilots will be onboard the UAM aircraft and interacting with legacy Air Traffic Services (ATS) but may have access to emerging technological capabilities. The Provider of Services for UAM Operations (PSU) will act as an information broker for cooperative areas via sharing operational intent information. Decision support tools on the ground and onboard the vehicle will supplement decision making by system actors. These new entrants into the airspace need to be accounted for in the progression of AAM/UAM research through simulation.

AAM simulation requires a coupling of replicated components of the current NAS and experimental instances of prospective components of a future NAS where AAM is ubiquitous. Different laboratories specialize in distinct areas of expertise and are best utilized through joint, synergetic research. NASA LaRC's Air Traffic Operations Laboratory (ATOL) and the Federal Aviation Administration's (FAA) William J. Hughes Technical Center (WJHTC) are engaged in this type of recurring cross-center activity through the NASA/FAA Laboratory Integrated Test Environment (NFLITE). The WJHTC houses laboratories with instantiations of current NAS systems while the ATOL introduces simulated AAM components, algorithms, and procedures for examination.

The High-Level Architecture (HLA) standard for distributed simulation enables this method of AAM research. The system actors have clearly defined roles, and rules for interactions among system participants are explicitly stipulated. These roles and interactions can be current and already active (or theoretical) in the NAS reflecting how the research expects the AAM ecosystem to evolve. The high degree of modularity allows efficient addition and subtraction of simulation participants and components. This standard is an effective tool for building an accurate representation of the current NAS while layering additional AAM concepts to research the far-term AAM ecosystem and researching key variables for analysis.

# 2. Background

AAM targets a revolutionary transformation of transportation in which novel vehicle types are introduced into the NAS. New, emerging, and disruptive technologies will fundamentally change the movement of people and goods. These technological innovations support substantive and voluminous data sharing among system participants. Pilots, passengers, air traffic controllers (ATC), vehicle manufacturers, and fleet operators are examples of stakeholders in this nascent environment. Thorough research in this area requires a proper approach so the roles and responsibilities of system actors need to be defined and delineated. Interactions within an AAM environment require accurate representation of system actors and resources. In this respect, simulation is a key research tool because the fully developed AAM environment does not yet exist, and simulation allows researchers the ability to explore AAM-enabling functions, technologies, and concepts in a controlled setting.

The HLA standard enables a more comprehensive simulation by combining, or federating, several simulations together. The standard enables the ability to connect simulations running on different computers into one federation regardless of operating systems and implementation language. The architecture specifies the following [2]:

1. **Run-Time Infrastructure (RTI)**: provides a standardized set of services through different programming languages, including information exchange, synchronization, and federation management.

2. **Federate**: individual simulation systems using the RTI services. The RTI services allows federates to exchange data and synchronize with other federates.
3. **Federation Object Model (FOM)**: Document that specifies Object and Interaction Classes, data types, and additional data utilized by individual federates to exchange information. There are standardized FOMs, called reference FOMs, frequently used as templates for FOM development. FOMs can be developed and extended in a modular fashion utilizing FOM modules.
4. **Federation**: Combination of 1 – 3 above. A set of federates connected to the same RTI with a common FOM.

Per IEEE Std 1516-2010 Framework and Rules [3], there are ten architectural rules that an HLA federation shall obey:

**Rules for Federations:**

1. Federations shall have an HLA FOM, documented in accordance with the HLA Object Management Template (OMT).
2. In a federation, all simulation-associated object instance representation shall be in the federates, not in the RTI.
3. During a federation execution, all exchange of FOM data among joined federates shall occur via the RTI.
4. During a federation execution, joined federates shall interact with the RTI in accordance with the HLA interface specification.
5. During a federation execution, an instance attribute shall be owned by at most one joined federate at any given time.

**Rules for Federates:**

6. Federates shall have an HLA Simulation Object Model (SOM), documented in accordance with the HLA OMT.
7. Federates shall be able to update and/or reflect any instance attributes and send and/or receive interactions, as specified in their SOMs.
8. Federates shall be able to transfer and/or accept ownership of instance attributes dynamically during a federation execution, as specified in their SOMs.
9. Federates shall be able to vary the conditions under which they provide updates of instance attributes, as specified in their SOMs.
10. Federates shall be able to manage local time in a way that will allow them to coordinate data exchange with other members of a federation.

