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Integrating Upper Class E Traffic Management (ETM) Operations into the National Airspace System: Use Cases and Research Questions

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As new categories of vehicles are introduced in the National Airspace System, so too are novel concepts for a cooperative approach to traffic management environments. One of these new environments, Upper Class E Traffic Management (ETM), is expected to include a variety of high altitude, long endurance vehicles with a range of performance capabilities and mission profiles that operate in cooperative areas above 60,000 feet. In addition to developing the rules, architecture, and systems for operations within the ETM environment itself, it is also important to consider how ETM vehicles will integrate with traditional Air Traffic Management and interact with Air Traffic Control (ATC) as they traverse ATC-controlled airspace and transition in and out of cooperative ETM operating areas.

As a first step toward future ETM demonstrations at the National Aeronautics and Space Administration (NASA) Ames Research Center's Airspace Operations Laboratory, use cases with step-by-step procedures were developed to identify both nominal and off-nominal scenarios in which ETM operations will interact with ATC. As NASA prepares to develop a simulation platform to demonstrate ETM cooperative practices and ETM-ATC interactions, the procedures, ATC roles and responsibilities, data exchange requirements, and research questions that were identified as part of use case development will inform scenario and system architecture design. The upcoming simulation work will include initial prototype ETM-ATC coordination tools to support ATC interactions with ETM operations.

This paper will briefly discuss NASA's upcoming ETM development work and then provide background on ETM-ATC interactions, describe each ETM-ATC interaction use case, and discuss open questions on concept, procedures, and assumptions.

Keywords—ATC, Upper Class E Traffic Management, ETM

I. INTRODUCTION

New types of vehicles with a range of performance capabilities and varying mission profiles, such as small Unmanned Aircraft Systems (sUAS) for delivery service or infrastructure inspection, electric vertical takeoff and landing (eVTOL) aircraft for air taxi passenger transport, and high-altitude long-endurance (HALE) vehicles providing communications or surveillance while loitering in the stratosphere, are being introduced in the National Airspace System (NAS). These new entrants are proposed to operate in one of three highly automated, cooperative traffic management environments: Unmanned Aircraft Systems (UAS) Traffic Management (UTM), Advanced / Urban Air Mobility (AAM / UAM) Traffic Management, or Upper Class E Traffic Management (ETM) [1–3]. Research and concept development are underway for each new traffic management domain.

II. EXTENSIBLE TRAFFIC MANAGEMENT (XTM)

The National Aeronautics and Space Administration (NASA) is performing research and development in coordination with the Federal Aviation Administration (FAA) and stakeholder communities to develop these traffic management concepts. After the recent completion of the UTM project, in which the feasibility of safe operations of small UAS operations under 400 ft was demonstrated, NASA started work to generalize the UTM architecture (e.g., digital information exchange and allowance for third-party provided services) in support of the AAM / UAM and ETM environments [1,4,5]. This generalized framework and common set of requirements for all three traffic management environments (UTM, AAM / UAM, and ETM) are referred to as Extensible Traffic Management (xTM) [5].

In support of identifying a generalizable xTM architecture across the three traffic management domains, we have identified common coordination procedures for interactions between xTM and the conventional air traffic control (ATC) environment. Our approach to the task of identifying common xTM-ATC interaction procedures began with the development of use cases for all three traffic management environments in which an xTM operation interacts with ATC. Each use case narrative was then expanded into individual step-by-step procedures which allowed us to identify procedures, roles / responsibilities, and data exchange requirements that are common across the different traffic management domains, as well as any exceptions to those commonalities. Our process for creating the use cases, a complete list of common procedures, and the insights that were gained from this work are described in further detail in [6,7]. The ETM-ATC interaction use cases that were created as part of this task will now serve as a starting point for the next phase of ETM-focused work that will be discussed in this paper.

III. Upper E Traffic Management (ETM)

While all three traffic management domains were addressed in the common procedures task described above, in this paper we will focus specifically on the ETM portion of this work in anticipation of upcoming ETM system architecture maturity and simulation opportunities. After an overview of NASA's upcoming ETM development work, this paper will provide background on ETM-ATC interactions (Section IV) and use cases (Section V), describe each ETM-ATC interaction use case (Sections VI–VIII), and discuss open questions on concept, procedures, and assumptions (Section IX).

A. Developing and Validating ETM Operations through Simulations / Demonstrations

NASA is engaging with the FAA to develop ETM technology, services, and procedures. Simulations and demonstrations will be used to validate ETM operations. A simulation platform to explore ETM operations and ETM-ATC interactions is to be developed in the Airspace Operations Laboratory (AOL) at NASA Ames.

Research and prototype development are needed to progress these simulations to their full potential. The ETM-ATC interaction use cases serve as a first step to identify and develop ETM-ATC operational interaction scenarios. The procedures, ATC roles / responsibilities, and data exchange requirements that were identified as part of use case development will inform the development of simulation scenarios. Prototype ETM-ATC coordination tools to support ATC interactions with ETM operations are anticipated.

Creating detailed scenarios based on the ETM-ATC interaction use cases for demonstration and prototype development will also afford the opportunity to solicit feedback from industry and the stakeholder community.

IV. ETM-ATC Interactions

Unlike the AAM / UAM and UTM operations that plan to operate at lower altitudes (under 5,000 ft and under 400 ft, respectively), ETM vehicles will generally operate at or above 60,000 ft (Flight Level (FL) 600). As ETM operations become more prevalent, they will need to integrate with the existing ATM system and interact with ATC.

There are two possible methods for integration with the existing ATM system. First, as a vehicle transits through ATC-controlled airspace, it can remain *under the control of ATC*, where ATC is responsible for managing separation between the ETM vehicle and other ATM traffic. As this applies to ETM operations, the ETM vehicle will be under ATC control during its ascent to / descent from FL600 or above.

