Initial Development of an Upper Class E Traffic Management (ETM) System for Stratospheric Flight Operations

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Abstract—**Advances in technologies across multiple areas have spurred the motivation and development of new entrants and use cases for the national airspace system to accommodate. The stratosphere, encompassing Upper Class E airspace, is of particular interest due to the types of aircraft that can operate there and the unique missions that can be carried out. The diversity of aircraft that plan to operate and the long durations envisioned presents a challenge for the management of that airspace in a manner that does not burden the current paradigm of air traffic service provision. Upper Class E Traffic Management (ETM) is an approach pioneered by NASA and FAA to enable the cooperative management of high-altitude airspace through operations in cooperative areas facilitated by information exchanges and coordination based on common operating practices. NASA has developed, implemented, and commenced initial tests of the underlying systems and architecture to enable ETM operations. The implementation is the first of its kind and meant to serve as a reference for broader adoption. This paper will present the architecture and details of the system components as well as how it has been implemented for the test. Summary results of initial connectivity tests are included to highlight the functionality of the ETM system, which provides the path forward for more complex operations and interactions at a greater scale.**

I. Introduction

The growing demand for high-altitude airspace driven by technological innovations poses challenges to existing regulations and support infrastructure [1-4], necessitating the development of concepts such as Upper Class E Traffic Management (ETM) to ensure safe and efficient management of high-altitude aircraft operations [5]. Due to the absence of specific airspace management provisions for civil aircraft operations above FL600 in the United States, the need for efficient and real-time information exchange becomes increasingly important to enable cooperative management of Upper Class E flight operations. With early roots in the Unmanned Aircraft System (UAS) Traffic Management (UTM) concept [6], NASA has been in development of the initial services and capabilities needed to support routine, scalable stratospheric operations facilitated by the ability to operate cooperatively via information exchanges and situation awareness gained through system interfaces [7-10].

This paper presents the preliminary development, research implementation, and practical use of an ETM system based on the concept that is in continued development in coordination with other government agencies and industry. This system is strategically designed to facilitate ETM operator-ESS (ETM Service Supplier) interaction by enabling operators to submit multiple flight operational intents. Additionally, it enhances situational awareness by providing real-time telemetry data of flight operations submitted by other operators in the same region, thereby promoting safer and more coordinated air traffic management systems. It also discusses the architecture and operational requirements, focusing on its role in streamlining the flight operation submissions as well as interaction with ESS. By providing a

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user-friendly platform for operators, this system empowers them to submit, monitor, and manage flight operations efficiently.

A central focus of the paper is the real-world implementation of the software client system and its interaction with the first reference of an ESS. It explores how the system is effectively integrated into operational environments, thereby demonstrating its practical utility. Through a simulated experiment, the paper showcases how operators can successfully submit multiple high altitude operational intents to the ESS, exemplifying the system's capability and setting the stage for future advancements in Upper class E air traffic management. The findings and insights presented in this paper provide valuable contributions to the field of air traffic management technology. The ETM client's successful development and implementation marks a significant step toward a more integrated and responsive airspace management framework. This paper serves as a key resource for those seeking to understand, adopt, and develop an ETM software client, with a focus on operator-ESS interaction.

II. Background

Upper Class E airspace, which covers the region above 60,000 feet above mean sea level (MSL) in the National Airspace System (NAS), is becoming increasingly accessible and attractive for various types of vehicles, such as high altitude, long endurance (HALE) vehicles, unmanned free balloons, airships, and supersonic/hypersonic aircraft (Fig. 1). These vehicles can offer valuable services for research, communication, and transportation purposes, but they also pose significant challenges for the current airspace infrastructure and management system, which are not designed to accommodate such diverse and complex operations. In this paper, we propose a traffic management system client for operators who intend to conduct operations in upper Class E airspace. The ETM client developed aims to support the upper Class E traffic management (ETM) concept, which is a collaborative effort between the FAA, NASA, and industry stakeholders to develop a new approach for managing traffic in this airspace. The ETM concept envisions a cooperative traffic management approach that scales beyond the current NAS infrastructure and workforce resources [11-15], supports the management of operations where no or limited air navigation service provider (ANSP) separation services are provided, and accommodates diverse operational needs. The core ESS and interactive client will enable operators to plan their flights to upper Class E airspace, interact with the ATM system and Air Traffic Control (ATC) during transit phases of flight, operate cooperatively with other ETM operators, and manage contingency events as needed. This paper is intended to serve as the initial technical reference of a traffic management system that ensures safe and efficient service provision in Upper Class E airspace for cooperatively managed operations.

Fig. 1 Illustration showing the diverse range of high-altitude vehicles that will be studied in the ETM Project [5]

III. ETM System Structure

Elements of the ETM concept address the manner in which operators plan their operations in upper Class E airspace, interact with the Air Traffic Management (ATM) system, and manage contingency events. To promote shared situational awareness among operators to aid in the planning and cooperative management of ETM operations, system components are needed to be in place. Based on initial concept development, the following supporting systems for ETM operations are currently identified and provided an overview in this section.