The following HLA terms are important in the context of current and future AAM/UAM research [3]:

- **Attribute:** Named characteristic of an object class or object instance.
- **Object:** Represents data that is continuous over some time epoch and contains attributes able to be updated. They are defined completely by these attributes within the FOM by means of an Object Class.
- **Interaction:** An explicit action taken by a federate that may have some effect or impact on another federate within a federation execution. They are defined in the FOM using an Interaction Class.
- **Datatypes:** A representation convention for a data element establishing its format, resolution, cardinality, and ordinality. They are specified in the FOM using HLA Datatypes.
- **Publish:** To announce to a federation the information a federate may provide to the federation.

- **Subscribe:** To announce to a federation the information a federate wants from the federation.

In the 1980s, the US Department of Defense (DoD) needed to perform cost-effective distributed simulation to simulate war games. The first major effort in this area was the SIMulator NETworking (SIMNET) project by the Defense Advanced Research Projects Agency (DARPA). SIMNET led to standards development for Distributed Interactive Simulation (DIS) in the 1990s. DIS introduced interoperability in distributed simulations among participants with heterogeneous environments. SIMNET and DIS implemented a single virtual environment involving multiple interacting simulations that led to the Aggregate Level Simulation Protocol (ALSP). ALSP allowed simulations to interact amongst each other over Local Area Networks (LAN) and Wide Area Networks (WAN). HLA improved upon this through combining analytic simulations with virtual environment technologies in one framework [4].

The Aviation Safety Research Act of 1988 required the FAA to implement a research program to develop dynamic simulation models of the ATC system that would provide analytical technology for predicting airport and air traffic control safety and capacity. One result of the follow-on investments was the creation of the National Simulation Capability (NSC) program. The NSC was meant to be an integrated setting where researchers could evaluate their ideas with a storehouse of simulation capabilities. Capabilities were not to be duplicated between participating organizations. NSC provided two-way connections for NAS simulation. There were two primary drivers of this early examination: The FAA's WJHTC and the Center for Advanced Aviation System Development (CAASD) of the MITRE Corporation. The WJHTC brought simulated real-world operational systems and equipment, while CAASD had simulations of future air transportation capabilities [5].

In the 1990's, the Joint FAA, Army, NASA Federation (JFAN) evaluated HLA as a technological solution for networking large numbers of simulations by integrating multiple cockpit simulation facilities with a combination of local- and wide-area networks and the Internet. It showed elementary viability of an HLA approach but still had issues to be corrected, such as federates not receiving data updates when using cross-country links. Then, in 2003, MITRE started investigating development of an open, standards-based set of object models and protocols coupled with software designed to allow simulation connections through the Internet for aviation research and development. This research evolved into AviationSimNet. AviationSimNet was designed as a collaboration among a cohort of aviation groups to implement the aforementioned standards for a global capability and an extendable specification for participants with an end-goal of a near universal, yet flexible, set of aviation simulation capabilities that could be connected anywhere in the world. These simulations could be larger and complex or smaller and scaled-down. The key is the central set of object and protocol standards for participants. The aviation environment AviationSimNet aimed to replicate largely already existed, so these standards could be layered over ones already in place for distributed simulation and aviation. At a more functional level, AviationSimNet specifies management of distributed simulations between aviation groups. It is an extendable and reusable environment that enables ATM simulation laboratories to connect across the globe [5].

The HLA standard is the foundation for the data communications framework of AviationSimNet. Not every potential participant is guaranteed to operate in an HLA-based environment. As a result, due to the HLA underpinnings of AviationSimNet, non-HLA simulation systems can be interfaced to a gateway that connects to the wider AviationSimNet environment. In this case, gateway federates perform the essential, real-time translation of data and protocols between the two mixed environments. The core HLA functionality is executed through the RTI, consisting of a central RTI Executive and a local RTI component installed in each simulation federate.