The second method for integrating ETM operations in the ATM system is to *enable ETM operations in traditionally ATC-controlled airspace* and relieve ATC of the responsibility of separating, managing, and communicating with the ETM operations. It is anticipated that after reaching FL600 or above, ETM vehicles will operate in cooperative operating regions [3]. In an ETM-operating region, ETM operators deconflict their flight paths – without air traffic service providers – through automated, cooperative negotiation processes called Cooperative Operating Practices (COPS). COPS are defined by the industry and the ETM community as agreements about operator interactions consisting of procedures, processes, algorithms, and rules that deal with conflict detection, negotiation, and compliance monitoring [8].

To ensure safety and efficiency, interactions with ATC 1) while in ATC-controlled airspace, and 2) while transitioning to / from cooperative ETM operating areas will need to be handled seamlessly.

V. ETM-ATC Interaction Use Cases: Background

After the initial set of ETM-ATC interaction use cases were developed, they were grouped by their *trigger event* – for example, planned entry into ATC-controlled airspace or emergency landing due to equipment failure. Ten distinct trigger events were identified that fall into three broad categories: planned / nominal trigger events (Table 1), operational area change trigger events (Table 2), and unplanned / off-nominal trigger events (Table 3).

TABLE I. Planned / Nominal Trigger Events

#	***Trigger Event***
1	Planned entry (ascent / climb) into an ETM-operating region.
2	Planned entry (ascent / climb) into an ETM-operating region with ATC intervention for traffic management.
3	Planned exit (descent / land) from an ETM-operating region.
4	Planned exit (descent / land) from an ETM-operating region with ATC intervention for traffic management.

TABLE II. Operational Area Change Trigger Events

#	***Trigger Event***
5	Conversion of ATC-controlled airspace into an ETM-operating region.
6	Return of an ETM-operating region back to ATC-controlled airspace.

TABLE III. Unplanned / Off-Nominal Trigger Events Requiring Non-Standard ATC Procedures

#	***Trigger Event***
7	Unplanned entry into ATC-controlled airspace requires non-standard ATC procedures: ETM operation desires to land and end their mission rather than return to the ETM-operating region.
8	Unplanned entry into ATC-controlled airspace requires non-standard ATC procedures: ETM operation desires to return to the ETM-operating region.
9	Unplanned entry into ATC-controlled airspace requires non-standard ATC procedures: ETM vehicle has lost C2 link, ETM Operator / RPIC does not have control of vehicle.
10	Unplanned entry of *many* ETM vehicles into ATC-controlled airspace requires non-standard ATC procedures: Many ETM operations enter because of a SIGMET weather advisory.

A. ETM Vehicles

A variety of diverse vehicles are expected to utilize the ETM environment, including crewed, fixed-wing vehicles (e.g., subsonic aircraft) and remotely piloted, high-altitude long endurance (HALE) vehicles with a range of capabilities, flight profiles, and mission durations that can last up to several months. Because of the disparate performance capabilities of these vehicles, we further broke down each ETM use case into four vehicle categories:

a) **Uncrewed HALE balloons and airships.** Balloons have limited vertical and lateral position control and, as a result, will have limited ability to comply with ATC instructions (e.g., hold during ascent / descent). Unlike other ETM vehicles, they will not file an Instrument Flight Rule (IFR) flight plan in ATC-controlled airspace [9]. Balloon operations are different from the other ETM vehicles in that they provide an *estimated flight path* rather than filing an IFR flight plan, do not communicate with ATC on the radio frequency, and have limited controllability, often needing different procedures than other ETM vehicles [7]. Airships may have more propulsion control, but maneuverability may still be limited.

b) **Slow-speed, uncrewed, fixed-wing HALE vehicles** are characterized by their spiral ascent / descent patterns and slow ascent / descent rates that may require special consideration by ATC in controlled airspace. Because of their susceptibility to wind, route flexibility is often an important aspect of transit.

c) **High-speed, uncrewed, fixed-wing HALE vehicles** (e.g., remotely piloted Global Hawk aircraft) have high-performance capabilities and are expected to operate like conventional, piloted aircraft in ATC-controlled airspace, similar to subsonic operations.

d) **High-speed, crewed, fixed-wing aircraft** (e.g., subsonic aircraft like business jets) have high-performance capabilities and are expected to operate like conventional, piloted aircraft in ATC-controlled airspace. Supersonic aircraft are included in the ETM-ATC interaction use cases, but whether supersonics will be considered part of the ETM environment is still an open question.

Generally, each of the ten Trigger Events outlined in Section V, include four use cases – one for each vehicle type.

B. *Phraseology*

In general, we use the term **Operator** to refer to the company / dispatcher who is responsible for the vehicle / planning. **Remote-pilot-in-command** (**RPIC**) or **pilot-in-command** (**PIC**) refer to the person piloting / controlling the vehicle / aircraft. However, for balloons and airships – where the Operator may also serve as the controlling entity – we merge these terms and refer to the **Operator / RPIC**.

In [7], we use the phrase "**xTM Operator service supplier**" to refer to a communication bridge between the xTM Operator and others in the xTM eco-system that provide tools, automation, or services to monitor the region, execute safe missions, store operational data, etc. In ETM operations, this is referred to as the **ETM service supplier** (**ESS**).

In [7], the phrase "**xTM Network service supplier automation**" is used to refer to network automation that connects multiple xTM Operator service suppliers together to share information and provide a cooperative framework for the operators. In ETM operations, this is called the **ESS Network**.

The ESS Network also provides a communication bridge to **Air Traffic Services (ATS).** ATS is a new, FAA-provided service that enables a gateway to the ESS Network to exchange relevant ETM vehicle information between ETM and the conventional ATM system. However, in this paper, we broaden the definition of ATS to include both automation and humans involved in the information exchange between ETM and conventional ATM. The reason for expanding the definition is that we envision that communication exchanges that center on human operators today, such as traffic management coordinators, may eventually be supplanted by ATS automation in future interactions with ETM, though it is unclear when a change like that may happen. Therefore, we describe ATS handling these information exchanges and coordination with an understanding that it may be done by the actual ATS or in conjunction with a human service provider [7].

In this document, the term **Air Traffic Control (ATC)** is used to signify air traffic controllers and / or other human service providers who communicate directly with the ETM vehicle's Operator / RPIC / PIC.

