Concept of Operations for an In-time Aviation Safety Management System (IASMS) for Upper E Airspace

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The National Airspace System undergoes continuous change including in the Upper Class E airspace involving increasingly complex operations and a widening diversity of vehicles. To secure a safe future system, the National Academies recommended an In-time Aviation Safety Management System (IASMS) that is extensible to Upper E. Current Air Traffic Management is not cost-effective to scale for future Upper E operations and diversity of vehicles so the Federal Aviation Administration developed an Upper E Traffic Management ConOps to safely integrate the diverse operations and vehicles having different performance characteristics and flight missions without disrupting current operations including space launch and reentry, suborbital flights, supersonic and hypersonic flights, slow moving or stationary unmanned balloons, and long endurance fixed wing vehicles that are slow, stationary, or high speed. IASMS integrates state-of-the-art predictive modeling with reactive and proactive analytics to detect hazards and mitigate risk precursors for Upper E operators. IASMS identifies emergent safety risks exposed by transformation of the NAS with new and increasingly complex operations. Safety intelligence will also expand the data available and offer insight to new approaches for implementing safety improvements to mitigate risk with more seamless "in-time" integration across the policy, risk management, safety assurance, and promotion pillars of SMS.

I. Introduction

The National Airspace System (NAS) undergoes continuous change including new technologies and innovations in Upper Class E airspace operations as part of Advanced Air Mobility (AAM). The increasingly complex operations in Upper E and the wide diversity of vehicles flying in and transiting this airspace require highly sophisticated capabilities for navigation and propulsion. Assuring safety will require a new approach. The National Academies recommended an In-time Aviation Safety Management System (IASMS) to secure a safe future NAS that is extensible to Upper E airspace [1].

This paper describes a Concept of Operations (ConOps) for an IASMS applicable to Upper E airspace and describes current and foreseen operations, benefits of in-time safety for risk management and safety assurance, and operation of an IASMS for operators in that airspace. NASA previously developed an IASMS ConOps for in-time safety for AAM generally and Part 450 space launch and reentry specifically [2, 3].

II. Current and Anticipated Operations in Upper E

Historically, use of Upper E has included military aircraft able to fly between FL600 and the Kármán line (approximately 327,000 feet) such as Department of Defense (DoD) unmanned vehicles, X-15s certified by Department of Defense to fly at FL800 (with restrictions), F-22s that routinely fly at FL600 to improve super-cruise (i.e., supersonic) performance, and Lockheed U-2s [4]. The Concorde had a maximum cruising altitude of 60,000 feet and the SR-71 85,000 feet. Traffic in Upper E airspace traditionally has not received any Air Traffic Control (ATC) separation services; instead, pilots in individual vehicles or remote space launch command centers have been expected to self-separate cooperatively or using visual separation.

NASA's Sky for All vision includes Upper E airspace in recognition of the current and future potential growth of operations involving space launch and reentry, suborbital flights, supersonic passenger aircraft, hypersonic aircraft, sophisticated high altitude, long endurance (HALE) vehicles, unmanned free balloons, and airships operating above FL600 [5]. The FAA foresees an information-centric National Airspace System (NAS) by 2035 in which services for Upper Class E Traffic Management (ETM) involve airspace volumes without traditional ATC services [6]. Instead, new extensible traffic management (xTM) services manage entrants whose operational performance expectations are different compared to these traditional ATC services, as depicted in Fig. 1 [7] and characterized in Table 1 [8]. That is, highly automated and third-party xTM services will apply industry practices to safely scale service growth. The predicted increase in Upper E operations, wide range of disparate vehicle performance characteristics, and unconventional operational needs present major challenges within the current airspace infrastructure and will require a new approach and solution.

Fig. 1 Building an xTM system for Upper Class E operations [7].

The growth in existing markets and emerging new markets such as space tourism and internet connectivity enabled by technology innovations will increase the number of vehicles operating in Upper E airspace. Highly automated and third-party xTM services will apply industry practices to safely scale service growth. The predicted increase in Upper E operations, wide range of disparate vehicle performance characteristics, and unconventional operational needs present major challenges within the current airspace infrastructure and will require a new approach and solution.

Table 1 Characteristics of Upper E vehicles (Adapted from [8]).

Vehicle type	Mission	Desired Notional Flight Level	Notional Cruise Speed	Notional gross Weight (lbs)	Notional Mission Duration time
Supersonic/Subsonic	Transport passengers	FL410 - FL600+	Mach 1.1 - 3	133,000 - 170,000	3 - 5 hours
HALE unmanned fixed wing	Military operations, surveillance missions, scientific research, communication service	FL500+	12 - 40 knots (true speed, wind dependent)	117 ~ 1,500	14 days - months
Unmanned free balloon (HALE & Short Endurance)	Communication service, scientific research	FL500 - FL650	8 - 15 knots (up to 100 knots, depending on winds)	~ 165	Months
High speed unmanned fixed wing	Military operations, surveillance missions, scientific research	FL500+	Mach 0.6	26,700	30+ hours
HALE airship	Communication service, scientific research	FL640 - FL650	8 knots (up to 100 knots, depending on winds)	~ 12,500	Months

The Federal Aviation Administration defined the ETM ConOps as a cooperative traffic management approach supported by the high-altitude operations industry [6]. The ETM ConOps identified limitations and challenges with current operations involving conventional fixed wing aircraft operating in Upper E airspace having lower atmospheric density. However, this means that sophisticated high altitude, long endurance (HALE) vehicles, unmanned free balloons, airships, supersonic/hypersonic aircraft, and balloon tourism can now efficiently and economically satisfy research objectives, demands for broad coverage services (i.e., earth sensing, telecommunications), and supersonic passenger flight. The FAA intends to mature the ETM ConOps with Upper E operators for an industry-supported cooperative traffic management approach. The FAA noted that characteristics of projected Upper E operations create unique challenges for equitable airspace management considering that some operations will be point-to-point while other operations will loiter in a pattern, move very slowly, or even remain stationary for extended periods of time. Vehicles may be vulnerable to wake turbulence or environmental conditions and so will require a larger airspace buffer for separation and operations. The needs for large volumes of airspace for long periods of time, the limited ability for some vehicles to maneuver, along with increased operational tempo of Upper E operations will increase the potential for airspace competition. Equitable airspace management is imperative to ensure fair, safe access for these operations.

In the United States, there are no specific provisions for aircraft operations above 60,000 feet for civil aircraft, and most existing applications are limited to military operations. Moreover, existing Air Traffic Management (ATM) systems are unable to cost-effectively accommodate Upper E airspace needs and the FAA does not provide air traffic control (ATC) separation services. DoD operations follow Military Authority Assumes Responsibility for Separation of Aircraft (MARSA).