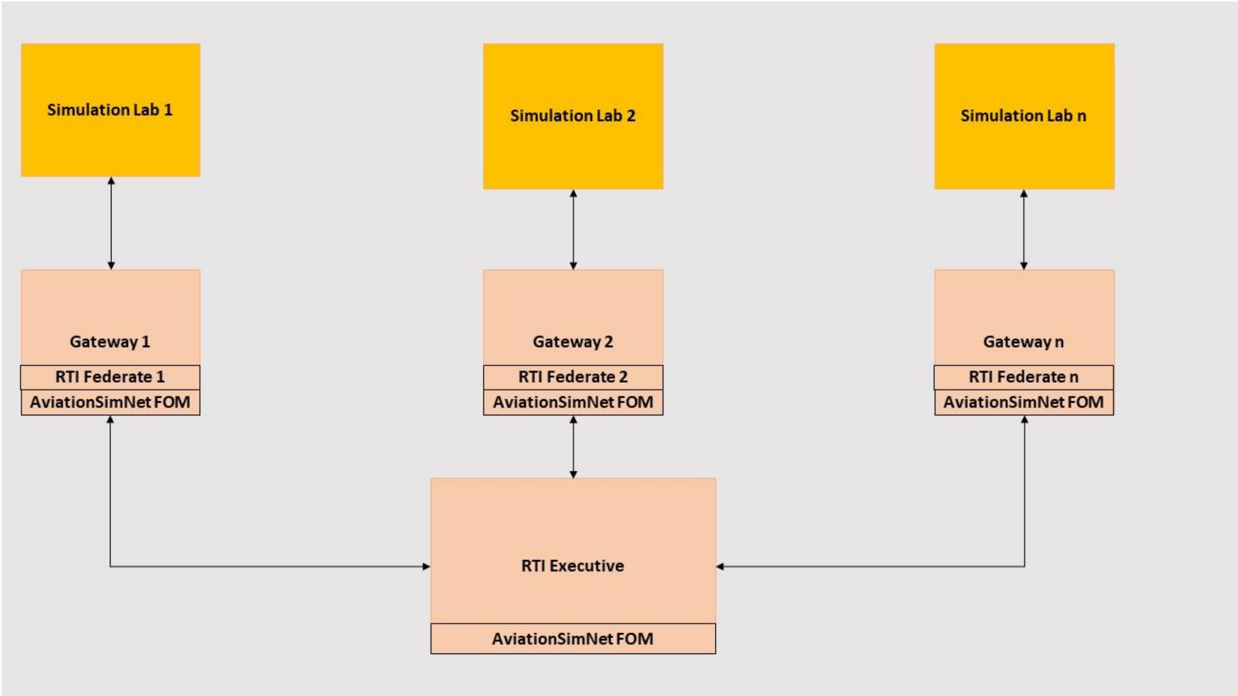


**Figure 1: Top Level AviationSimNet-Based Architecture Diagram**

Going up to the architectural level of AviationSimNet, the HLA-based foundation includes three enhancements:

1. A simulation coordination component called the AviationSimNet SimCenter,
2. An aviation-based FOM, and
3. Distributed Voice Communication

### 2.1. AviationSimNet SimCenter

SimCenter refers to the server used in an AviationSimNet Federation. Only one participant in the simulation needs to host the SimCenter. The SimCenter has four elements: an RTI Executive, a voice relay server, the simulation manager, and the collaborator web server. The voice relay server enables voice communications among the simulation actors. Its architecture permits mixed usage of custom-built and commercial voice software. The majority of Commercial Off-The-Shelf (COTS) voice software have inherent difficulties functioning on wide-area networks. AviationSimNet's voice relay server mitigates these problems.

The simulation manager directs the simulation participants through start-up, pause, shutdown, and runtime health monitoring. The startup stage has two parts: internal state initiation for individual entities and pre-startup data exchange among separate entities. AviationSimNet specification explains the procedures to be utilized at runtime. However, since the participants are located separately, additional coordination among human operators is necessary.

The collaborator joins an AviationSimNet federate to a web service, uses that federate as a simulation manager, and reflects simulation events to the web service interface for monitoring and tracking purposes. Simulation members can use the collaborator to recognize when other sites are ready to start a new simulation, when software components connect or disconnect from the RTI, and track real-time status of simulation-level events [5].

