A 2035 VISION FOR AIR TRAFFIC MANAGEMENT SERVICES

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Preliminary

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Final draft to be provided by the Federal Aviation Administration subsequent to agency coordination.

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INTRODUCTION

The past decades have seen a phenomenal increase in information connectivity between people, business, and government through electronic communication and a multitude of devices. This connectivity, plus the large-scale growth in available data and delivery of actionable information, is accessible to all decision makers, wherever they may be located. With corresponding increases in computation power and storage, new technologies have emerged to secure, leverage, and learn from the massive data that is being accumulated. Growth in this area shows few signs of abatement, with capabilities having reached a level of maturity enabling their widespread adoption by safety-centric industries such as Air Traffic Management (ATM). Embracing this information revolution within ATM provides opportunities for performance enhancement in aviation, as it has for many other businesses.

Simultaneously, exciting new opportunities are occurring in aviation and aerospace. Leading this charge is significant investment in research and development of autonomy; electrification of aviation; high-speed and long-endurance aircraft in the higher altitudes; and increased volume of space vehicle operations. Success in these areas is sure to transform daily life by enabling the movement of people and goods on demand. Further, aviation's role will increase beyond transportation, providing platforms for telecommunications and earth-sensing services for all communities. The aviation system is in the discovery and rapid innovation phase for incorporating these new vehicles, controls, and business models. A key to this transformation is ensuring that the growth in the number and types of these vehicles can be accommodated in high-volume coexistence with traditional air transportation. This document lays out a vision to achieve this growth with a focus on safety, scalability, sustainability, and cost effectiveness.

ATM embraces the information revolution

The emergent missions and operations each exhibit different characteristics that challenge the current regulatory structure and operational procedures. Over the next few years, Unmanned Aircraft Systems (UAS) will expand airspace access for remotely piloted small UAS (sUAS) that remain within line of sight to those that operate beyond visual line-of-sight (BVLOS), in swarms, and even on-airport. BVLOS operations together with small package delivery (SPD) operations will shape future UAS Traffic Management (UTM) capabilities and services. The UTM role in managing low-density airspace below 400 feet enables an increasing scale of operations with multiple launches, landings, and crossings to be coordinated. These multiple variations in characteristics give rise to the need for a common information approach to all operations to ensure that they can all meet their desired goals. Innovative new technologies provide the information-based opportunity to develop new, shared traffic management services. While traditional Air Traffic Control (ATC) services

This vision is for a safe, scalable, cost-effective NAS

will still exist, the manner in which ATC and traditional ATM services are provided will rapidly evolve as the current system of sharing of information (at specific times based on voice- and paper-based paradigms) gives way to a continuous sharing and decision environment.

At the same time, the current ATM system has been successful at delivering enhanced performance but has reached a point of dwindling incremental benefits achieved from additional enhanced capabilities. While advances in airframes, avionics, and propulsion continue to drive unprecedented air transport vehicle efficiency and safety, growth in these operations is projected to follow the low rates of population growth. The mature system employs the types of advanced capabilities needed to deliver efficient flows between the commercial transport airports.

The potential influx of new vehicles surpasses the number of operations performed by traditional airspace users, creating an exciting new chapter for the aviation world. The new business models and vehicle characteristics include private spacecraft launches, aviation as sensing and telecommunications platforms, air carrier-size uncrewed cargo aircraft, and Urban Air Mobility (UAM) aircraft. Many of these vehicles will require an evolving set of flight rules that mix the self-reliance and responsibility of visual flight rules (VFR) with instrument flight rules' (IFR) reliance on electronic means of communication, surveillance, and monitoring of separation. Add to this an increased reliance on automation and artificial intelligence for flight control of the aircraft. By 2035, UAS operations apply new flight rules to co-exist in controlled airspace with manned aircraft. The system enables regularly scheduled UAS arrivals and departures at Class B, C, and D airports, and permits optionally piloted aircraft for large cargo operations. ATC services will be available to UAS operators filing IFR flight plans, and routine or scheduled operations occur as the equipment and automation on the UAS and in the ATC infrastructure can accommodate them. Passenger transport from vertiports in major metropolitan areas enable air taxi services by remote pilots.