Part 450 space launch and reentry traverses upper E airspace with Temporary Fight Restrictions (TFRs) blocking airspace extending to include the potential debris field in case of an accident. The FAA developed the Commercial Space Integration into the National Airspace System (CSINAS) concept of operation based on key principles including that the cooperative airspace management environment would use agreed-to standards for exchange of surveillance and intent information [9]. The IASMS ConOps was applied to address safety risk management and assurance with space launch and reentry [3].

There have been no civil accidents occurring in Upper E airspace that have been investigated by the National Transportation Safety Board (NTSB). There have been accidents of civil vehicles capable of flying in Upper E airspace, but these accidents occurred below 60,000 feet.

The U.S. human space flight safety record from the FAA, shown in Table 2, started with Mercury flights in 1961, and suborbital space flights only count rocket-powered space bound vehicles [10]. Licensed or permitted launches and reentries, as well as launches and reentries conducted by and for the U.S. government, were counted in the human space flight safety record and vehicle safety record.

Table 2 U.S. human space flight safety record (adapted from [10]).

Launch Type	Total Number of People on Flight	Total Number of People Died or Seriously Injured	Total Number of Human Space Flights	Total Number of Catastrophic Failures
Orbital (Total)	947	17	171	3
Suborbital (Total)	261	3	218	2
Total	1208	20	389	5

Of the twenty fatalities and serious injuries, eight have occurred at altitudes above FL600 in two Air Force and NASA Accidents. In 1967 an X-15 flew to an altitude of 266,000 feet and a speed of Mach 5. During descent the pilot experienced flight control issues which exerted increasing loads on the aircraft as it descended. The aircraft broke apart at 62,000 feet killing the pilot [11]. On February 1, 2003, the Space Shuttle Columbia broke apart at an altitude of 209,800 feet while flying at a speed of Mach 19.5 killing all seven crew members [12]. Damage to the shuttle, which occurred at launch, allowed super-heated air to penetrate the shuttle during reentry which led to structural failure.

The most recent accident occurred on October 31, 2014, when a Scaled Composites SpaceShipTwo (SS2) broke apart at 46,000 feet soon after release from its launch vehicle, which resulted in one fatality and one serious injury. The SS2 is designed for space tourism reaching a maximum altitude of 360,000 feet and operating at speeds up to Mach 1.4. The aircraft was being operated under an experimental permit according to 14 CFR Part 437 [13]. The NTSB determined the probable cause to be a "Scaled Composites failure to consider and protect against the possibility that a single human error could result in a catastrophic hazard to the SpaceShipTwo vehicle." These accidents demonstrate how, at these altitudes and speeds, any mechanical malfunction or human error can have catastrophic results.

III. In-time Safety Needs

The FAA described challenges with Upper E airspace operations, including that significantly different performance characteristics of diverse vehicles and flight missions need to be safely integrated without disrupting current operations. These vehicles and missions include space launch and reentry, suborbital flights, supersonic/ hypersonic flights, slow moving or stationary unmanned balloons, and long endurance fixed wing vehicles that are slow, stationary, or high speed [6]. These are demanding challenges that strain Class E service provision capabilities, resources, infrastructure, and regulatory structure. Unique operations, new technological components, sophisticated capabilities, and communication, navigation, and surveillance (CNS) needs will exceed conventional operations and necessitate a new collaborative approach between industry and government regulators. Operational concerns include safe separation between vehicles operating in and transiting through Upper E airspace, vehicle vulnerability to wake turbulence, and wind conditions that necessitate larger airspace buffers for separation and maneuvering.

Operations are anticipated to range from hours to months for long duration flights, which may fly across multiple Flight Information Regions or internationally. Managing access to Upper E will need to be equitable to ensure fair and safe access for these operations. These needs come into focus as historically Upper E airspace was used predominantly for military operations and infrequent operations such as involving weather balloons [4]. Standards and data sharing requirements include providing minimum safe operational volumes based on vehicle maneuverability, communication delay, and control/operator response time [14]. Defining the minimum safe operational boundary for different vehicles operating or transiting Upper E is important to providing limited airspace management service.

Current Air Traffic Management (ATM) service delivery is not cost-effective in expanding and evolving to handle future Upper E operations. ETM must scale beyond the current NAS infrastructure and manpower resources to meet future operational market demands. At the same time, Upper E airspace operators may not necessarily desire the FAA to provide ATC separation services even if it could become available. ETM must promote shared situation awareness among operators. The FAA posed the need to develop a new ETM regulatory framework, operating rules, performance-based standards and procedures, and roles and responsibilities to align with agency goals and meet the requirements for safe and efficient operations.

IV. IASMS for Upper E Operations

Key attributes of the ConOps this paper addresses are integrating different sources of operational data for use in reactive and proactive data analytics and predictive modeling based on data and decision fusion, machine learning over many types of data, in-time decision making and execution, system modeling, human-system integration best practices, and safety intelligence and learning from all operations.

The IASMS ConOps derives from NASA Aeronautics Research Mission Directorate (ARMD) Strategic Thrust 5 that focuses on in-time safety assurance for aviation transformation (see https://www.nasa.gov/aeroresearch/strategy). For the NAS envisioned for 2045, the thrust focus involves in-time safety assurance through domain-specific safety monitoring and alerting tools, integrated reactive, proactive, and predictive technologies with domain-level applications, and in-time safety risk management.

The traditional framework of a Safety Management System (SMS) established by the International Civil Aviation Organization (ICAO) involves four pillars, as shown in Fig. 2 [15]. Each pillar is comprised of several components. The IASMS ConOps initially focused on the two pillars that were most closely related to the National Academies recommendations: Risk Management and Safety Assurance. Prior to the IASMS ConOps, the ConOps for in-time system-wide safety assurance (ISSA) addressed only the risks within the urban air mobility (UAM) domain. With a widening perspective, the IASMS ConOps is applicable to commercial air carriers, cargo carriers, and all other domains of the NAS and has intersections with all four SMS pillars.