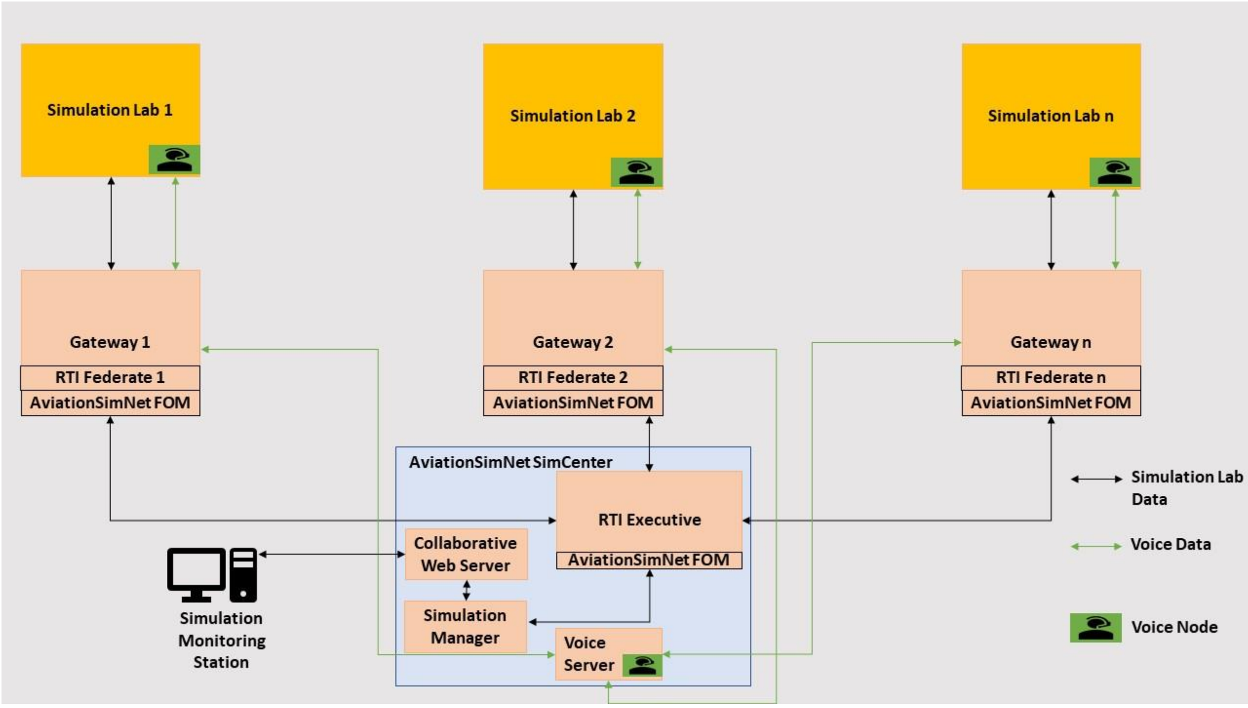


**Figure 2: AviationSimNet SimCenter Architecture Diagram**

## 2.2. AviationSimNet FOM

The AviationSimNet FOM defines the aviation domain in the HLA federation. The HLA basis of the FOM makes it extensible, allowing for the addition of aviation-related objects and interactions over time. The objects and interactions of the original FOM were identified by the AviationSimNet Standards Working Group and Version 3.1 of the FOM was published in September 2007. This edition focused on aircraft state and flight data objects along with weather data. At the time, the interaction class Flight Specific Reroute was added to support examination of automation tools for communication between traffic flow managers and ATC. The Rapid Update Cycle (RUC) information, which is a data structure of wind, temperature, and pressure observations, was added because many of the organizations involved with AviationSimNet have simulation environments that need and comprehend RUC [5].

```xml
<interactionClass name="WxRequestRUC"
  sharing="PublishSubscribe"
  transportation="HLAreliable"
  order="Receive"
  semantics="A request that the publisher of RUC data sends a WxNotifyRUC interaction satisfying the parameters of the request.
  Bounding box parameters are only used if requesting a specific subset of the RUC observation.">
  <parameter name="gridID"
             semantics="The NCDC grid used for the RUC model."
             dataType="ASNrucGrid"/>
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             Expressed as the total number of seconds elasped since midnight GMT 01/01/1970."
             dataType="UnsignedLong"/>
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             dataType="ASNdegrees"/>
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             dataType="HLAASCIIstring"/>
</interactionClass>
```

**Figure 3: Excerpt from AviationSimNet FOM containing RUC Data Interaction**

## 3. HLA Applied to Legacy Air Traffic Operations: AviationSimNet

In 2005, MITRE/CAASD and NASA Langley Research Center (LaRC) conducted the first multi-organizational implementation of AviationSimNet. This exercise aimed to demonstrate the feasibility of Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS) and Airborne Precision Spacing. AviationSimNet enabled both participants to link each center's necessary simulation components into one environment. MITRE supplied simulated ATC ground system, an avionics simulator, and a flight simulator. NASA LaRC supplied flight simulators through Aircraft Simulation Capability for Traffic Operations Research (ASTOR) and high-fidelity flight simulators that incorporated the appropriate conceptual algorithms [5].