1. System Architecture and Components

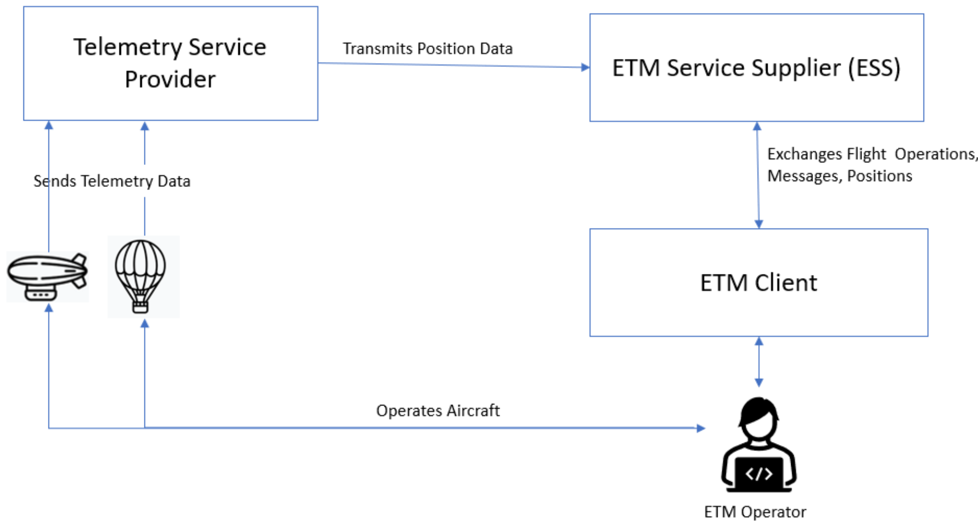

Fig. 2 Basic overview of initial system ETM architecture

a. ETM Service Supplier (ESS)

The ESS is a core element of the ETM architecture and serves as the primary means by which entities intending to operate in the stratosphere will be able to plan their operations, communicate their intent to other airspace users, and exchange data for situation awareness and adherence to established cooperative operating practices. In the future, the ESS may be the primary source of information to provide information of cooperative operations to the NAS data systems for the ANSP's awareness and inclusion in decision making processes.

The ESS plays an integral role in facilitating operations planning, intent sharing, traffic de-confliction, conformance monitoring, and various other functions vital to airspace management. While the ETM concept continues to evolve, the technical aspects of the ESS and its role in airspace management will evolve to a certain extent. At a high level, some of the identified roles of an ESS are as follows (these are but a subset of the overall ESS roles and capabilities):

i. *Communication Facilitator*: Functions as communication intermediary among ETM participants, therefore bolstering Operators' capacity to adhere to the regulatory and operational mandates governing upper Class E operations.

ii. *Conformance Monitoring*: Assess the location of a supported aircraft relative to its published Operational Intent spatially and temporally. The ESS can furnish Operators with comprehensive information regarding scheduled operations within a specific airspace volume, thus allowing the Operators to assess the feasibility of carrying out their missions as planned or adjusting as needed to remain within the intended volume of airspace.

iii. *Data Collection*: Capability to maintain comprehensive records of all the operational data within historical database, serving purposes related to analytics, regulatory compliance, and Operator accountability. Further discussions with regulatory and operational stakeholders will be needed to establish the guidelines regarding data retention and availability.

b. ETM Client

The ETM Client is a software system intended to provide 1) a user interface for planning and coordination of flight plan execution, 2) display ETM operation data on a map for situational awareness, and 3) communicate with ESS and other supplemental services to provide all the necessary data needed for Upper class E participation and air traffic awareness for operators.

c. Telemetry Service Provider

The Telemetry Service Provider acquires telemetry data from aircraft through diverse communication protocols. Upon receipt of this telemetry data, the service transforms the information into standardized and valid position data understandable to ESS. It is possible that this service will be integrated with other components (e.g., ETM Client) as part of a more consolidated system.

2. ETM Operator API

The ETM Operator API serves as an intermediary that enables seamless communication and data exchange between two separate software services, in this case, ETM Service Supplier (ESS) and ETM Client as shown in Fig. 3 [16]. This interface defines a set of rules, protocols, and endpoints, allowing these two systems to interact effectively without needing to understand the intricacies of each other's internal workings.

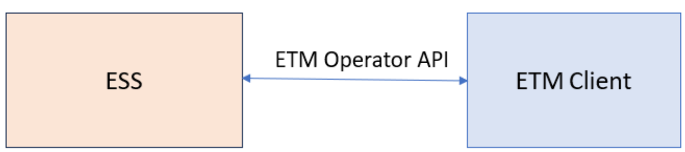

Fig. 3 ETM Operator API connectivity

In this context, the API facilitates the exchange of critical information and commands between ESS and ETM Client. For instance, it may allow the ETM Client to submit the ETM operations and receive the status of the same operation, monitor telemetry data received from the ESS, or receive real-time alerts and notifications from the ESS as shown in Fig. 4(a). Conversely, the ESS can utilize the API to inform the ETM Client of its operational status, operation conflicts, and other relevant data. This bi-directional communication streamlines the coordination between ESS and ETM Client, ensuring that it functions optimally in response to the Operator's requirements and operational needs. Ultimately, the API plays a pivotal role in enhancing the efficiency and reliability of this vital interaction between the ESS and the ETM Client.

Furthermore, the API also defines the object schema and outlines the mandatory and optional fields within these objects as shown in Fig. 4(b). This structured approach aids the Operator in creating and managing these objects with precision. By adhering to these predefined standards, the Operator can seamlessly create and modify objects within the system, ensuring consistency and accuracy. With a well-defined object structure, the Operator can confidently interact with the system, knowing that the information they input aligns with the established guidelines, thus enhancing the overall efficiency and reliability of the communication process.