VI. ETM-ATC Interaction Use Cases: Planned / Nominal Trigger Events (#1–4)

Trigger Events #1–4 focus on nominal scenarios in which ETM vehicles need to transit through ATC-controlled airspace. This will occur regularly for all ETM vehicles during the climb and descent phases of flight as they transit through ATC-controlled airspace before reaching an ETM-operating region at or above FL600.

In the use cases for Trigger Events #1–4, ATC manages and interacts with ETM operations using *standard ATC* procedures, which have the following characteristics: 1) the ETM Operator / RPIC / PIC has control over where and when the vehicle enters ATC-controlled airspace; 2) there is enough time for the Operator / RPIC / PIC / ESS Network to coordinate with ATS / ATC before transitioning between ETM and ATC operations; and 3) the ATC controller has the cognitive and airspace capacity to merge ETM traffic into their sector without increasing workload. The first four Trigger Events are described further in the following sections.

A. *Trigger Event #1: Planned entry (ascent / climb) into an ETM-operating region.*

For every ETM flight, the vehicle will climb through ATC-controlled airspace to reach an ETM-operating region. The use cases in Trigger Event #1 assume that the airspace is sparsely populated and that ascent can occur uninterrupted. Following are the sequence of events expected for these flights.

Pre-Departure: An ETM Operator is planning an operation in Upper Class E airspace. In all four ETM-vehicle categories, the ETM vehicle Operator uses their ESS / ESS Network to coordinate the vehicle's approximate entry time, location, and operational intent within the ETM-operating region and create a four-dimensional trajectory (4DT) Operation Plan.

Because the vehicle will traverse ATC-controlled airspace to reach the ETM-operating region, the Operation Plan is contingent upon coordination with ATS. The ETM Operator provides ATS with the required information about the intended operation and notifies the nearest ATC facility. If ATS does not need the Operator to alter their launch / departure time or route, ATS provides authorization for the operation.

With the exception of the balloon Operator who provides an *estimated flight path* for ascent, the Operator files an IFR flight plan for ATC-controlled airspace to arrive at the base of the ETM-operating region at the entry time and location to meet their Operation Plan.

With the exception of the balloon Operator who notifies ATS upon launch, the Operator / RPIC / PIC requests a departure clearance from ATC.

Ascent / Climb through ATC-Controlled Airspace: For high-speed, uncrewed / crewed fixed-wing vehicles, ATC maintains standard IFR separation from other IFR traffic during ascent through lower Class E and Class A airspace. However, for the balloon / airship and slow-speed HALE, due to their lack of maneuverability, ATC may use other methods to ensure safety of flight.

The ETM vehicles are expected to transmit telemetry data via ADS-B and a transponder in accordance with IFR procedures in ATC-controlled airspace. Due to weight limitations, a balloon may be equipped with only a transponder or ADS-B.

The Operator / RPIC / PIC communicate with ATC on standard radio frequencies, with the exception of the balloon Operator / RPIC who is in contact with ATS.

Transition into the ETM-Operating Region: When the time arrives to enter the ETM-operating region, the Operator / RPIC / PIC notifies ATS / ATC that they are nearing the ETM-operating region. ATC acknowledges the vehicle, cancels the IFR flight plan, and clears the Operator / RPIC / PIC to leave the frequency. For balloons, ATS simply acknowledges them since they do not have an IFR flight plan.

After the vehicle enters the ETM-operating region, the Operator / RPIC / PIC instructs the vehicle to fly the Operation Plan. The ESS monitors ETM vehicle conformance to its operational intent and the ESS Network monitors conformance in relation to the other ETM operations and the ETM-operating region boundaries. In the ETM-operating region, vehicles are expected to continue broadcasting using ADS-B.

B. *Trigger Event #2: Planned entry (ascent / climb) into an ETM-operating region with ATC intervention for traffic management.*

The use cases in Trigger Event #2 are the same as #1 in that the Operators plan an operation in an ETM-operating region, however, during ascent, ATC needs to reroute commercial airline traffic around storm activity. As a result, ATC would like to temporarily halt the ETM vehicle's ascent.

In response to ATC's instruction, the slow-speed HALE's RPIC temporarily halts the vehicle's ascent and holds altitude while maintaining a circular flight path around the specified waypoint until traffic is clear. The RPIC / PIC of the high-speed, uncrewed / crewed vehicles alter their course (i.e., vector or level off at altitude) as instructed by ATC, to avoid the potential conflict with rerouted commercial aircraft. However, the balloon and airship are not able to halt their climb. The balloon is not able to hold altitude during ascent; the airship has some propulsion control during ascent, but unlikely enough for conflict maneuverability. As a result, ATC manages the traffic conflict by *maneuvering other aircraft* to keep them well clear of the balloon / airship.

After traffic passes, ATC advises the vehicles that held or changed course to resume their climb. The remainder of the route is unchanged.

In-Flight Replanning for the ETM-Operating Region: Due to the impact of ATC's temporary hold for traffic management and depending on the conformance window needed to enter the ETM-operating region, it is likely that the ESS will need to recalculate the entry time / location and create a new Operation Plan. The slow-speed HALE's susceptibility to wind and slow ascent rate may also contribute to the need to recalculate entry time / location. While the balloon / airship were not able to pause their ascent like the other vehicles, their susceptibility to wind and duration of transit time may be enough to alter their entry time / location.

As necessary, the ESS coordinates a new Operation Plan with the ESS Network for a more precise entry point and time that conforms to the current position / trajectory and is conflict free in the ETM-operating region. Once deconflicted, the ESS Network returns an approval message to the ESS and approves the Operation Plan.

If the newly coordinated entry point and time require an adjustment to the flight path in ATC airspace, the Operator / PIC / RPIC would coordinate with ATC for a change that enables them to meet the new entry point / time.

Following replanning, the use cases in Trigger Event #2 conclude with the same nominal steps for ascending to and transitioning into the ETM-operating region as in Trigger Event #1.

C. *Trigger Event #3: Planned exit (descent / land) from an ETM-operating region.*

Similar to Trigger Event #1, at the end of every ETM mission the vehicle exits the ETM-operating region and descends through ATC-controlled airspace before landing. These use cases assume that during descent, the airspace is sparsely populated and that descent can occur uninterrupted. Following are the sequence of events expected for these flights.