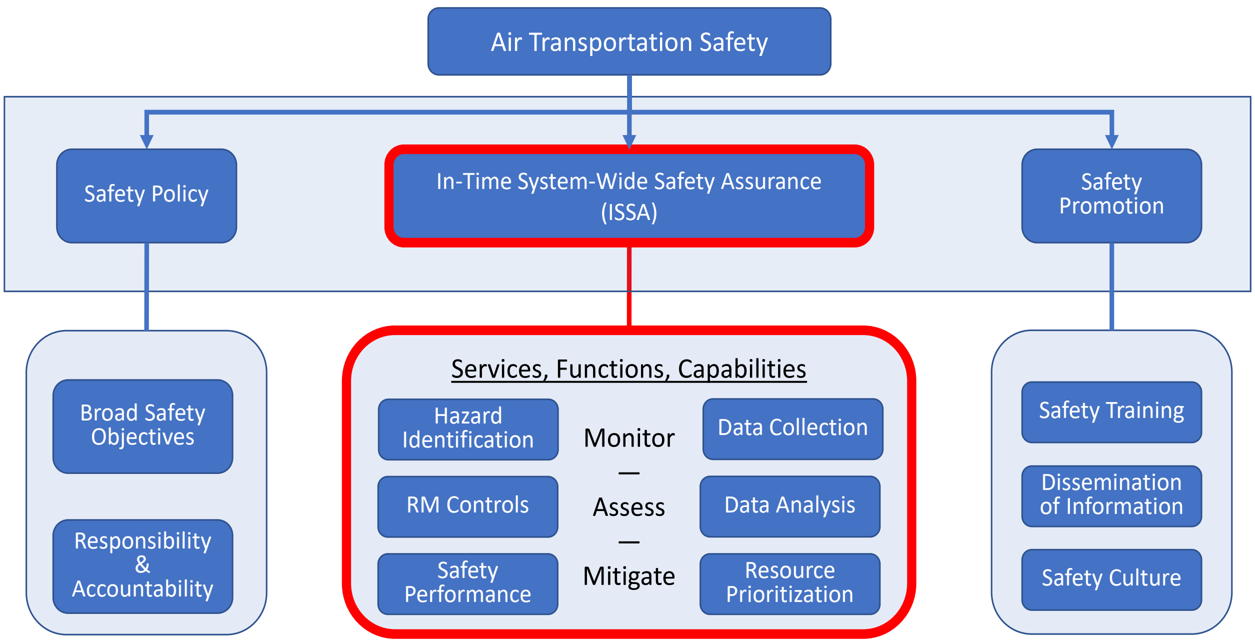

Fig. 2 ICAO SMS framework for IASMS.

Title 14 of the Code of Federal Regulations (14 CFR) Part 5 requires implementation of SMS by Part 121 commercial air carriers. Part 5 identifies what basic processes are integral to an effective SMS but does not specify the methods for how to implement these processes. The Federal Aviation Administration (FAA) provides guidance and methods of developing and implementing an SMS to demonstrate means of compliance in Advisory Circular (AC) 120-92B called Safety Management Systems for Aviation Service Providers (dated January 8, 2015) [16].

The SMS framework contained in AC 120-92B is shown in Fig. 3, which integrates the IASMS key functions of Monitor, Assess, and Mitigate. The approach outlines the integration of the processes for safety risk management and assurance. Risk management involves early identification of hazards and ensuring controls are designed to manage safety hazards at an acceptable level. Safety assurance monitors how controls are used operationally as they continue to mitigate risk as intended. Loops between safety risk management and assurance include the operational monitoring of risk controls to validate their efficacy and monitoring of operational data for emergent or different hazards that require new or a change to risk controls.

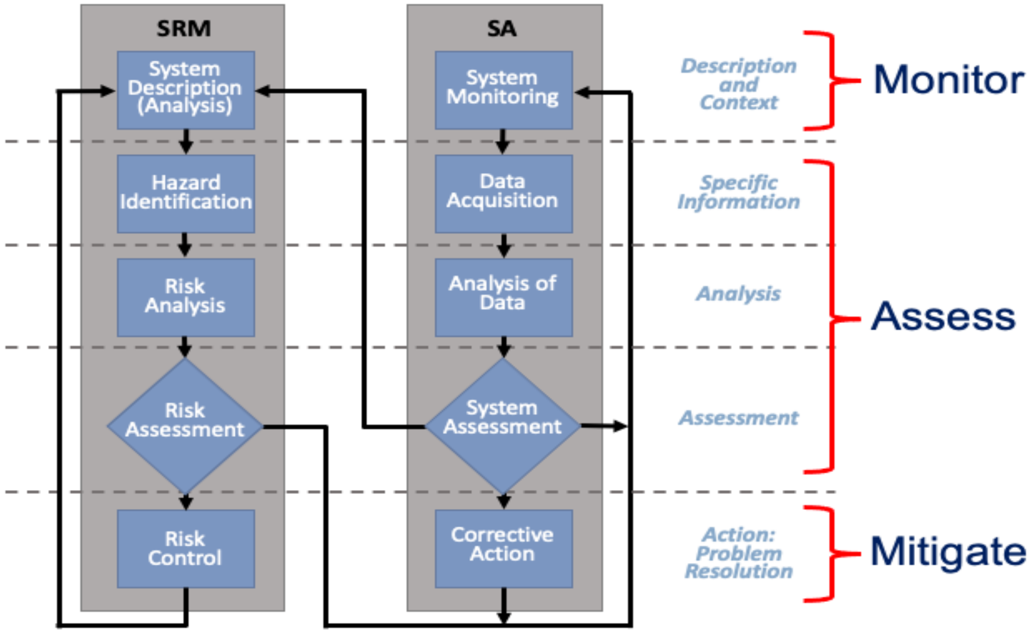

Fig. 3 FAA SMS framework for Part 121 Air Carriers with IASMS functions (adapted from [16] Fig. 2.1).

For safety assurance, AC 120-92B identifies methods for flight-by-flight monitoring of operational performance of systems and their associated risk controls. Some of these methods collect data shared with an entity managed by the FAA called the Aviation Safety Information Analysis and Sharing (ASIAS) system. The methods used by airlines to collect data and share with ASIAS include Flight Operations Quality Assurance (FOQA) and Aviation Safety Action Program (ASAP). AC 120-92B identifies additional methods and sources of operational performance data including Line Operations Safety Audit (LOSA), Advanced Qualification Program (AQP), and the Aviation Safety Reporting System (ASRS).

V. Hazards and Shortfalls

Based on the FAA ETM ConOps and the 2035 vision, and prior NASA IASMS research on space launch and re-entry, hazards and safety mitigation needs have been initially defined as shown in Table 3. The table gives examples of specific hazards, possible outcomes, causes, and mitigations. Until more data is gathered on operations in Upper Class E airspace and on the types of vehicles, it will be difficult to assess the risk associated with each hazard.

Table 3 Hazards, causes, and mitigation needs.

Hazards/Outcomes	Causes	Mitigation Needs
Flight outside of approved airspace leading to collision or near collision with another aircraft	• GPS failure • Communication failure • Pilot error • Weather uncertainty especially winds • Loss of control	• Policy and technical capabilities to address operations above FL600. • Coordination between stakeholders who utilize and are affected by Upper Class E airspace availability. • Sharing and ability to receive and distribute data on operations in and/or transit through Upper E airspace. • Ability to determine the current position and state of operations in and/or transit through Upper E airspace accurately and reliably in all environments. • Ability to correlate aircraft position flying in Upper A airspace.