Another exercise of AviationSimNet illustrated the implementation of air traffic flow strategies by sending reroutes through En Route automation instead of voice communication. Laboratory participants included MITRE/CAASD and Lockheed Martin Corporation's Transportation and Security Solutions (LMTSS) business unit. MITRE/CAASD provided the Collaborative Routing Coordination Tool (CRCT) that instantiated the traffic flow technology. LMTSS hosted an instance of the User Request Evaluation Tool (URET) to implement the En Route functionality. During simulation, data was exchanged through AviationSimNet. Airborne reroutes from CRCT were sent by AviationSimNet to URET through Lockheed's System-Wide Information Management (SWIM) prototype infrastructure. AviationSimNet allowed the two entities to collaborate on initial requirements for connection between Traffic Flow Management (TFM) and En Route domains due to its inherent modularity and flexibility [5].

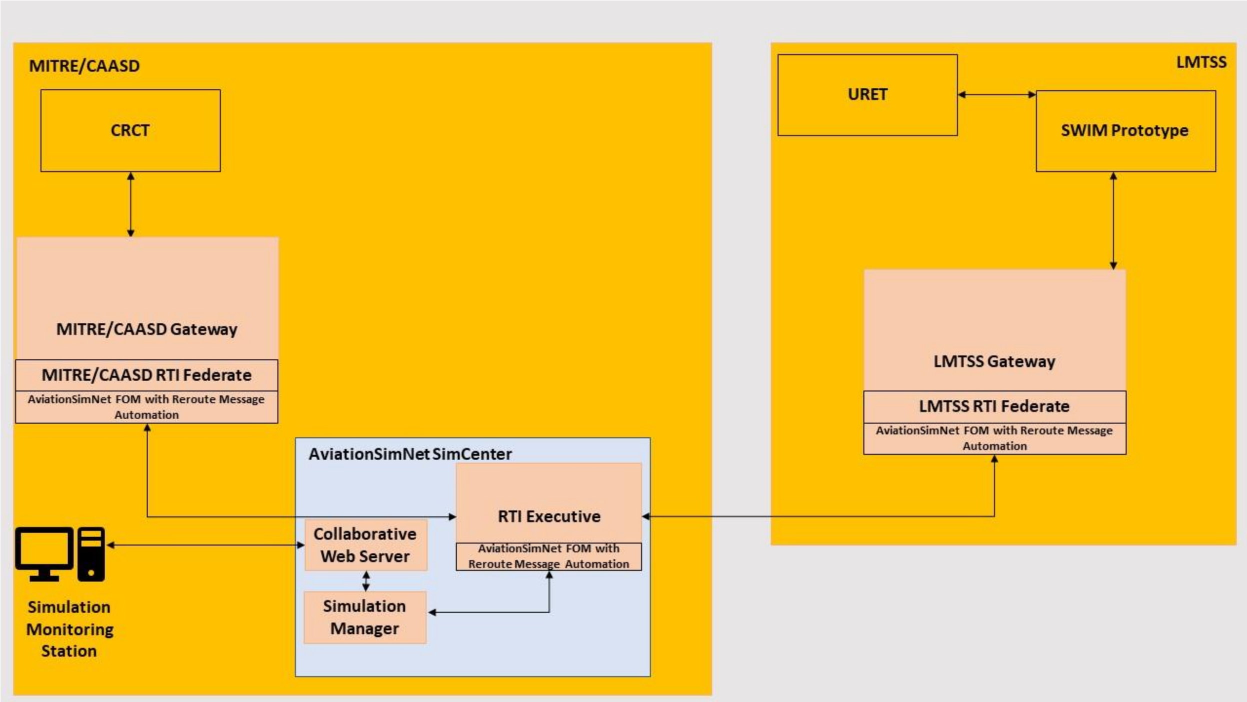


**Figure 4: HLA Used for Automated Rerouting Messages**

## 4. HLA Applied to AAM Operations Research

The NASA/FAA Laboratory Integrated Test Environment (NFLITE) is a collaborative and integrated research effort between NASA LaRC and the FAA's WJHTC to investigate future AAM operations and concepts in the NAS. The laboratories at WJHTC represent current-day capabilities and operations in the NAS, while NASA LaRC's laboratories simulate novel vehicle types, Air Traffic Management (ATM) algorithms, airspace procedures, and airspace constructs. NASA LaRC and WJHTC participate in recurring cross-center distributed simulation sessions with defined roles for each participant, including the piloting of present-day aircraft and emerging eVTOL vehicles.