Preparing to exit the ETM-Operation Region: An ETM Operator conducting a mission in an ETM-operating region cooperatively managed by the ESS Network has completed their operation and plans to exit the ETM-operating region and descend through Class A and lower Class E airspace to land. The Operator uses their ESS / ESS Network to continuously update and coordinate the vehicle's operational intent and conformance window, including the time and location to *exit* the ETM-operating region.

The Operation Plan to exit the region is contingent upon coordination with ATS. The Operator provides ATS with the required information about their intended exit from the ETM-operating region and notifies the appropriate ATC facility of the expected exit location and planned exit time. If ATS does not need the Operator to alter their exit time or location, ATS provides authorization for the operation.

With the exception of the balloon Operator who provides an *estimated flight path* for descent, the Operator files an IFR flight plan to leave the ETM-operating region and enter Class A controlled airspace.

Descent through ATC-Controlled Airspace: With the exception of the balloon, the Operator / RPIC / PIC contacts the proper ATC sector as their vehicle approaches the bottom of the ETM-operating region and requests to pick up their IFR clearance from ATC to enter Class A airspace. ATC identifies the vehicle by assigning the discrete beacon code from the IFR flight plan, surveys traffic to ensure there are no conflicts, and issues the IFR clearance. The balloon Operator / RPIC initiates descent at the agreed upon time and notifies ATS which issues permission to enter Class A airspace. As the balloon descends, the Operator / RPIC monitors the balloon and provides updates to ATS, as necessary.

For high-speed, uncrewed / crewed fixed-wing vehicles, ATC maintains standard IFR separation from other IFR traffic during descent through Class A and lower Class E airspace. However, for the balloon / airship and slow-speed HALE, due to their lack of maneuverability, ATC may use other methods to ensure safety of flight.

The Operator / RPIC / PIC communicates with ATC on standard radio frequencies, with the exception of the balloon Operator / RPIC who is in contact with ATS.

Vehicles proceed to an airport or landing area. For vehicles that received an IFR clearance, ATC cancels their IFR flight plan. The balloon operator / RPIC notifies ATS when the balloon is on the ground.

D. *Trigger Event #4: Planned exit (descent / land) from an ETM-operating region with ATC intervention for traffic management.*

The use cases in Trigger Event #4 are the same as #3 in that ETM Operators have completed an operation and plan to exit the ETM-operating region and descend through Class A airspace, however, during descent, ATC needs to reroute commercial airline traffic around storm activity. As a result, ATC would like to temporarily halt the vehicle's descent.

In response to ATC's instruction, the slow-speed HALE's RPIC temporarily halts the vehicle's descent and holds altitude while maintaining a circular flight path around the specified waypoint until traffic is clear. The RPIC / PIC of the high-speed, uncrewed / crewed vehicles alter their course (i.e., vector or level off at altitude) as instructed by ATC, to avoid the potential conflict with rerouted commercial aircraft. However, the balloon and airship are not able halt their descent. The balloon is not able to hold the descent for long, if at all. The airship has some propulsion control during descent, but unlikely enough for conflict maneuverability. As a result, ATC manages the traffic conflict by *maneuvering other aircraft* to keep them well clear of the balloon / airship.

After traffic passes, ATC advises the vehicles that held or changed course to resume their descent. The remainder of the route is unchanged. The use cases in Trigger Event #4 conclude with the same nominal steps for descent and landing as in Trigger Event #3.

VII. ETM-ATC Interaction Use Cases: Operational Area Change Trigger Events (#5–6)

Another method for handling scenarios in which ETM vehicles need to enter ATC-controlled airspace is to relieve ATC of the responsibility of separating, managing, and communicating with the ETM operations, and instead, temporarily authorize the airspace to operate fully as a cooperative area under ETM operations. These situations can occur when the nominal flight paths of ETM vehicles traverse sparsely populated ATC-controlled airspace, and it is more efficient to authorize cooperative ETM operations in that area than for ATC to manage the operations.

The use cases in Trigger Events #5 and #6 capture the sequence of events associated with these types of operational area changes, in which ATS and ATC coordinate the authorization of a new ETM-operating region with the ESS Network and ETM Operator / RPIC / PIC (Trigger Event #5) or take back control of an active ETM-operating region (Trigger Event #6).

A. *Trigger Event #5: Conversion of ATC-controlled airspace into an ETM-operating region.*

For ETM operations, Trigger Event #5 may occur in scenarios such as when ETM operators conducting a mission in an ETM-operating region above FL600 determine that it would be more advantageous to their mission to expand their ETM operations to a region below FL600, which is normally in Class A airspace under ATC control. Such conversion of ATC-controlled airspace into an ETM-operating region requires airspace authorization procedures.

Trigger Event #5 includes use cases for three of the four ETM-vehicle categories. A use case for high-speed, crewed aircraft (e.g., business jet, supersonic) was not created because these aircraft may operate under ATC control rather than request a new ETM-operation region.

ETM Operator Requests an ETM-Operating Region: To begin the process, the ETM Operator, via the ESS, uses the ESS Network to send a request to ATS to authorize the use of a new ETM-operating region. The ESS Network coordinates with ATS for the creation of a new ETM-operating region.

ATS / ATC Coordination and Approval: ATS determines which ATC facility controls the requested airspace and coordinates with them to transfer operational control to the ESS Network. Both ATS and ATC control facilities have access to mapping of the proposed ETM-operating region, including impacted ATM traffic. The ATC facility checks traffic predictions for the requested time period and provides approval to ATS for the transfer of operational control to an ESS Network-managed operating region. ATC should continue to display the new ETM-operating region to ensure that they do not allow any traffic to penetrate the area.

New Operation Plan for New ETM-Operation Region: The ESS Network reconfigures its assigned airspace to reflect the newly created ETM-operating region as eligible for use and monitoring. The ETM Operator creates a new Operation Plan to operate within the ETM-operating region using the ESS and submits the plan to the ESS Network for coordination. Once deconflicted, the ESS Network returns an approval message to the ESS and approves the Operation Plan.