		• Complete, timely, and accurate data for operators to effectively predict the planned trajectory of an operation in and/or transit through Upper E airspace with entry into ATC-controlled airspace. • Separation standards, procedures and/or techniques available to third-party separation service providers to separate operations in Upper E airspace. • Ability to develop and distribute tactical options to support decision-making during nominal and off-nominal events.
Mechanical failure leading to collision with persons on the ground or critical infrastructure	• Design errors • Maintenance errors • Flight planning errors	• Complete, timely, and accurate data for operators to effectively predict the planned trajectory of an operation in and/or transit through Upper E airspace on operation of the NAS • Redundancy of critical systems • FAA certification requirements • Flight termination system to slow decent after critical failure
Critical system failures or degradation leading to loss of vehicle	• GPS signal degradation • Loss or Latency of command-and-control communications link • Power failure • Third party xTM service provider failure	• Ability to proactively monitor vehicle health status and respond efficiently to off-nominal vehicles operations. • Ability to select and implement a pre-defined contingency plan or other established procedure. • If the vehicle's flight path leads to ATC-controlled airspace, xTM Service Suppliers are expected to notify Air Traffic Service (ATS) about the unplanned vehicle entry, which in turn can notify the impacted ATC entity. ATC is responsible for clearing all aircraft in the vicinity of the xTM vehicle's anticipated location and trajectory.
Physical-environment conditions leading to loss of vehicle	• Weather uncertainty • Solar activity affecting GPS signal	• Common weather picture for FAA, operator, and third-party service providers to understand how weather will affect departure or launch probability and projected NAS impact.

Safety analysis could also consider another vehicle intruding into one own's approved airspace leading to a traffic collision or near collision. For example, an intruder could unintentionally enter one own's designated approved airspace and the intruder could be a non-cooperative operator/operation/vehicle.

Mitigation of the hazard of traffic collision avoidance involves a multi-dimensional solution. Safety data and IASMS predictive modeling could consider the minimum safe separation distance based such as on position reporting accuracy (e.g., error, latency), wake vortex, maneuverability of the vehicle, and control response time [14]. Position reporting error (i.e., cross-track error or along-track error) could differ with the type of vehicle [17].

Overarching SMS considerations include NAS operational metrics that consider safety, efficiency, capacity, and performance. Other considerations include:

- Inability to develop and distribute best practices and disseminate them among stakeholders.
- Risks to the NAS may reach across safety and ATC FAA offices.
- ICAO and States policies define obligations to share data about Upper E airspace operations and potential hazards and off-nominal events during real-time operations, e.g., aircraft need to be protected from uncontrolled reentries of space debris.

Some of the hazard mitigation strategies could be accomplished by developing SFCs that can be used in an IASMS across aviation operators and third-party service providers, such as the following:

1) Developing a standardized planning process between FAA air traffic control (ATC) and operators to increase situational awareness and data sharing.
2) Developing automated tools to evaluate the impact of operations in the NAS.
3) Developing automated data sharing mechanisms among the relevant stakeholders.
4) Developing a standardized set of data and format for data exchange between stakeholders.
5) Developing improved hazard analysis methodologies to decrease the required size and duration of the protected airspace.
6) Developing tools and procedures that enable ATC to plan for and handle nominal and off-nominal operations more efficiently.
7) Leverage or develop tracking capabilities for vehicles from surface to the NAS automation boundary and back to surface when needed.
8) Providing FAA, aviation, and launch/reentry operators with a common weather picture to understand how weather will affect launch probability and projected NAS impact for planning and increased NAS predictability.

These and other efforts would maximize technological advancements and developments in industry for space and other NAS users while meeting NAS requirements. Also, it should be noted that each ICAO State can decide how to use airspace classifications including at what altitude they begin.

The FAA ASIAS ConOps 3.0 identified future changes including use of advanced data analytics that leverage data fusion capabilities developed in ASIAS 2.0, along with improved collaborative activities and improved responsiveness for requested information and studies [18]. Predictive analytics, such as machine learning and artificial intelligence (ML/AI), will use advanced tools to continually integrate and analyze current and under-utilized data sources to identify emerging risks and enable adaptation to them. Predictive analytics will become integral to normal business operations. This is expected to increase the effectiveness in discovering vulnerabilities by tightly integrating automated processes with the expertise of human subject matter experts (SMEs).

Increasingly complex aviation safety issues necessitate new analytic methods and tools to identify complex patterns and detect emergent risks. The objective is to rapidly discover patterns in data that may predict negative outcomes before the next safety event occurs. Upper E operators would benefit from development of technologies that integrate and fuse large, disparate sets of data from multiple sources. The approach enables the execution of a system-wide risk assessment to help achieve in-time safety risk management. ML/AI can fuse and interpret complex patterns in data that might otherwise appear as insignificant. This improved speed and characterization of system-wide risk identification would augment existing SMS processes supporting safety risk management and assurance.

The FAA ETM ConOps represented transitions to and from Upper E airspace as shown in Fig. 4. In Upper E airspace, operators are intended to have shared situational awareness to cooperatively manage separation. ATM systems will be interoperable with Operator systems used for cooperative separation, ensuring data access and that management is in place to satisfy ATC needs when separating vehicles under their control from those that are managed cooperatively. Operators will de-conflict operations according to agreed-upon industry business rules involving Operator-to-Operator coordination or through automated processes with built in rulesets that resolve competition for airspace when Operator intent information is shared. In Upper E, strategic separation could be non-cooperative, where one operator such as flying a balloon must alter its ascent trajectory in order to avoid a second operator, such as an airship. Strategic separation might also be cooperative where both operators maneuver following a negotiated protocol or an established playbook [19].