### 4.1. Overview of NFLITE Capabilities at NASA LaRC-

NASA LaRC has developed a suite of tools and platforms to advance airspace research and traffic operations. These tools enable comprehensive research and simulation of flight operations within the NAS. Below is a detailed description of the key components and their functionalities:

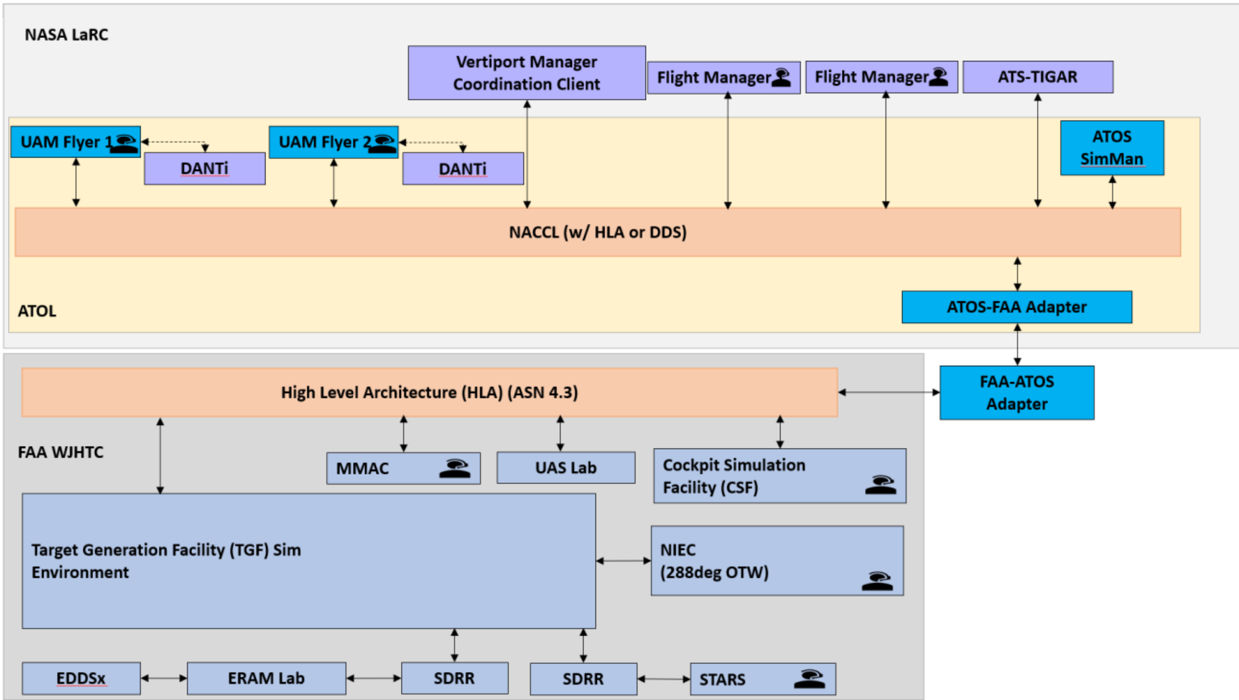


**Figure 5: Representation of NFLITE Components**

## Airspace and Traffic Operations Simulation (ATOS)

A distributed simulation platform for researching flight operations in the NAS. It is a medium to high fidelity air traffic simulation environment develped to investigate interactions between aircraft, airspace, and ground control. The simulation infrastructure enables a myriad of simulations and simulation capabilities to run in a distributed manner. ATOS uses the NASA ATM Common Communication Library (NACCL) to enable communication between the many entities instantiated within the simulation [6].

## ATOS Simulation Manager (SimMan)

The Simulation Manager initiates, controls, and monitors ATOS simulations. It can command the ATOS federates into various simulation states such as reset, hold, and operate. All of the NASA LaRC HLA federate participants are started and stopped from this application.