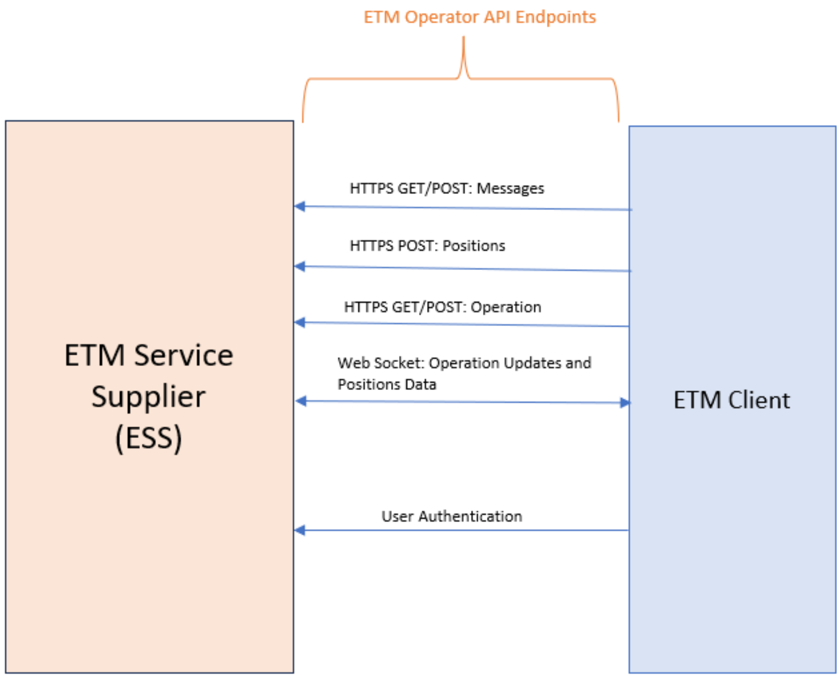

Fig. 4 (a) ETM Operator API endpoints

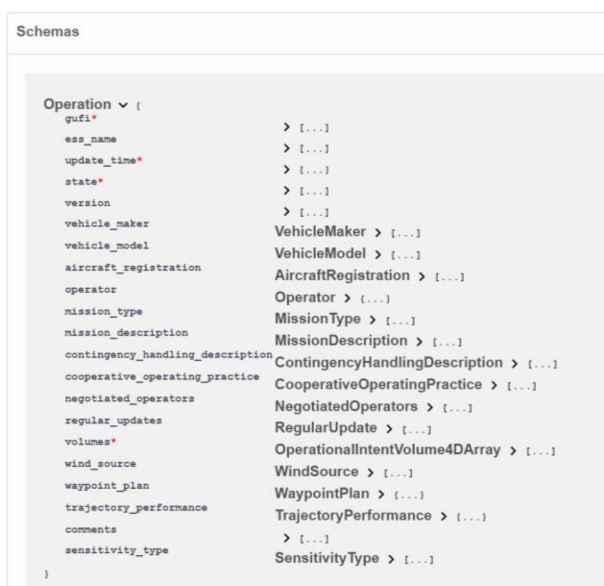

Fig. 4 (b) Object Schema Example of an Operational Intent

IV. Architecture and Implementation

The ETM software architecture is designed and implemented to facilitate seamless and efficient management of traffic operations as discussed in section III. The NASA ETM Service Supplier acts as the central hub, providing essential services and resources needed for ETM operations. It is responsible for processing requests, managing data, and ensuring the overall integrity and performance of the ETM system. The ETM Client, on the other hand, is the interface through which operators interact with the ETM system. This client application allows operators to submit operational intents, monitor ongoing operations, and receive updates and alerts from the ETM Service Supplier. By using the ETM Operator API, the ETM Client can communicate effectively with the NASA ETM Service Supplier, enabling real-time data exchange and coordination. The ETM Operator API is the crucial link that facilitates communication between the NASA ETM Service Supplier and the ETM Client. It defines the protocols and data formats for exchanging information, ensuring that both services can interact smoothly and reliably.

In this section, we will discuss the architecture developed at NASA to support the requirements of ETM operations. The architecture comprises two primary services: the NASA ETM Service Supplier (NESS) and the ETM Client. These two services communicate with each other using the ETM Operator API. Below, we will delve into the architecture and each of its components in detail.