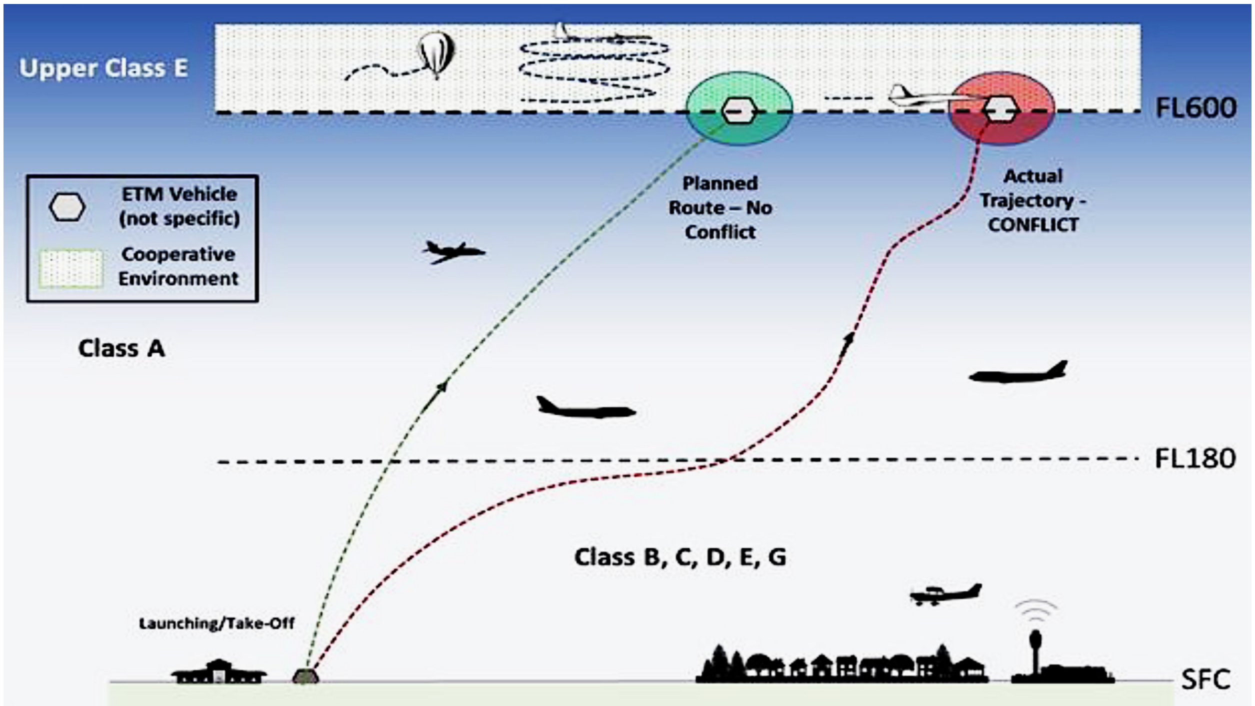

Fig. 4 Launch and transit to Upper Class E airspace (from [6]).

In addition, vehicles that depend on sunlight may temporarily fly through adjoining upper Class A airspace overnight, as shown in Fig. 5, with ATC temporarily extending the Upper E cooperative environment while continuing to clear aircraft through a conflict-free transit corridor.

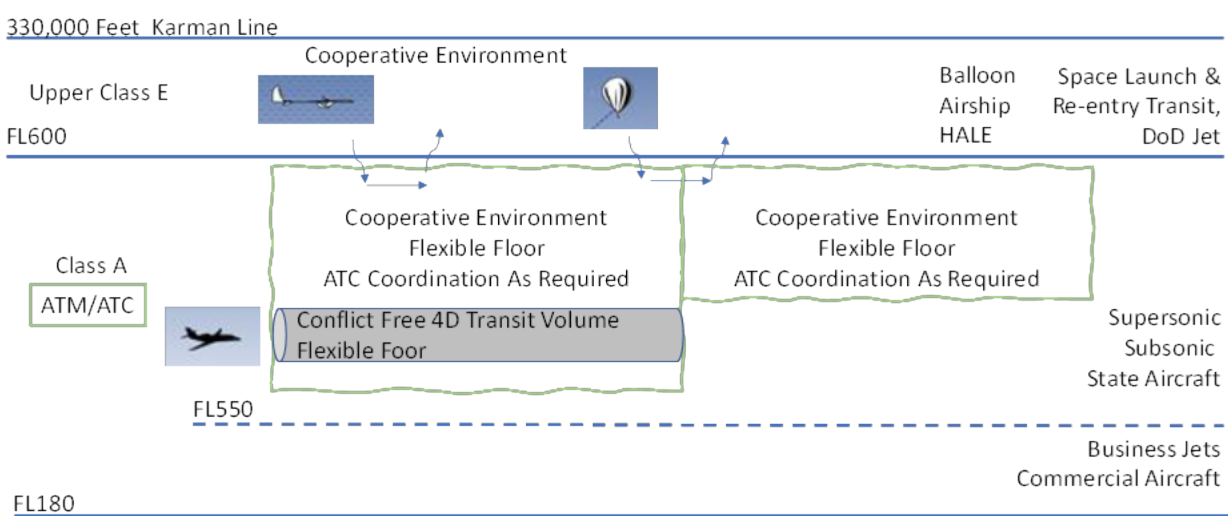

Fig. 5 Cooperative environments in Upper Class E airspace and extending into Upper Class A airspace.

These increasingly complex future operations in the NAS use Services, Functions, and Capabilities (SFCs) that provide for safety risk management and assurance. SFCs are integrated as part of operational systems and the IASMS, as shown in Fig. 6. Some SFCs serve both operational and IASMS purposes, i.e., any one SFC could uniquely fit as either operational or IASMS within an architecture layer or could fit in multiple layers. This one-to-one or one-to-many alignment reflects the interdependencies among SFCs in how data and information are used and to mitigate risk.

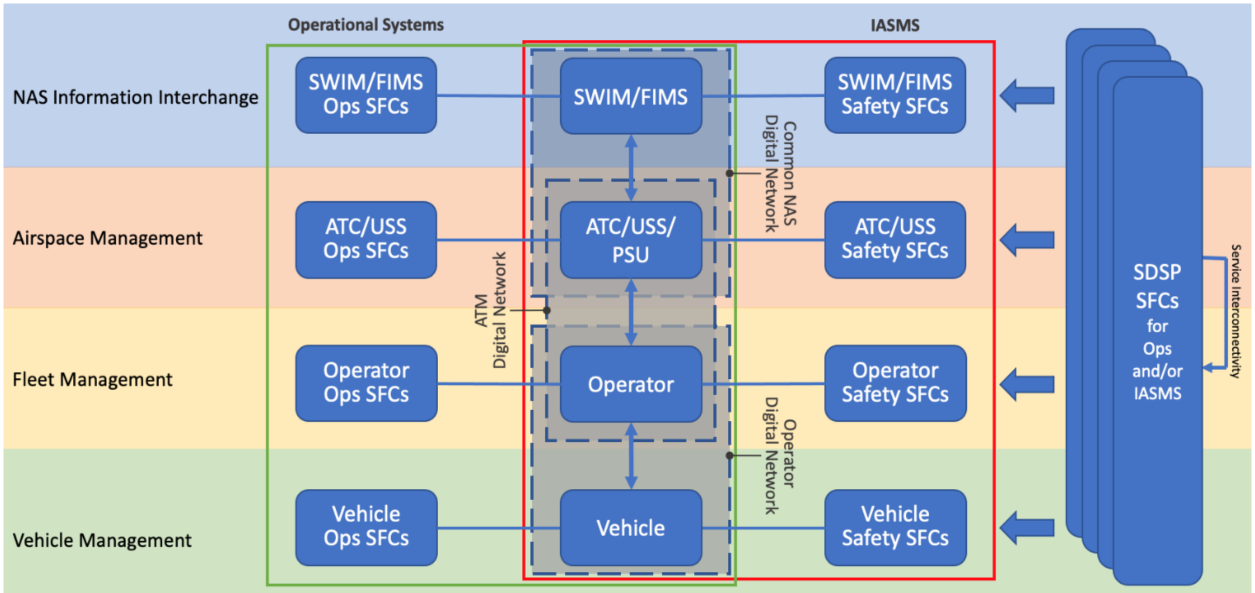

Fig. 6 SFCs as part of Operational systems and the IASMS.