## NASA ATM Common Communication Library (NACCL)

An Application Programming Interface (API) wrapper developed to interface with either HLA or Data Distribution Service (DDS) to enable a distributed simulation across many computers. NACCL enables the software developer to communicate with other software components without needing to understand the HLA transport layer [6].

## Urban Air Mobility (UAM) Flyer

An aircraft simulator normally configured as a UAM vehicle, such as the NASA 6-passenger eVTOL. It uses a mid-fidelity, 6-degree-of-freedom aircraft dynamics model and employs a guidance system tailored to flying 4DT trajectories.

## Advanced Trajectory Services – Toolkit for Integrated Ground/Air Research (ATS-TIGAR)

ATS-TIGAR is a capability designed for prototype application and algorithm development and scenario analysis in support of AAM concept definition and requirements exploration. In addition, the toolkit provides a suite of applications that support laboratory activities with various system actor interactions.

**Flight Manager**

The Flight manager is an ATS-TIGAR application that allows a pseudo-pilot to control multiple UAM flight operations simultaneously. Not to be confused with a remote pilot station, such as those used to support multiple remote Uncrewed Aircraft Systems (UAS) operations, the application allows the emulation of many piloted flight operations with a limited number of participants.

**Vertiport Manager Client**

An ATS-TIGAR application that provides a user interface for the Vertiport Management actor. The Vertiport Manager Client is responsible for the management of the vertiport automation and may also be responsible for executing several manual actions as required for the overall management of the flow of operations to a given vertiport.

## 4.2. Overview of NFLITE Capabilities at FAA WJHTC

The FAA's WJHTC comprises several key facilities and laboratories that support advanced air traffic control research, development, and testing. Below are the main components and their capabilities:

**Target Generation Facility (TGF)**

The TGF is a dynamic, real-time air traffic simulation capability designed to generate realistic aircraft trajectories and associated digital radar messages for aircraft in a simulated airspace environment.

**National Airspace System (NAS) Innovation and Emerging Concepts (NIEC) Laboratory**

A laboratory that serves as an FAA Air Traffic Control research and exploration platform located at the WJHTC. NIEC provides a real-time and flexible environment to develop, explore, integrate, and evaluate the broad framework of concepts, technologies, and systems introduced by the Info-centric NAS.

**En-Route Automation Modernization (ERAM) Laboratory**

A laboratory emulating the ERAM system that leverages both physical and virtual laboratories to provide En-Route capability testing. The ERAM system provides real-time aeronautical information, increases flexibility in routing aircraft around congestion, weather, and other airspace restrictions, and enables seamless information sharing and coordination between controllers and Air Route Traffic Control Centers (ARTCC).

**En-Route Data Distribution System (EDDS)**

A data distribution system located at each of the 20 ARTCCs in the contiguous United States that facilitates transmission of ERAM data to the SWIM Flight Data Publication Service (SFDPS). A WJHTC instance of this system provides real-time aeronautical data to the ERAM Laboratory.

**Simulation Driver Radar Recorders (SDRR)**

A tool that can be configured to insert local, interfacility, and surveillance messages to a multitude of NAS ATC systems. SDRR can connect and relay data between physical systems and record incoming surveillance data. It can be setup to emulate and respond to messages from En-Route, Terminal, and other flight and surveillance data systems. SDRR can replay recorded surveillance files, inject custom static simulation scenarios, or for dynamic simulation [7].

**Standard Terminal Automation Replacement System (STARS) Lab**

A WJHTC laboratory that houses multiple STARS instances that are driven by other simulated and real-time data to facilitate terminal capability testing. STARS is responsible for the separating and sequencing of aircraft, providing conflict and terrain avoidance alerts, weather advisories, and radar vectoring for departing and arriving air traffic. The STARS lab receives data via the ERAM lab and sends generated data to other labs through an SDRR. A test controller is positioned in the STARS Lab, acting as the Terminal

Approach controller.

**Cockpit Simulation Facility (CSF)**

A WJHTC simulation laboratory that maintains and operates flight simulators of several common civilian aircraft in service today. The CSF develops and tests new technologies which enhance ATC or ATC ground and Airborne Flight Information transfer and management.

**NextGen UAS Laboratory**

An FAA research platform used to explore, study, and evaluate UAS concepts through modeling, simulation, and development activities. The lab includes simulated UAS ground control workstations, a 4-Dimensional Trajectory-enabled Flight Management System (FMS), a voice communications simulation platform, Automatic Dependent Surveillance Broadcast (ADS-B) and radar surveillance, and weather workstations [8].