B. Trigger Event #6: Return of an ETM-operating region back to ATC-controlled airspace.

Use cases in Trigger Event #6 involve the return of a cooperative ETM-operating region back to ATC control.

ATS Notifies the ESS Network: An Air Route Traffic Control Center (ARTCC) facility notifies ATS that part of the ETM-operating region needs to be returned to ATC control. The ESS Network receives notification from ATS and notifies ESSs that currently have flights within the region of the requirement to vacate. ETM Operators will need sufficient time to replan and move their vehicles, taking into account the number of vehicles, traffic density, and vehicle capability. For example, a slow-speed HALE may take longer to vacate a region because of its slow ascent / descent rate.

In response to the notification, the ETM Operators decide to move the ETM vehicles in this region to a different, already-active ETM-operating region, instead of leaving them on their current Operational Plans and transferring their control to ATC. Using the ESS, each Operator creates a new Operation Plan and submits the plan to the ESS Network for coordination. Once deconflicted, the ESS Network returns an approval message to the ESS and approves the Operation Plan. The Operator / RPIC / PIC instructs the vehicle to climb to the active ETM-operating region and fly the Operation Plan. Prior to the designated time, the ESS Network notifies ATS that all vehicles have vacated the airspace.

ATS notifies the ARTCC that they have control of the airspace and the ARTCC high-altitude sector begins utilizing the airspace at the designated time.

VIII. ETM-ATC Interaction Use Cases: Unplanned / Off-Nominal Trigger Events (#7–10)

In contrast to the planned / nominal use cases in Trigger Events #1–4, use cases with an unplanned / off-nominal Trigger Event (#7–10) explore *non-standard ATC* procedures, where a sense of urgency is created and ATC has to take timely action because: 1) an off-nominal event, such as an equipment failure, urgent need to land, lost C2 link, or severe weather has occurred such that the Operator / RPIC / PIC has <u>little to no</u> control over where / when the vehicle enters ATC-controlled airspace; 2) the ETM Operator / RPIC / PIC and ESS Network <u>do not</u> have adequate time to fully coordinate with ATS / ATC prior to entering ATC-controlled airspace; and 3) the ETM vehicle that is on a trajectory to enter ATC-controlled airspace will create a more immediate need to move other traffic, resulting in a significant increase in ATC workload. These unplanned / off-nominal Trigger Events (#7–10) are described in the following sections.

A. Trigger Event #7: Unplanned entry into ATC-controlled airspace requires non-standard ATC procedures: The ETM operation desires to land and end their mission.

The use cases in Trigger Event #7 involve ETM vehicles exiting an ETM-operating region and entering ATC-controlled airspace. The ETM Operators land and end their mission without returning to the ETM-operating region.

Equipment Failure and Decision to Land: The balloon / airship and slow-speed HALE are slowly losing altitude and automated controls are unable to return the vehicles to their programmed altitude. The RPIC / PIC of the high-speed, uncrewed / crewed vehicles experiences an equipment failure where Standard Operating Procedure (SOP) requires an immediate descent.

As a result of the equipment failure, the vehicle begins to descend toward, and possibly enter, ATC-controlled Class A airspace before either the Operator / RPIC / PIC (verbally) or the ESS Network (automation) has had time to fully coordinate with ATS / ATC or receive explicit approval. The Operator / RPIC / PIC decides they must land the vehicle immediately.

ESS Network Notifies ATS / ATC: As the vehicle begins to descend, the ESS Network detects that the vehicle is out of conformance with its Operation Plan and notifies ATS that an ETM vehicle is on a trajectory to enter ATC-controlled airspace. In turn, ATS advises the appropriate ATC facility, which then provides the information to the appropriate sector(s). However, given the urgent nature of the emergency, the initial notification from the ESS Network to ATS, the ATC facility, and sector(s) may not contain complete information (e.g., vehicle intent). ATC sectors protect for imminent ETM vehicle incursion as necessary which may require moving other traffic and using larger buffers than standard separation.

The ESS Network also informs all ESSs of any conflicts resulting from the vehicle's deviation from its Operation Plan. If any conflicts are detected, the ESSs de-conflict from each other in accordance with COPS.

ETM Operator / RPIC / PIC: The Operator / RPIC / PIC coordinates with their ESS to determine where to divert (e.g., a nearby field or alternate airport).

With the exception of the balloon Operator who provides an *estimated flight path* for descent to ATS, the ETM Operator – possibly done through the ESS – provides their new, proposed IFR flight plan for descent to the alternate airport / landing site to ATC.

The Operator / RPIC / PIC switches the beacon code to 7700 (to indicate an emergency, when appropriate) and initiates the first verbal contact with ATC (for the balloon operator, ATS) to notify them of the emergency and desire to land immediately. Ideally, the Operator / RPIC / PIC is able to contact ATC prior to the vehicle entering ATC-controlled airspace, however, due to the urgent nature of the situation, the flight may have already entered ATC-controlled airspace by the time this first radio call is made.

ATC: ATC observes the 7700 beacon code on the radar and verifies radar contact. If ATC does not have radar contact, separation from other traffic would be more difficult and require a much larger buffer. ATC surveys traffic to ensure no conflictions, and with the exception of the balloon, issues the IFR clearance to the Operator / RPIC / PIC. However, if ATS / ATC has not yet received the IFR flight plan because of the urgent nature of the situation, the Operator / RPIC / PIC may be asked to provide information required for ATC to manage the vehicle's descent, including the current location, altitude, projected descent trajectory, time parameters, and procedures.

For high-speed, uncrewed / crewed fixed-wing vehicles, ATC maintains standard IFR separation from other IFR traffic during descent through Class A and lower Class E airspace. However, for the balloon / airship and slow-speed HALE, due to their lack of maneuverability, ATC may use other methods to ensure safety of flight.

Vehicles proceed to an airport or landing area. For vehicles that received an IFR clearance, ATC cancels their IFR flight plan. The balloon operator / RPIC notifies ATS when the balloon is on the ground.