1. Software Architecture

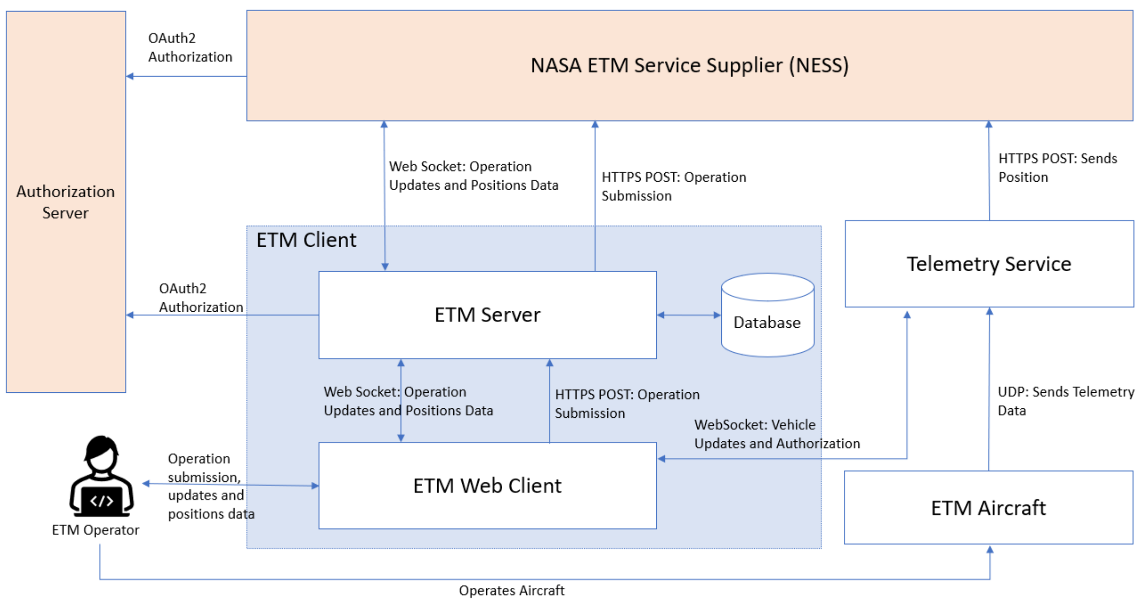

Fig. 5 High Level Software Architecture and Component Connectivity for ETM

2. Component Connectivity and Information Flow

As part of the ETM ecosystem, the ETM Client interacts with multiple systems to provide situational awareness as well as processes operational data submitted by ETM operators. In the current implementation, all the data transmitted between different systems are in JSON format, which is a lightweight data-interchange format. As shown in the Fig. 5, the following is an initial description of the connectivity details between ETM Client (ETM Web Client & ETM Server), ESS, Telemetry Server, and Author Server which provides service to support ETM Operators who primarily operates the ETM Web Client:

a. ETM Web Client (ETM WC)

On initial *ETM WC* load, it loads existing operation records, logged in user profile, and application configurations from the ETM Server. It communicates to the ETM Server by two different connections:

i. *WebSocket Secure (WSS) Connection*: The ETM WC establishes a WebSocket over an encrypted TLS connection with ETM Server. It allows for bi-directional communication between a client and a server in a way that is much more efficient and responsive than traditional HTTP-based approaches. To update the operator in real-time, ETM WC receives real-time operation updates such as status, operation modification, messages, and vehicle positions from the ETM Server

ii. *HTTPS Connection*: The ETM operators use the ETM Web Client to submit operational intents using RESTful API to the ETM Server using a secured HTTP POST method.

b. *ETM Server*
The ETM server establishes a connection with the ESS system by utilizing secure communication protocols, namely HTTPS (Hypertext Transfer Protocol Secure) and WebSocket Secure (WSS). In this process, it adheres to the specified schemas and endpoints outlined in the ETM Operator API for the purpose of exchanging JSON-encoded data between the two systems. Upon the establishment of successful connections, the ETM Server and ESS inter-exchange information in two ways:

i. The ETM Server dispatches operational intents and operation updates to the ESS and this transmission is achieved through the utilization of the HTTPS POST method, facilitated by the endpoints delineated in the Operator API.

ii. Furthermore, the ETM Server subscribes to the ESS system via WebSocket connection to receive various messages pertaining to operational updates as well as positional data.

Additionally, the server maintains a log of all operations submitted by operators to enhance the operation loading on the ETM Web Client and for data-collection purposes. To accomplish this, the ETM Server utilizes MongoDB, a document model database known for its high availability and horizontal scaling capabilities.

c. *NASA ETM Service Supplier (NESS)*
The NESS facilitates the secure and efficient utilization of airspace, independent of direct provision of air traffic services. Serving as a communication intermediary, NESS adheres to the ETM Operator API specifications and carefully records all operational intents submitted to it. In the context of this paper, ESS performs three primary responsibilities:

i. *Operation Intent Submission Process*: The NESS bears the responsibility of authorizing and validating incoming operational intents from the ETM Client. Authorization involves verifying the OAuth2 token with the Author Server, followed by validation using the ETM Operator API schema. Upon acceptance of the operational intent, NESS initiates the provision of regular operational updates through a WebSocket connection. These updates are observable in the Operation Table view of the ETM Client, as illustrated in Fig. 9.

ii. *Provide positional data*: The NESS plays a key role in furnishing situational awareness to operators. It receives valid positional data from the Telemetry service and publishes it to all subscribed ETM Clients. ETM Operators can visualize this information on the Map View, illustrated in Fig. 8.

iii. *Record keeping*: Retains all incoming operational intents, positions, and updates to provide operational records to subscribed ETM Clients. This stored data serves not only troubleshooting and analytics purposes but also facilitates historical insights for ETM Clients. For reliable record-keeping, the information is stored in MongoDB, a NoSQL database recognized for its high availability.

Furthermore, the aspect of conformance monitoring responsibility has not been integrated into the initial development phase. A comprehensive discussion on this matter is slated for exploration in a forthcoming paper.

d. Telemetry Service

The Telemetry Service acquires telemetry data from the host vehicle through diverse communication protocols, including ADS-B, Mavlink, and others. The paper does not delve into the preferred communication protocol for Upper Class E aircraft. To maintain simplicity and focus, the User Datagram Protocol (UDP) is specifically employed in this study to facilitate communication between the Simulated Vehicle and Telemetry Service. Following telemetry data reception, the Telemetry Service undergoes a conversion process aligning with the position schema outlined by the ETM Operator API. Subsequently, the system employs the HTTPS POST method to convey the processed data to the ESS, as depicted in **Fig. 6**. Upon receipt of position data, ESS verifies the OAuth2 token and validates the schema for the received information. The validated data is then disseminated to ETM Clients subscribed to ESS positions via the WebSocket communication protocol.