We are at a point where new vehicles and modes of operation, including autonomous systems, have begun to join the aviation world and are expected to grow to unprecedented numbers. Enabling this growth requires reaching beyond traditional ATM to adopt inventive new concepts by applying modern, innovative technologies. In turn, these concepts and technologies bring enhancements to continuing traditional ATM roles. Computer assistance and modern high-speed communication between aircraft and the ground will make aviation much simpler for all aviation professionals. This simplification of human duties will allow for new aviation concepts we cannot even imagine today.

MOTIVATION AND OPPORTUNITIES

Changes in Aviation

The emergence of new airborne vehicles, performing new missions and operating in new ways to execute these missions in the airspace, offers an opportunity for changes to the National Airspace System (NAS) that not only accommodate them, but also offer alternative flight rules for future traffic management concepts. These new types of NAS users and their anticipated high number of operations provide the chance to enhance conventional ATM methods for sharing NAS resources. Space commerce and national security missions, uncrewed aircraft, fully autonomous vehicles, lighter-than-air aircraft (balloons), and constellations of aircraft each exhibit many different operational characteristics. While their need for safe operation and integration within the current ATM system can be met, accommodation within traditional ATM is not scalable to the expected growth in these operations. Achieving scalable accommodation requires a shift in decision making (away from individual-flight-based ATC) for these new operations. New traffic management services and flight rules will be developed that can coexist with traditional ATM services and eventually migrate into traditional ATM. Innovative new technologies provide necessary information and the means to analyze it to recognize the present and future state of the system. Armed with such knowledge, all participants can better manage and optimize their operation. Absent stove-piped information, decision making can shift to the most appropriate stakeholder.

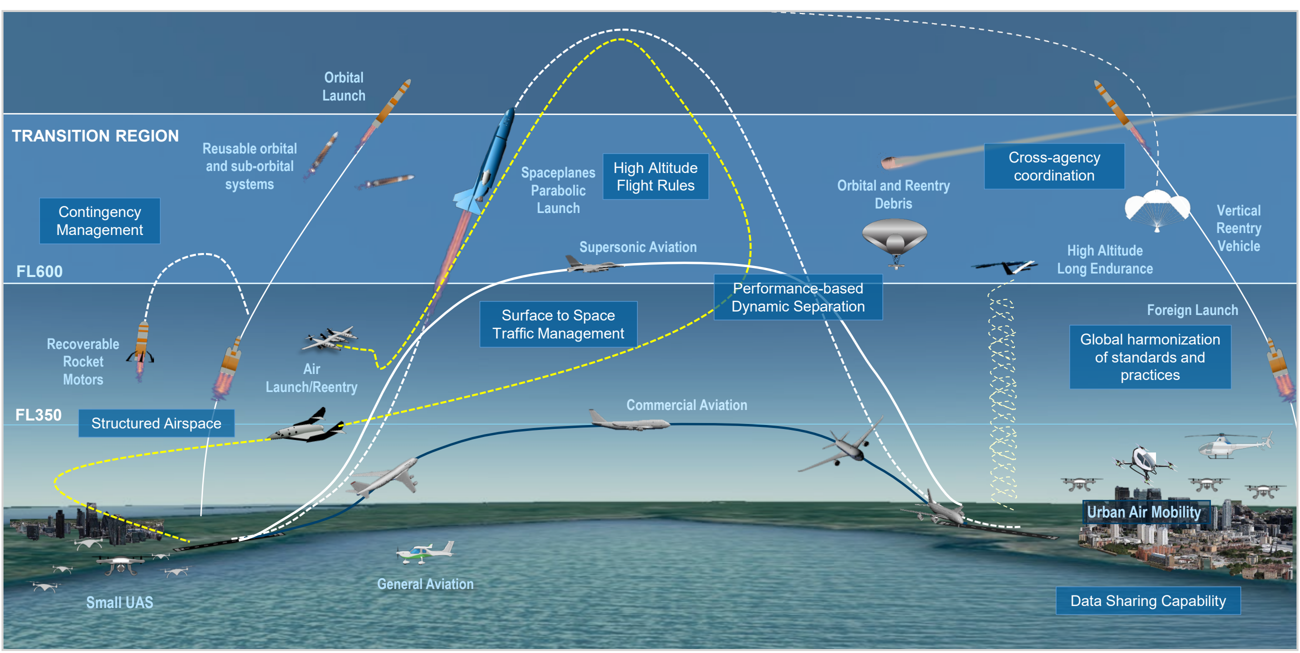
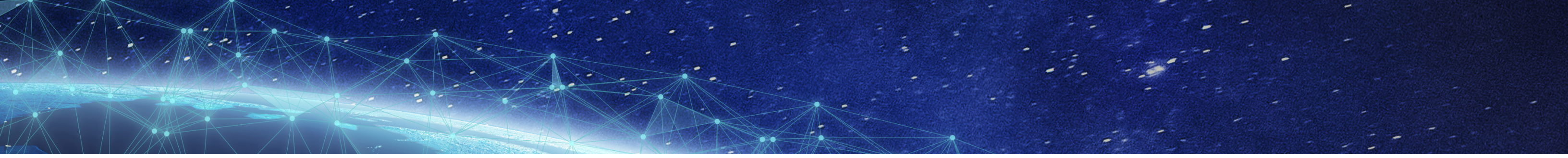