Figure 5 shows the configuration and components of NFLITE. Specific to HLA Distributed Simulation, the AviationSimNet SimCenter is hosted at the WJHTC with participating AviationSimNet FOM-compliant legacy air traffic system federates connected at the TGF, Mike Monroney Aeronautical Center (MMAC), NextGen UAS Lab, and the Cockpit Simulation Facility (CSF). AAM AviationSimNet FOM-compliant federates are located at the Air Traffic Operations Laboratory (ATOL) at NASA LaRC and connect into the federation through the two adapter programs in the figure above. Since the beginning of NFLITE in 2019, the AviationSimNet FOM has been updated to allow for AAM concepts research through distributed simulation.

```
<interactionClass name="ERAMFlightPlan"
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  transportation="HLAreliable"
  order="Receive"
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                       be a digit.  Examples would be AAL113, TRS182, N17263, or HINASA."/>

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             dataType="HLAASCIIstring"
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                       Some examples of this are B737, A321, or NQDE."/>

  <parameter name="airborneEquipmentQualifier"
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                       I think we are expecting you to send an 'L' here or a 'M' for example. "/>

  <parameter name="tailNumber"
             dataType="HLAASCIIstring"
             semantics="ICAO-4444 identifier of the airframe used by the flight.  Up to 8 characters.
                       Some examples are 821DX, 481D, or 4016MR."/>

  <parameter name="requestedAltitude"
             dataType="UnsignedShort"
             semantics="The planned cruising altitude for the first or the whole portion of the route to be flown.
                       Measured in FL (Flight Level, hundreds of feet) above the WGS84 geodetic earth model.  This
                       position is relative to the aircraft's center of mass with the assumption of an empty fuselage
                       and no fuel.  Examples we would expect are 300, 280, or 165."/>
```

**Figure 6: Excerpt from AviationSimNet FOM used for AAM Research**

Figure 6 above shows ERAMFlightPlan as an interaction added to the AviationSimNet FOM to investigate AAM vehicle traffic integration into the existing NAS. Within NFLITE, flight plans are filed for the simulated AAM operations performed by the UAM Flyers and ATS-TIGAR. Flight plan filing provides a beacon code assignment from ERAM for the AAM aircraft following the specific flight plan. The beacon code provides the AAM vehicle unique identification on the STARS display to enhance controller situational awareness. The Visual Flight Rules (VFR) flight plan filing eliminated the need for the air traffic facility to utilize an internal cache of beacon codes, manually enter the flight plan information, and verbally issue the beacon code to the pilot. Thus, flight plan filing reduced frequency congestion and controller workload [9].

## 5. HLA Distributed Simulation and Applications to Future AAM Research

HLA Distributed Simulation allows for the layering of new ideas and approaches, offering significant flexibility and modularity. Past examples of this include:

- **Foundation for Automation Tools** [5]**:**
    - HLA served as the foundation for studying automation tools designed to support communication between ATC and traffic flow managers. During the research, a new requirement for weather data emerged. Due to HLA's modularity, this requirement was swiftly addressed by adding new elements to the FOM.

- **Integration of Simulators** [5]**:**
    - HLA supported the connection of ground, flight, and avionics simulators with conceptual algorithms for CAVS and Airborne Precision Spacing research. This integration facilitated comprehensive studies involving multiple simulation components.

- **Automated Re-Routing Communication** [5]**:**
    - The modularity of HLA allowed the investigation of automated airborne re-routing messages versus traditional voice communication over radios. This research explored the efficiency and effectiveness of different communication methods.

AAM aircraft, such as eVTOL vehicles, require new mechanisms for communication, interaction procedures, and data sharing techniques to ensure safe operations. NFLITE uses HLA to research the integration of these new vehicle types into the NAS. For example, one mechanism examined was the sharing of flight plan information using a currently deployed system to enhance ATC situational awareness of AAM operations.

Future AAM research should build on previous work by layering additional notional interactions and mechanisms to effectively scale AAM operations. The modularity of HLA allows for the quick insertion of new systems, procedures, and data exchanges. Innovative communication methods, along with roles, responsibilities, and procedures, can be rapidly prototyped and integrated. Data interchanges can also be implemented and refined based on research results and analysis. In summary, HLA-based simulations will illustrate the aspects of AAM that are better controlled through software or automation versus procedural solutions.

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