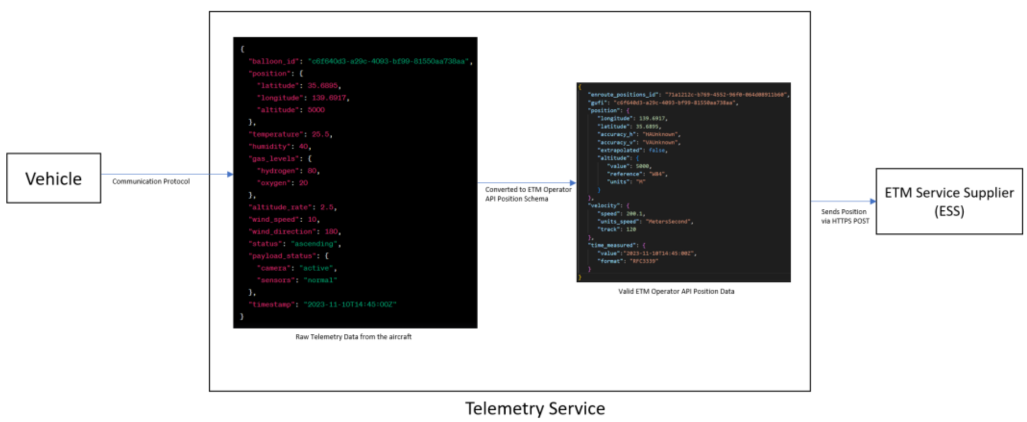

Fig 6. Telemetry Data Transmission and Conversion using Telemetry Service

e. *Authorization Server*

The Authorization Server functions as an authoritative entity within this system architecture, employing the OAuth 2.0 authorization framework to grant permissions and facilitate secure, efficient communication between distinct systems such as ETM Server, ETM Client and Telemetry Server. All the ETM Operator RESTful API requests, user authentication, and data exchange over WebSocket are verified by OAuth 2 tokens. This authorization mechanism serves as a critical piece for ensuring data integrity, privacy, and controlled access to system resources.

V. Simulation Environment

The initial implementation of the stated ETM system is currently being tested through internal simulation and checkout processes. As part of a progression toward supporting live ETM operations, the next step in the process is to conduct collaborative simulations with independent industry partners connected via established protocols described earlier. To facilitate the planned testing, NASA facilities and interfaces will play a key role in providing the operational picture of the ETM environment as well as the means in which to interact with simulation actors.

1. Facility

Located at NASA Ames Research Center in California’s Silicon Valley, the Airspace Operations Laboratory (AOL) facility provides integrated airspace systems and data views on multiple displays (Fig. 7). The laboratory also serves as simulation control for the Upper class E airspace operations as part of the scenario development and rapid prototyping of ETM concepts. Simulation capabilities have been adapted from traditional air traffic research to UAS Traffic Management (UTM), which has been further adapted to support simulation of ETM operations from the laboratory.

Fig. 7 Airspace Operations Laboratory: NASA Ames Research Center

2. ETM User Interface

The ETM User Interface has been developed to provide system actors with the ability to view the operational picture of the ETM environment from multiple perspectives. The interface is composed of multiple components to suit the needs of its users in managing operations and interacting with external systems.

a. Map View

The map view furnishes immediate real-time situational awareness of all ongoing operations, as depicted in Fig. 8. Furthermore, it employs a color-coded system to classify volumes and trajectories in accordance with their operational status, thereby enhancing the operators' ability to monitor active ETM operations with ease.

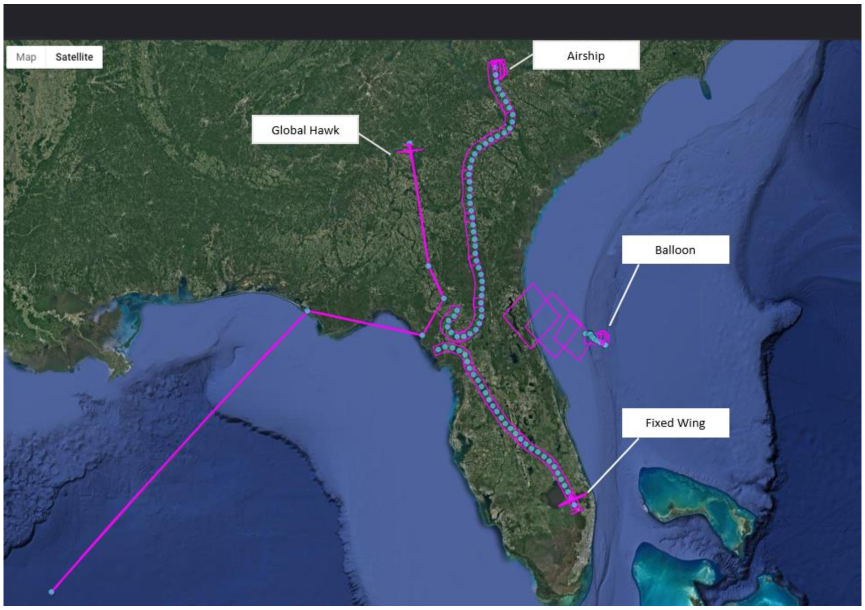

Fig. 8 Map View with multiple operations and associated information

b. Operation Table View

The operations table shows all the active and closed operations as shown in Fig. 9. There are various columns displayed on the operations view such as gufi, callsign, state, status, controls of the ETM operations. The operation's state is color-coded so that the ETM operator can easily notice the current state (rejected, accepted, active, non-conforming, contingent, and closed) of an operation.