Figure 1. Diversity of Vehicles, Missions, and Business Models Drives the 2035 Vision



Technological Opportunity

New technologies lead to the introduction of these new vehicles and to a fully shared information environment that makes it possible to overcome the complex challenges these new vehicle operations would otherwise introduce. At the highest level, full connectivity and smart/learning systems enable the 2035 NAS to function. Other technologies provide necessary infrastructure, security, and analytics for ubiquitous information sharing and safety assurance, while propulsion system advancements enable new vehicle types to be aeronautically and economically viable.

Full connectivity comes from infrastructure supporting NAS operations that enables all systems to share data. Advances in cellular technology and the Internet of Things (IoT) provide ubiquitous system-to-system communication and enable improved situational awareness of vehicles, subsystems, and ATM stakeholders. Autonomous systems rely on this situational awareness to safely operate in the airspace.

Information systems operate with a level of information assurance well beyond current levels. Information attributes are tracked and shared in real time, enabling a performance-based system. End-to-end information integrity is assured across a diverse communications infrastructure without reliance on a trusted environment. Cybersecurity implemented by all end systems and network diversity ensure reliability, continuity of operations, and maintain the advertised level of service. Cloud technologies enable dynamic configuration of information resources to meet the real-time demands of user and service provider applications.

Data from the operation is collected, shared, and stored for numerous purposes. In real time, systems can construct actionable recommendations from this data and leverage augmented reality to present the information, allowing for greater understanding and better outcomes. Data is collected to analyze and monitor actual system performance, to conduct virtual testing through digital twins that assess the rapid changes proposed, to tailor operational solutions, and in general to reduce risk in the operation of the vehicle. The systems themselves consume data to continually improve decision support through machine learning. By capturing cause and effect actions experienced in the environment, systems can optimize decision points in the future and improve performance and safety.

Each of these technologies is built using modern software-development environments and best practices. System development is fast, dynamic, and efficient in responding to changing needs and advancements.

Propulsion system advancements in the areas of batteries, solar power, electric motors, efficient jets, low-boom supersonic aircraft, and reusable orbital and sub-orbital systems have been achieved and provide the drive for user business applications.