B. Trigger Event #8: Unplanned entry into ATC-controlled airspace requires non-standard ATC procedures: The Operator desires to return to the ETM-operating region.

The use cases in Trigger Event #8 involve ETM vehicles returning back to an ETM-operating region to continue their mission after an event that forces them to enter ATC-controlled airspace.

Equipment Issue and Decision to Return to the ETM-Operating Region: An Operator is conducting a mission in an ETM-operating region cooperatively managed by an ESS Network. Similar to the use cases in Trigger Event #7, the Operator / RPIC / PIC experiences an equipment issue that causes the vehicle to descend toward, and possibly enter, ATC-controlled Class A airspace before either the Operator / RPIC (verbally) or the ESS Network (automation) has had time to fully coordinate with ATC or receive explicit approval. In this use case, the Operator / RPIC / PIC decides they want to return to the ETM-operating region.

ESS Network Notifies ATS / ATC: As the vehicle begins to descend, the ESS Network detects that the vehicle is out of conformance with its Operation Plan and notifies ATS that an ETM vehicle is on a trajectory to enter ATC-controlled airspace. In turn, ATS advises the appropriate ATC facility, which then provides the information to the appropriate sector(s). However, given the urgent nature of the emergency, this initial notification from the ESS Network may not contain complete information (e.g., vehicle intent). ATC sectors protect for imminent ETM vehicle incursion as necessary which may require moving other traffic and using larger buffers than standard separation.

The ESS Network also informs all ESSs of any conflicts resulting from the vehicle's deviation from its Operation Plan. If any conflicts are detected, the ESSs de-conflict from each other in accordance with COPS.

ETM Operator / RPIC / PIC: The Operator / RPIC / PIC initiates verbal contact with ATC (for the balloon operator, ATS) to notify them of the situation, state their approximate position and altitude, and that they are troubleshooting the problem. Ideally, the Operator / RPIC / PIC is able to contact ATS / ATC prior to the vehicle entering ATC-controlled airspace, however, due to the urgent nature of the situation, the flight may have already entered ATC-controlled airspace by the time this first radio call is made. The Operator / RPIC / PIC squawks the assigned code, continues troubleshooting procedures, and determines that the equipment issue can be repaired. Once repaired, the Operator / RPIC / PIC wants to return to the ETM-operating region as soon as possible.

The ESS coordinates a new Operation Plan with the ESS Network to reenter and continue operating within the ETM-operating region. The ESS plans with the ESS Network for an entry point and time that conforms to the current position / trajectory and is conflict free in the ETM-operating region.

Once deconflicted, the ESS Network returns an approval message to the ESS and approves the Operation Plan. If there is a conflict, the Operator / RPIC / PIC adjusts their reentry point or time and coordinates again with the ESS Network or negotiates with the conflicting ESS in accordance with COPS. The Operation Plan should be conflict free before it is shared with ATS / ATC.

With the exception of the balloon Operator who provides an *estimated flight path* for ascent to ATS, the ETM Operator – possibly done through the ESS – provides their new, proposed IFR flight plan for returning to the ETM-operating region to ATC. With the exception of the balloon Operator who calls ATS to request permission to climb back to the ETM-operating region, the Operator / RPIC / PIC calls ATC to request a clearance to return to the ETM-operating region.

ATC: ATC scans for traffic and issues an IFR clearance with a heading and altitude that will return the vehicle to the ETM-operating region. If reentry into the ETM-operating region is delayed by replanning / deconflicting – causing the ETM vehicle to spend additional time in ATC-controlled airspace – ATC workload will increase due to providing instructions to the Operator / RPIC / PIC and separating them from ATM traffic.

Transition back into the ETM-Operating Region: The Operator / RPIC / PIC instructs the vehicle to fly the assigned route and altitude, in accordance with the IFR clearance. As the balloon ascends, the Operator / RPIC / PIC monitors the vehicle, re-calculating the trajectory and predicted entry location at regular intervals, and provides updates to ATS as appropriate.

When the time arrives to enter the ETM-operating region, the Operator / RPIC / PIC notifies ATS / ATC that they are nearing the ETM-operating region. ATC acknowledges the vehicle, cancels the IFR flight plan, and clears the Operator /

RPIC / PIC to leave the frequency. For balloons, ATS simply acknowledges them since they do not have an IFR flight plan.

C. *Trigger Event #9: Unplanned entry into ATC-controlled airspace requiring non-standard ATC procedures: The ETM vehicle has lost command and control (C2) link.*

Because only uncrewed, remotely piloted vehicles are impacted by the loss of a C2 link, Trigger Event #9 does not include a use case for high-speed, *crewed* aircraft.

Command and Control (C2) Link is Lost: As an Operator is conducting a mission in an ETM-operating region cooperatively managed by an ESS Network, the C2 link between the ground station and the ETM vehicle is lost. After a predetermined amount of time with lost link, the vehicle defaults to its <u>pre-programmed lost C2 link contingency procedure</u>. While there may be several options for a pre-programmed lost link procedure, in these use cases, we assume that the vehicle is programmed to land immediately at the nearest viable location. Like the use cases in Trigger Events #7 and #8, the vehicle will possibly enter ATC-controlled Class A airspace before either the Operator / RPIC (verbally) or the ESS Network (automation) has had time to fully coordinate with ATC or receive explicit approval. The Operator / RPIC attempts to reestablish the C2 link, but is unable.

ESS Network Notifies ATS / ATC: The ESS Network detects that the vehicle is out of conformance with its Operation Plan. It notifies ATS that an ETM vehicle is deviating from its Operation Plan and is on a trajectory to enter ATC-controlled airspace. In turn, ATS advises the appropriate ATC facility, which then provides the information to the appropriate sector(s). ATC sectors protect for imminent ETM vehicle incursion as necessary which may require moving other traffic and using larger buffers than standard separation.

Whether the details of the vehicle's lost C2 link contingency procedure are filed as part of a Certificate of Authorization (COA), or spelled out by the Operator / RPIC to ATC, we assume that ATC has knowledge of the vehicle's full contingency procedure (flight path).