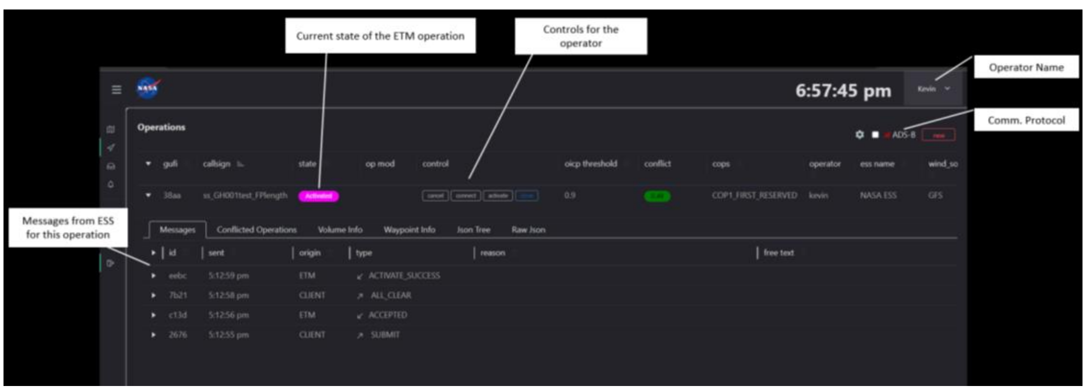

Fig. 9 Operations Table View

As depicted in Fig. 9, individual sub-tabs are allocated for various operation aspects, including Messages, Conflicted Operations, Volume Info, Waypoint Info, and the overall JSON format of the operation. The Message tab serves as a monitoring interface for operators to observe messages originating from the ESS and other interconnected services. The Volume Info and Waypoint Info tabs display the present active volume and waypoints in a tabular format, respectively. The Conflicted Operations tab is specifically designed to present a list of operations conflicting with the current operation—an area designated for future work.

c. Operation Submission Dialog

As shown in Fig. 10, the operational submission dialog encompasses key information such as the operation's start time, GUFI (unique ID), callsign, volume definitions, waypoint plan data, and additional ETM-specified data elements. All these elements are defined according to the ETM Operator API intended for processing by the connected ESS. The ETM operator completes the operation details and, upon reviewing all the information within the dialog, proceeds to submit the operation. This submission is facilitated by the ETM Server, which transmits the operation details to the ESS for further processing and operation support.

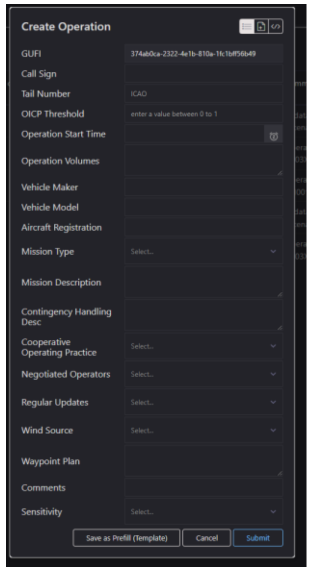

Fig. 10 Operation Submission Dialog Box

VI. Initial Simulation Experiment

In this initial phase of development, we implemented the ETM Client, NASA ESS (NESS), and Telemetry Service based on the architecture discussed in section V. As part of the initial simulation, we submitted four Operational Intents (OIs) plans to the NESS through connected ETM Clients. These OIs are associated with four ETM operators along with their simulated aircraft that will transmit telemetry data to the Telemetry Service as shown in table 1.

Operator Name	Call Sign	Simulated Vehicle Type	Operation Length	True Air Speed
ETM Alpha	NASA1B	Balloon	4 hours	12.47 Knots
ETM Bravo	NASA1A	Airship	2 hours	42.83 Knots
ETM Charlie	NASA1H	Fixed Wing	3 hours 30 Minutes	44.79 Knots
ETM Delta	NASA1G	Global Hawk	2 hours 19 Minutes	115 Knots

Table 1: Simulated Operation Details

The primary objectives of this initial experiment were to consume ETM Operator API, defining the functionality for each service, designing the system architecture, and implementing these functionalities to analyze the communication flow between different components within the ETM ecosystem. Various simulated aircraft (Balloon, Airship, Fixed Wing, and Global Hawk) employed alongside their respective volume intents for each operational intent. During this initial experiment, only nominal operations with no intent intersections or conflicts with other operations were included. Data from the simulated operations displayed on both the ETM Client Map view and Operational Table view for ETM operators’ situation awareness and planning purposes as shown later in Fig. 14.