Business and Social Opportunities

The emergence of new entities (e.g., third party, community, or commercial) providing traffic management services to new entrants offers an opportunity to leverage services and the associated infrastructure for ATM applications. The entrants take aviation away from the paper and voice paradigm that is currently a major component of ATC. The new entrants cannot be supported by traditional means and will force aviation into a continuous engagement through information exchanges. Message protocols derived from verbal communication, for interpretation on the aircraft, will not support these operations. All interpretation will be made by in-ground automation and sent as aircraft-specific flight parameters.

New entrants will lead the way to new ways of doing ATM, made possible through a combination of technological advancements coupled with the social acceptance of changes implied by the technology. Examples include the social acceptance of pilotless aircraft for a broader set of missions, the expansion of UAM, and the increased frequency of sUAS flights over densely populated areas.

Leveraging Opportunities Towards System Performance

New entrants will drive the rapid adoption of advancements, providing an opportunity to leverage them as the NAS moves towards becoming performance based. Specifically:

- **Rules of the Air:** Regulatory structures and rules create the environment for diverse operations and distributed operational services provided by suppliers beyond traditional ATC.
- **Participation:** All vehicles and service suppliers are connected essentially all the time.

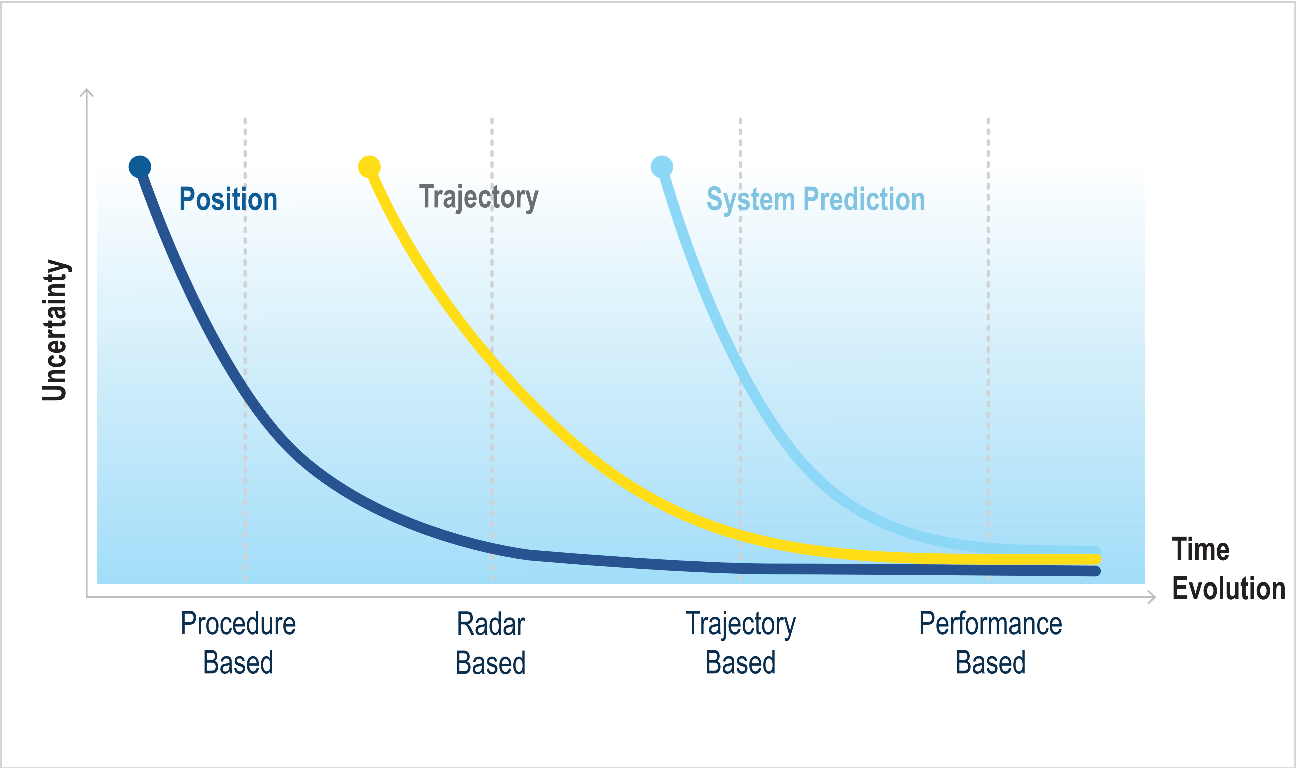


Figure 2. Evolution of the NAS

- **Big Data:** A continuous input of observations across multiple sources provides an accurate "now-cast" of the system as input to improve future predictions of system state.
- **Trajectory:** The Next Generation Air Transportation System (NextGen) has moved ATC beyond the radar state to improved single-flight trajectories, which collectively allow decisions based on the expected system future as a shared view. Moving to a performance-based paradigm represents a step beyond traditional ATC to an environment in which most operators do not engage directly with ATC and the trajectory/intent is used to cooperatively separate flight vehicles.
- **Conflict Management:** Information exchange, including decisions, allows conflict management to migrate away from a tactical voice-based source of uncertainty to strategic plans.
- **State of Uncertainty:** Improved uncertainty and knowledge of uncertainty allow for decisions to be made at the right time.
- **Market Balancing:** Shared knowledge of system state allows decisions to be made closer to where the decision matters (i.e., "moved to the edge") and made by the stakeholders with the best knowledge of impact.