VI. IASMS System Architecture

The notional integrated system architecture for the current NAS involving Upper E airspace is shown in Fig. 7. The architecture represents the integration of IASMS safety services with the vehicle (aircraft) and operations, and with proactive and post-flight services that share data and analysis across multiple operators. IASMS safety services could be scaled for different operators.

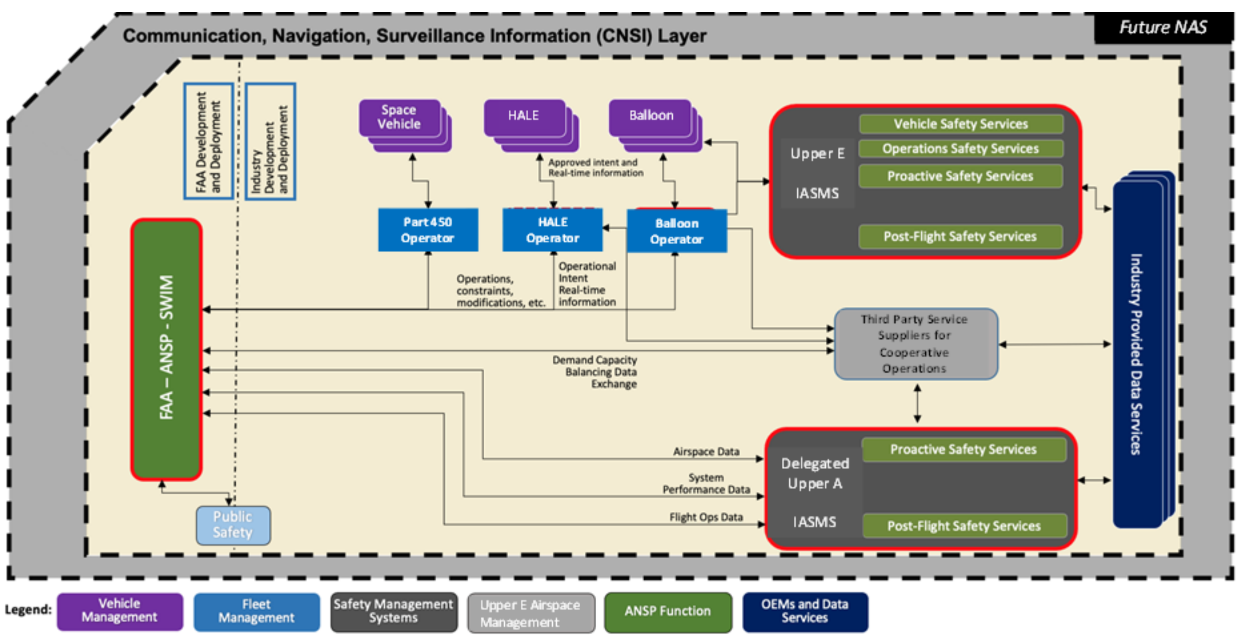

Fig. 7 Notional integrated system architecture of the future NAS.

In some instances, there could be multiple xTM Upper Class E Service Suppliers (ESS) [7]. ESS roles and responsibilities with each other and with their respective operators would frame the definition of the information architecture and the common SFCs required to assure in-time safety management including data exchange protocols, software functions, and system performance requirements. An example of ESS operations from which SFCs could be defined is shown in Fig. 8.

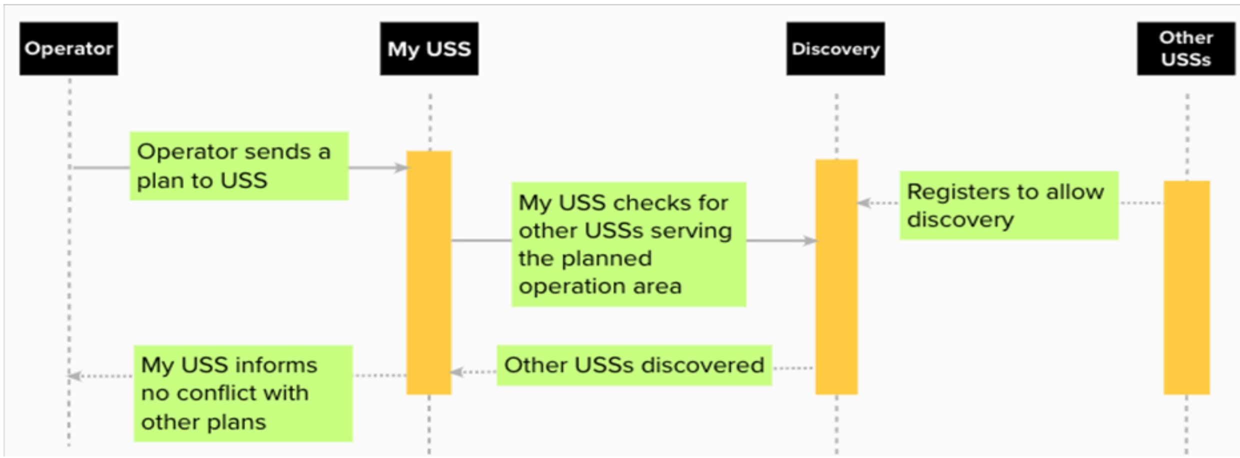

Fig. 8 Common SFCs required to support Upper E Service Suppliers' operations (from [7]).

VII. SFCs for Upper E Operations

An analysis is examining what SFCs are needed for Upper E operations. For example, strategic conflict management could be performed on the aircraft by the aircraft operator's ground function or by a collaborative traffic management (xTM) provider that is servicing the airspace [20]. These architectural tradeoffs will involve decision-making by operators and service providers as factors such as operating weight, available spectrum, and data sharing are considered.