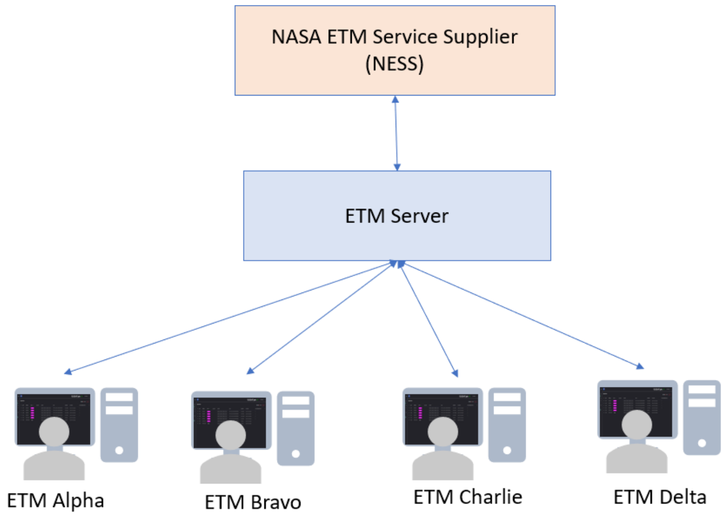

Fig. 11 Simulation set up at the NASA AOL facility

For the connectivity experiment, we used four instances of ETM Web Client (ETM WC) in four different machines to keep separate sessions for each operator as shown in Fig. 11. In each machine, the operator can load ETM WC in a web browser using a URL. After operators logged in, we have a connectivity signal component which shows if the operators are connected to NESS, ETM Server and Telemetry Service as shown in Fig. 12.

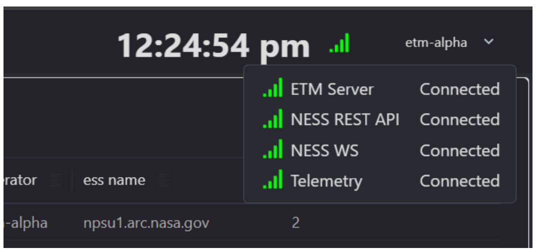

Fig. 12 Connectivity status signal

For the initial connectivity phase, we have submitted four nominal operations that are not in conflict with each other. Figure 13 illustrates the individual views of these operations at various stages of their respective lifecycles. Additionally, operators have the ability to monitor their own operations, as depicted in figure 13. During the initial phase, it is crucial to ensure that the submitted operations do not interfere with one another. By carefully planning and reviewing the operational intents, we have designed four distinct operations that can run simultaneously without causing any conflicts. Figure 13 provides a detailed visualization of how each operation progresses through different stages, offering a clear understanding of their individual lifecycles. This visualization helps in identifying potential issues early and ensures smooth execution. Moreover, the ability for operators to view their own operations allows for better management and real-time monitoring, ensuring that each operation is proceeding as intended.

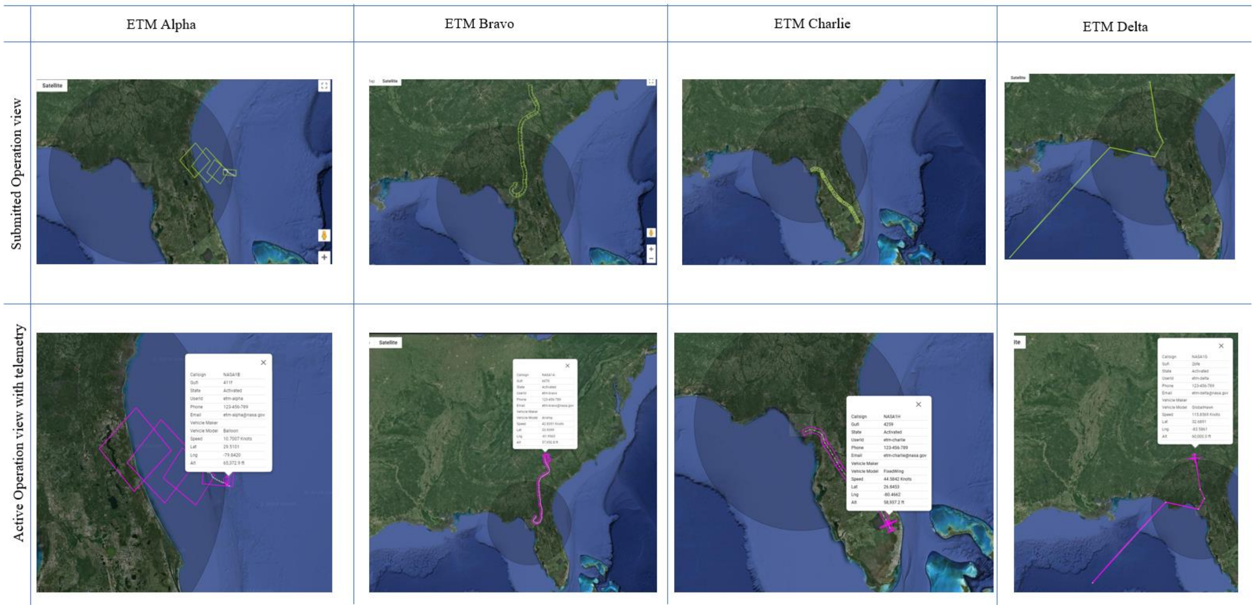

Fig. 13 Accepted and Activated Operation View with Telemetry Data for each operation

To enhance situational awareness for operators, they also have the ability to view all operations submitted in the operational area by other operators, as shown in Fig. 14. This capability aids in designing better operational intents and managing conflicts with other operations, which will be discussed in future work. To provide operators with a comprehensive view of all ongoing operations in their operational area significantly improves their situational awareness. As illustrated in Fig. 14, operators can monitor not only their own operations but also those initiated by others. This holistic view allows them to anticipate potential conflicts and coordinate more effectively. By understanding the broader operational landscape, operators can design their operational intents with greater precision, taking into account the activities and plans of their peers. This proactive approach minimizes the risk of conflicts and enhances overall operational efficiency. Future work will delve deeper into strategies for conflict resolution and further optimization of operational intents.