Within the ETM-operation region, the ESS Network also informs all ESSs of any conflicts resulting from the vehicle's deviation from its Operation Plan. If any conflicts are detected, the ESSs de-conflict from each other in accordance with COPS.

According to the pre-programmed lost C2 link contingency procedure, the vehicle switches its beacon code to 7400 (per lost link protocol). Because ADS-B is enabled, ATC should be able to see the vehicle on their radar and the Operator / RPIC continue to receive vehicle telemetry information.

ETM Operator / RPIC Contacts ATS / ATC: The Operator / RPIC initiates verbal contact with ATC (for the balloon operator, ATS) to inform them that the vehicle is now navigating according to its pre-programmed lost C2 link contingency procedure. Ideally, the Operator / RPIC is able to contact ATC prior to the vehicle entering ATC-controlled airspace, however, due to the lost link, the flight may have already entered ATC-controlled airspace by the time this first radio call is made.

ATC: ATC acknowledges, observes the 7400 beacon code, and verifies radar contact. ATC maintains standard IFR separation from other IFR traffic by moving other traffic, as necessary, to accommodate the vehicle's lost C2 link contingency procedure. ATC provides IFR separation until the vehicle lands, is cleared to land, or enters uncontrolled Class G airspace.

Upon landing, the Operator / RPIC notifies ATS / ATC that the vehicle is on the ground.

D. *Trigger Event #10: Unplanned entry of <u>many</u> ETM vehicles into ATC-controlled airspace requiring non-standard ATC procedures.*

Like Trigger Events #7, 8, and 9, the use cases in Trigger Event #10 involve an unplanned exit from an active ETM-operating region. However, rather than only a single vehicle entering ATC-controlled airspace, these use cases explore the unplanned entry of *many* ETM vehicles at the same time, a scenario that could be triggered by, for example, a Temporary Flight Restriction (TFR), the designation of a Military Operations Area (MOA) / Special Use Airspace (SUA), or a SIGMET weather advisory.

Although the procedures are similar to the single ETM vehicle entry scenario, the series of vehicles entering may significantly impact ATC workload, requiring further actions to handle the unplanned entry. These actions may include: 1) Splitting ATC sectors or adding extra controllers. 2) Denying entry to all other aircraft entering the sectors while controllers deal with the unplanned entry of the ETM vehicles.

ETM Operators and ATS / ATC may have several options in a situation like this, including: 1) ETM Operators request a new ETM-operating region (Trigger Event #5). 2) ETM operations move into ATC-controlled airspace where ATC uses procedures similar to the "Point Out" process. This option would allow ETM vehicles to enter ATC-controlled airspace without an official transfer of control. It would require the ESS Network to provide ATS with detailed target information on all ETM flights and ATC to keep all other traffic away from those flights while they are in ATC-controlled airspace. This option would most likely be used if the ETM vehicles plan to return to the ETM-operating region within a short period of time (i.e., after loitering, hovering, or holding nearby). 3) ETM vehicles descend into Class A airspace and control of the vehicles is transferred from the ETM system to ATC, where ATC provides IFR services – this option is described in the following use cases.

Weather Advisory Impacts Multiple ETM Vehicles: *Multiple* ETM Operators are conducting a mission in a cooperative ETM-operating region managed by an ESS Network. During normal operations, each ESS receives a SIGMET weather advisory from the FAA for a large thunderstorm building up into the Stratosphere and affecting numerous airborne flights in the region. The ESSs activate data on the weather cell via third-party service tools and determine that the ETM flights within the operating region will *not* be able to safely complete their intended operations. Each ESS determines that its vehicle(s) will need to utilize Class A airspace. The Operator / RPIC / PIC agrees that the best option is to descend below the weather, into Class A airspace. Each Operator / RPIC / PIC uses their ESS to develop a new Operation Plan to descend and exit the ETM-operating region. Each ESS submits the new Operation Plan to the ESS Network to ensure de-confliction.

ESS Network Notifies ATS / ATC: The ESS Network notifies ATS that due to the SIGMET, multiple vehicles need to exit the ETM-operating region and each vehicle, with the exception of balloons, will request an IFR flight plan to enter ATC airspace. In turn, ATS advises the appropriate ATC facility, which then provides the information to the appropriate sector(s). However, depending on how much time there is for coordination, this initial notification from the ESS Network may not contain complete information (e.g., vehicle intent). ATC sectors protect for imminent ETM vehicle incursion as necessary which may require moving other traffic and using larger buffers than standard separation.

The ESS Network also informs all ESSs of any conflicts resulting from the vehicle's descent. If any conflicts are detected, the ESSs de-conflict from each other in accordance with COPS.

ETM Operator / RPIC / PIC: The balloon / airship and slow-speed HALE Operators decide that they will return to base or proceed to a secondary landing area to end their mission early. High-speed, uncrewed / crewed Operators decide to remain in ATC-controlled airspace and continue to their original destination until the planned end of the mission.

With the exception of the balloon Operator who provides an *estimated flight path* for descent to ATS, the ETM Operators – possibly done through the ESS – provide their new, proposed IFR flight plan to ATS for returning to base, proceeding to a secondary landing area, or remaining in ATC-controlled airspace and continuing to their original destination.

Each ESS coordinates with its Operator / RPIC / PIC so that all vehicles in the ETM-operating region initiate their new Operation Plan. The Operator / RPIC / PIC for each vehicle acknowledges and executes the new routing to exit the ETM-operating region.

ATC-Controlled Airspace: With the exception of the balloon operator who notifies ATS, each Operator / RPIC / PIC initiates verbal contact with ATC to request pick up of their IFR clearance to enter and operate in Class A airspace. ATC verifies radar contact and altitude, scans for traffic to ensure no conflictions, and issues the IFR clearance. Because the balloon does not receive an IFR clearance, ATS provides the balloon's Operator / RPIC a discrete beacon code to squawk and permission to enter and operate in Class A airspace. If ATC does not have radar contact, separation from other traffic would be more difficult and require a much larger buffer.