Part of this analysis involves a short scenario, or "vignette," that highlights the kinds of operations that are likely to occur in the 2040 timeframe. This vignette considered an autonomous solar-powered fixed wing UAS, or high-altitude pseudo satellite (HAPS), with a humanitarian mission to provide internet connectivity to a disaster zone. This vignette explores the capabilities and underlying functions that would need to be in place to ensure that new entrants, such as HAPS, are able to ensure safe separation from other vehicles. Maintaining safe separation may require changes to flight plans as vehicle capabilities change, and when hazardous weather or other conditions alter the risk level of the airspace in which the vehicles are operating.

This analysis postulated several capabilities necessary to safely execute the operation described in the vignette. These include system health monitoring, performance-based separation management, real-time system-wide airspace risk monitoring, and integration across data sources with differing but known or characterized levels of data quality assurance. The landscape diagram for the vignette is shown in Fig. 9.

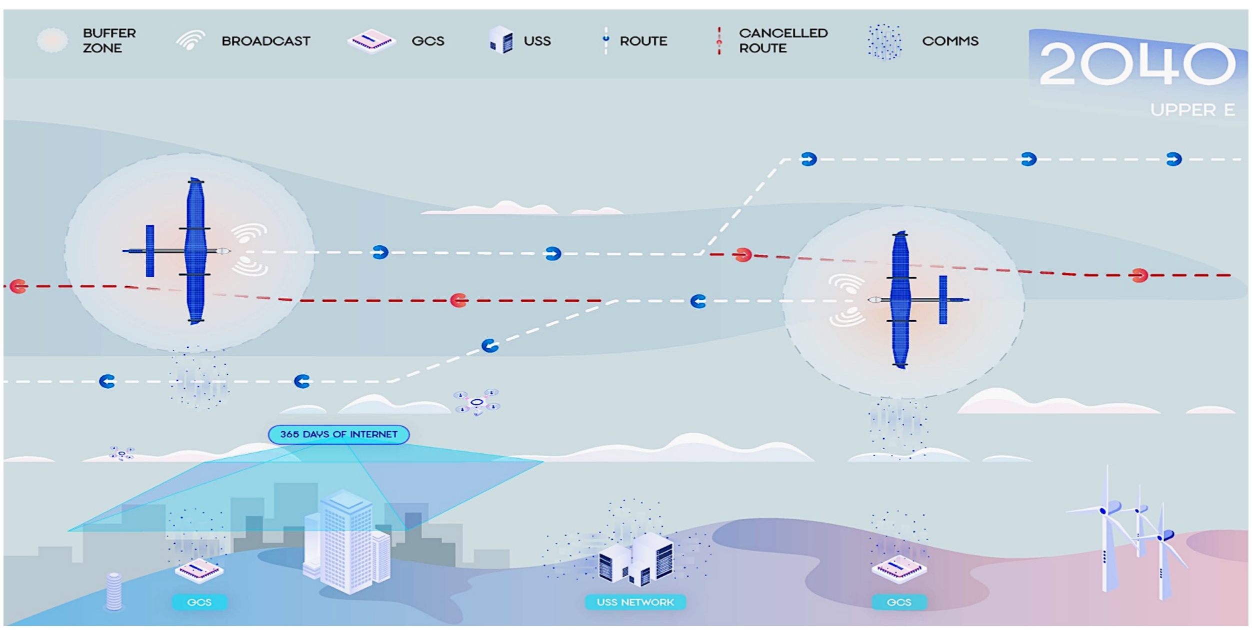

Fig. 9 Landscape diagram for Upper E vignette.

VIII. Benefits of In-time Safety

IASMS is intended to provide in-time safety risk management and assurance to detect, assess, and mitigate operational risk more effectively and rapidly. With IASMS the effectiveness of risk mitigations will transverse between changes to system design for risk management and management policy, procedures, and practices to assure operational safety. The IASMS will scale for increasingly complex operations to optimally adapt to vehicle flight management, airspace constraints, contingency management, and other factors. Whereas many aspects of today's SMS tend to be labor-intensive, IASMS enables pilots, data analysts, safety managers, and others to work more efficiently and smartly using human-computer interfaces to manage larger volumes of data and information through use of semi and automated systems, and IASMS will improve use of new and under-utilized sources of data with new tools for predictive data analytics to identify safety risks.

Development of IASMS capabilities for Upper E airspace operations are based on the following considerations:

- Improve and ensure the responsiveness of SMS for those operators required to have an SMS.
- Improve and ensure hazard mitigation effectiveness of IASMS.
- Improve and ensure the scalability of IASMS.
- Improve and ensure the utilization of resources by IASMS.
- Improve and strengthen the safety business case of IASMS.

The safety business case of IASMS that flows from operators includes gaining FAA certification and safety approvals for their vehicles and operations. Operators also brand their flights as having world-class safety to promote public acceptance. Part of the safety business case also addresses controlling the costs of liability by mitigating accidents, fatalities, injuries, and incidents. That is, the costs of today's assured safety systems balanced with avoiding costly accidents and harm to people are re-balanced with IASMS use of increasingly complex semi and automated systems.

IX. Reactive, Proactive, and Predictive Data Analytics

Safety systems are generally considered to be reactive, proactive, or predictive in nature, with each making certain contributions to understanding causal and contributory factors to accidents, incidents, exceedances, and other anomalous situations.

Reactive safety responds to events and attempts to do something to address the hazard identified in an accident, incident, or safety-concerning event, but after it has already occurred to prevent it from occurring again. Data analytics take a different form and include tabulations to show frequency of occurrence of causal and contributory factors.

Proactive safety seeks to assess threats to operations such as emergent risk and apply mitigating action in some way before an accident or incident happens. The objective of proactive SMS is to identify precursors and anomalies and potential causal factors through data markers and system behaviors that may lead to hazardous operations and attempt to preemptively stop the event before it occurs. All available historical and latent safety operational data are monitored and assessed to identify hazards and emergent risks from past accidents or incidents or safety concerning events. Proactive safety identifies leading indicators that can result in threats to operations and unsafe conditions. Proactive safety can include human contributions to safety in which safety culture encourages human operators to mitigate deviations from normal operations before they might lead to unsafe conditions.

Predictive safety is characterized by the goal to mitigate a potential risk as determined from patterns identified in normal everyday operational data (i.e., not accident data) to prevent an accident that has not yet happened but will probably occur if left unaddressed. Predictive safety identifies previously unknown or emergent risk identified through data analytics applied to large data sets. Predictive safety management attempts to identify all possible risks in different scenarios based on both observed but also hypothesized situations/circumstances in order to anticipate future risk controls, risk mitigation options, safety assurance, and organizational needs. Importantly, predictive SMS is complementary to, and not a replacement for both reactive and proactive SMS; that is, they are intended to work collectively to enhance airline safety.