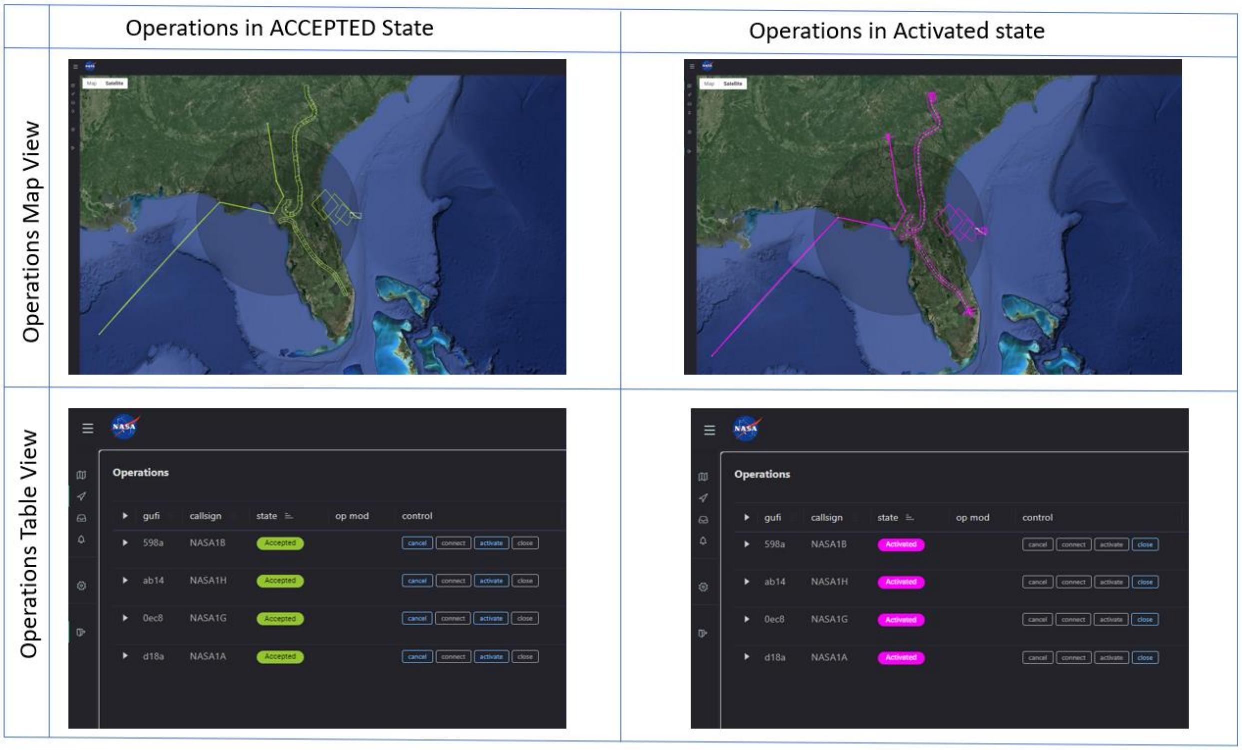

Fig. 14 Situational Awareness on ETM Web Client for Operators

As per our experiment, we conclude that we have successfully implemented the ETM Operator API. In table 2, we have shown our initial implementation and connectivity with NESS using ETM Operator API results. Success is indicated by a check mark (✓) and failure by an x mark.

Operators	**Authenticated**	**Operation Submitted**	**Operation Plan Visible**	**Position Submitted**	**Position Visible**
ETM Alpha	✓	✓	✓	✓	✓
ETM Bravo	✓	✓	✓	✓	✓
ETM Charlie	✓	✓	✓	✓	✓
ETM Delta	✓	✓	✓	✓	✓

Table 2: Experiment's result

VII.Next Steps and Considerations

This paper explains the initial stages of developing the systems likely needed to support the realization of the Upper Class E Traffic Management (ETM) concept and integrating the ETM Operator API into the broader system architecture. These efforts are integral components of the ongoing research within the ETM research effort at the Airspace Operations Laboratory at NASA Ames Research Center. The current work represents a foundation, with ongoing developments and refinements actively underway. Future steps in the ETM ecosystem's evolution include scenario development, conformance monitoring support, conflict management, cooperative agreements with other ETM operators, and the presentation of these critical details to ETM operators to facilitate efficient decision-making and operational management. Subsequent publications will delve into advancements in the entire system architecture's development and testing, along with the analysis of potential ETM scenarios, which will be crafted through industry collaboration.

VIII. Conclusion

Collaboration between NASA ETM researchers, industry partners, and stakeholders have been instrumental in tackling the technical challenges associated with developing the ETM system architecture. This architecture serves as the foundation for addressing communication processes among ETM operators, conflict management, and enhancing situational awareness overall in the National Airspace System. While there are ongoing technical challenges, the progress achieved thus far has laid a robust foundation for future research endeavors. The progress holds promising potential for further integration into the broader transportation system, marking a significant step toward advancing air traffic management capabilities and overall safety in upper class E airspace.

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