Each Operator / RPIC / PIC flies their vehicle in accordance with their IFR clearance. As the balloon descends, the Operator / RPIC monitors their vehicle, re-calculating the trajectory and predicted landing location at regular intervals, and provides updates to ATS as appropriate. ATC notes the approximate region of the balloon's descent on radar and keeps other traffic well clear of the balloon's operating envelope during its descent.

For high-speed, uncrewed / crewed fixed-wing vehicles, ATC maintains standard IFR separation from IFR traffic and other ETM flights entering ATC-controlled airspace. However, for the balloon / airship and slow-speed HALE, due to their lack of maneuverability, ATC may use other methods to ensure safety of flight.

Vehicles proceed to an airport or landing area. For vehicles that received an IFR clearance, ATC cancels their IFR flight plan. The balloon operator / RPIC notifies ATS when the balloon is on the ground.

IX. Open Questions on Concept, Procedures, and Assumptions

In the previous sections VI–VIII, ETM-ATC interaction use case procedures were detailed. Sections VI and VII described procedures for nominal operations during the climb and descent phases of flight, as well as a scenario in which ATC-controlled airspace is temporarily authorized to allow full ETM operations. Section VIII described procedures for unplanned, off-nominal events that may require a specialized set of procedures depending on the nature and the severity of the events.

The primary goal of detailing the ETM-ATC interaction use cases and procedures, beyond those outlined in the ETM concept documents, was to instantiate the concept enough to be able to prototype and demonstrate it in simulations or live test environments. The deeper level of specificity in the concept, procedures, and assumptions outlined in this paper might not fully align with the eventual final ETM concept. However, this initial effort will allow for a prototype development that can explore options and assess their feasibility, which can in turn provide insights during subsequent concept iterations.

During the procedure development, several questions emerged with respect to the assumptions about how ETM operations are expected to interact with the ATC controllers. Following are some of the questions that we have identified:

- Will "standard IFR separation" apply to ETM vehicles with limited controllability that may not be able respond to ATC instructions to fly a precise route or pause ascent / descent like conventional aircraft? For example, a balloon's limited controllability precludes it from following a predetermined vertical / lateral route, as conventional aircraft do as part of an IFR clearance. If these vehicles do not follow standard IFR separation, how will they be handled by ATC? What information and visual representation does ATC need about the vehicle's intent, location, and speed? What procedures, standards, and tools will ATC use to keep other traffic separated from these kinds of vehicles?
- Some ETM vehicles, such as balloons, do not currently file a conventional IFR flight plan and procedures for notification and authorization differ from conventional aircraft. When future ETM operations are integrated in the NAS, will these vehicles need to file IFR flight plans?
- Currently, many ETM vehicles, such as remotely piloted aircraft, are allowed to operate with a combination of Letters of Authorization (LOA), COAs, and Notices to Air

Missions (NOTAMs). In future ETM operations, are they expected to operate using these same mechanisms? If so, to what extent will the process for filing LOAs, COAs, and NOTAMs be automated / digitized?

- In situations where ATC cannot see or identify the ETM vehicles on the radar, what procedures and tools will the controller use to keep other traffic well clear of ETM vehicles? Will they provide separation services? If so, will they need to use standard separation?

- How will ETM-operating regions be demarcated from ATC-controlled airspace? Where, how, and by what entity will these regions be structured? How will ATC controllers or ETM Operators know where the boundaries are? Will they need visualization tools to keep track of the transition points / boundaries between ETM and ATC operations? Will they need automated coordination tools to enable smooth entry / exit transitions between the two operations?

- When ATS / ATC authorizes a new ETM-operating region in areas that are normally controlled by ATC, how automated, dynamic, and flexible will the authorization process be? Are tools needed to identify the predicted traffic flow and airspace utilization in order to automate the process of identifying potential airspace that can be authorized for ETM operations? How does an ATC controller / Traffic Manager determine when it is better to authorize a new cooperative ETM-operating region where ETM vehicles operate under ETM control as opposed to ATC retaining control of the airspace and allowing ETM vehicles to transit under ATC control?

- State / military operations currently make up most current Upper-Class E airspace operations. These vehicles often elect to discontinue IFR services while operating above FL600 (e.g., they operate in restricted airspace, similar to Military Authority Assumes Responsibility for Separation of Aircraft (MARSA)). As use of Upper Class E airspace grows, to what degree will state / military operations participate / share in ETM operations or will it be a one-way process in which the military can see the ETM operations and take responsibility for avoiding them?

- During the transition between a cooperative ETM-operating region and ATC-controlled airspace operations, there will need to be coordination and information exchange between human Operators (RPIC / PIC and ATC) and two automated systems (ESS Network and ATS). For a given ETM-ATC interaction scenario, coordination procedures need to identify which entity is in communication (verbal and / or digital) with which other entities. For example, when ETM vehicles enter ATC-controlled airspace, it is unclear whether the RPIC / PIC will verbally communicate directly with ATC or whether information will pass digitally via the ESS Network to ATS and then to ATC.

- When ETM vehicles exit an ETM-operating region and enter ATC-controlled airspace, will their original IFR flight plan still be on file, or will they need to file a new flight plan? If so, how will they generate and file the flight plan prior to exiting the ETM region? If ATC approval is needed for the new flight plan, what happens if the controller does not have sufficient time prior to the vehicle's entrance?

These questions constitute some of many that need to be answered and specified in designing the scenarios, procedures, and tool prototypes for future ETM-ATC interaction demonstrations. Assumptions about IFR flight plans and vehicle separation, along with the need for coordination and information exchange processes will guide the development, validity, and feasibility of the future ETM-ATC environment.

X. Summary and Conclusions

New types of vehicles with varying mission profiles are proposed to operate in a highly automated, cooperative traffic management environment in Upper Class E airspace. As a part of ETM development, NASA plans to create prototype tools to support ATC interactions with ETM operations.

As a first step, ETM-ATC interaction use cases and their procedures were identified, which we now plan to incorporate in the development of the ETM simulation environment. The procedures, ATC roles / responsibilities, and data exchange requirements that were identified as part of the use cases will inform the creation of ETM-ATC interaction scenarios for the upcoming demonstration and simulation activities.

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