Predictive analytics builds on advanced methods for data-driven anomaly detection using ML/AI. Data-driven anomaly detection coupled with domain expert feedback on the operational significance of the identified off-nominal conditions can effectively identify operationally significant anomalies during operations and provide explanations for them. Precursor identification methods can be used by domain experts to identify undesirable effects and their precursors. This approach represents effective teamwork between human domain experts and ML/AI to accurately identify sequences of events that can lead to anomalous operations, thereby increasing trust in autonomous systems. Human autonomy teaming design concepts and principles will be important to facilitate and develop this approach. Analytic techniques from other AAM domains may be extensible to Upper E operators such as with data-driven predictive modeling [21].

As an example, one study examined an initial machine learning method that predicted unstable high-energy landing (long or hard) with 80% accuracy. The air traffic controller could be alerted about a potentially unstable high-energy landing situation and potentially recommend a go-around to the flight crew. Research on a data mining study called Vehicle Integrated Prognostic Reasoner (VIPR) examined precursors to in-flight engine incidents [22]. Depending on the nature of the engine problem, VIPR was able to detect conditions in flights prior to the incident. That is, precursors to an in-flight engine shutdown were detected about 30 flights prior to the incident to a flight engine shutdown caused by a high vibration event about 20 flights prior to the incident, and to an engine on-fire safety incident some 4 to 5 flights prior to the incident.

X. Safety Intelligence and Learning from All Operations

Safety Intelligence is a composite of reactive, proactive, and predictive SMS that represent different windows to identifying and understanding safety risk. Each provides an important safety shield, but by itself is not sufficient to mitigate all possible risk that could occur.

The IASMS can provide a path for Upper E operators to develop a common industry vision for safety intelligence and learning from all operations. Learning from all operations has intersections with the ICAO SMS pillars shown in Fig. 2 and offers new opportunities to add to the breadth of data available to a variety of data repositories. Such data could be used to augment safety risk management and assurance processes by informing new safety enhancements with key insights and lessons learned of what has been done to avoid particular risks in similar circumstances. All participating parties would share safety information and data such as across the FAA, ASIAS, ICAO, International Air Transport Association (IATA), and other stakeholders.

By effectively transforming their SMS to IASMS, Upper E operators will be able to more effectively mine operational data and shorten iterative review cycle times between design and performance as shown in Fig. 3. In-time decision making will be enabled by ML/AI that will automatically detect and elevate critical risks for immediate attention. As decision makers gain confidence and trust in IASMS, a subsequent concern may emerge which is over-reliance on ML/AI for safety critical decisions with drift toward always accepting recommended risk mitigations regardless of unique situational factors.

ICAO, as part of its SMS approach, emphasizes the global need for developing safety intelligence that leverages safety data and information to develop predictive and actionable insights leading to “in-time” data-driven decisions. Sharing safety information including both Safety I and Safety II data will be increasingly important to not only identifying hazards and emergent risks as aviation evolves internationally to different markets and missions with new entrants such as AAM, but also to inform new designs and approaches to optimize safety and performance.

Tools that help establish safety intelligence, such as an IASMS-enabled safety dashboard that seeks to characterize system-wide risk in-time could provide a portal to advanced predictive analytics and improve knowledge management. Domestic and international safety dashboards enabled by IASMS data services enhanced by learning from all operations offer the potential to provide in-time information important to efficiently manage operational risks and risk controls.

XI. Opportunities to Further Develop IASMS for Upper E Airspace

There are different opportunities to demonstrate how IASMS could scale and address the diversity of operators using detailed operational scenarios that explain how it could work. These scenarios will define IASMS services, functions, and capabilities needed to manage safety hazards identified and trace these to the IASMS system functions: monitor, assess, and mitigate. There would be multiple operational scenarios for each type of operator such as for operational missions, vehicle/aircraft capabilities, airspace constraints, environment characteristics, and management of contingencies. Similarly, there would be different operational scenarios for safety actors working with IASMS in a manner reflecting the operational scenarios in ASIAS 3.0. The FAA, through industry engagement, intends to integrate further industry input into a Version 2.0 of its ETM ConOps. This maturing of the ConOps will provide a broader and more comprehensive vision of the shared industry-FAA partnership for ETM operations.

XII. Future Challenges

Transforming Part 121 with integration of IASMS as part of the vision for 2045 NAS poses significant challenges for enabling in-time safety. An incremental path using basic building blocks will provide lessons to speed the refinements. IASMS advances aviation safety by addressing and integrating the four pillars of the ICAO-defined SMS. A benefit for Upper E operators is its extensibility to operations around the globe and operators originating in other countries.

Predictive analytics in particular will advance the state-of-the-art in detecting and mitigating safety anomalies, precursors, and trends for Upper E operators as well as identifying emergent safety risks exposed by transformation of the NAS with AAM operations. Moreover, safety intelligence will expand the data that is available and offer insight to new approaches for implementing effective safety enhancements and safety promotion to mitigate risk with more seamless “in-time” integration across the policy, promotion, risk management, and safety assurance pillars of SMS.

Based on these capabilities, a number of research and policy analysis efforts were identified that will need to be addressed in order for this vignette to be possible by 2040. Efforts in the near-term could include strategy development and will require stakeholder collaboration such as:

1) Government/industry collaboration on airspace evolution strategy.
2) Spectrum strategy for the exchange of information supporting higher-density operations in Upper E airspace.
3) Development of a strategy, consistent with international use of spectrum, for safety-critical communications for all operators including new entrants in Upper E airspace.
4) Establishment of a UTM risk assessment framework.

These efforts will inform the development of requirements and policies associated with safety services, safety data exchange, risk assessment, and airspace access equity issues. Additional effort will be needed in key areas including:

1) Development of minimum functional and performance requirements for xTM providers, as well as indemnity questions related to the provision of safety services.
2) Development of data exchange requirements for xTM providers and for new entrants to provide safety data.
3) Policy on contention management for Upper E airspace volumes when there are competing uses.
4) Establishment of validation suites for delivery of, or operation of, safety services by autonomous systems.

Accomplishing these activities will be necessary for operational systems and procedures to be developed and approved. Further, leveraging the types of efforts referenced above will allow, by the 2035 timeframe, that research and operational evaluations can focus on ensuring the effectiveness of in-time risk assessment and autonomous separation services in Upper E airspace.

Acknowledgement

The authors extend their appreciation to Jaewoo Jung and the NASA xTM team for their technical contributions. The authors also extend their appreciation to Mrs. Laura Bass (Analytical Mechanics Associates, Inc.) for her valuable contributions in the development of this paper.

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