TRADITIONAL AIR TRAFFIC MANAGEMENT—REACHING MATURITY

The Federal Aviation Administration's (FAA's) investments in NextGen deliver benefits to the NAS and operators in the following areas:

- Extending Performance-Based Navigation (PBN)
- Surveillance improvements (e.g., Automatic Dependent Surveillance-Broadcast [ADS-B])
- Data communications services
- Automation systems (e.g., Terminal Flight Data Manager [TFDM], Time-Based Flow Management [TBFM])
- Flight data management and information sharing (e.g., System Wide Information Management [SWIM])
- Transparent, sustainable, agile, and resilient NAS

These investments, starting from a basis in the early 2000s, focus on traditional ATM services and operations, delivering benefits in efficiency and contributing, within the ATC umbrella, to the safest means of transport available. The culmination in full Trajectory-Based Operations (TBO) provides for efficient and predictable operations, while maintaining operational flexibility. By 2025, these improvements across inter-related areas provide the foundation for this 2035 vision:

- Information exchange
- Ground-based automation
- Aircraft systems

Together these changes are responsible for a mature ATM that delivers benefits in efficiency, predictability, capacity, access, flexibility, and environment.

Safety and security continue to improve under NextGen. A safety continuum aligns expectations for safety with the attributes of different operations, vehicles, and airspace conditions. The FAA certification process relies on multiple layers of cross-checks beginning with the compliance philosophy and the strength of system developers' compliance assurance systems. Developmental assurance provides components to support safe outcomes in the operations for which they are designed. Operators, UTM service providers, and system integrators assure the components of the systems and aircraft are integrated and operated as designed through their Safety Management Systems (SMS). Evaluations of safety risks, using available data, inform operators and inspectors about areas of concern to reduce the likelihood of future incidents and accidents. Remotely piloted vehicles are operated within the ATM system and operation, and are reliant on ATC for separation.

While some new entrants wish to be included in and can be accommodated within these traditional ATM services, the approach has reached maturity. UAS and space operations are accommodated with consideration for safety and efficiency. Small UAS operations within visual line of sight of the pilot are permitted in this timeframe. UAS traffic predominantly remains segregated from manned flights. Airspace access rules require UAS operators to obtain an

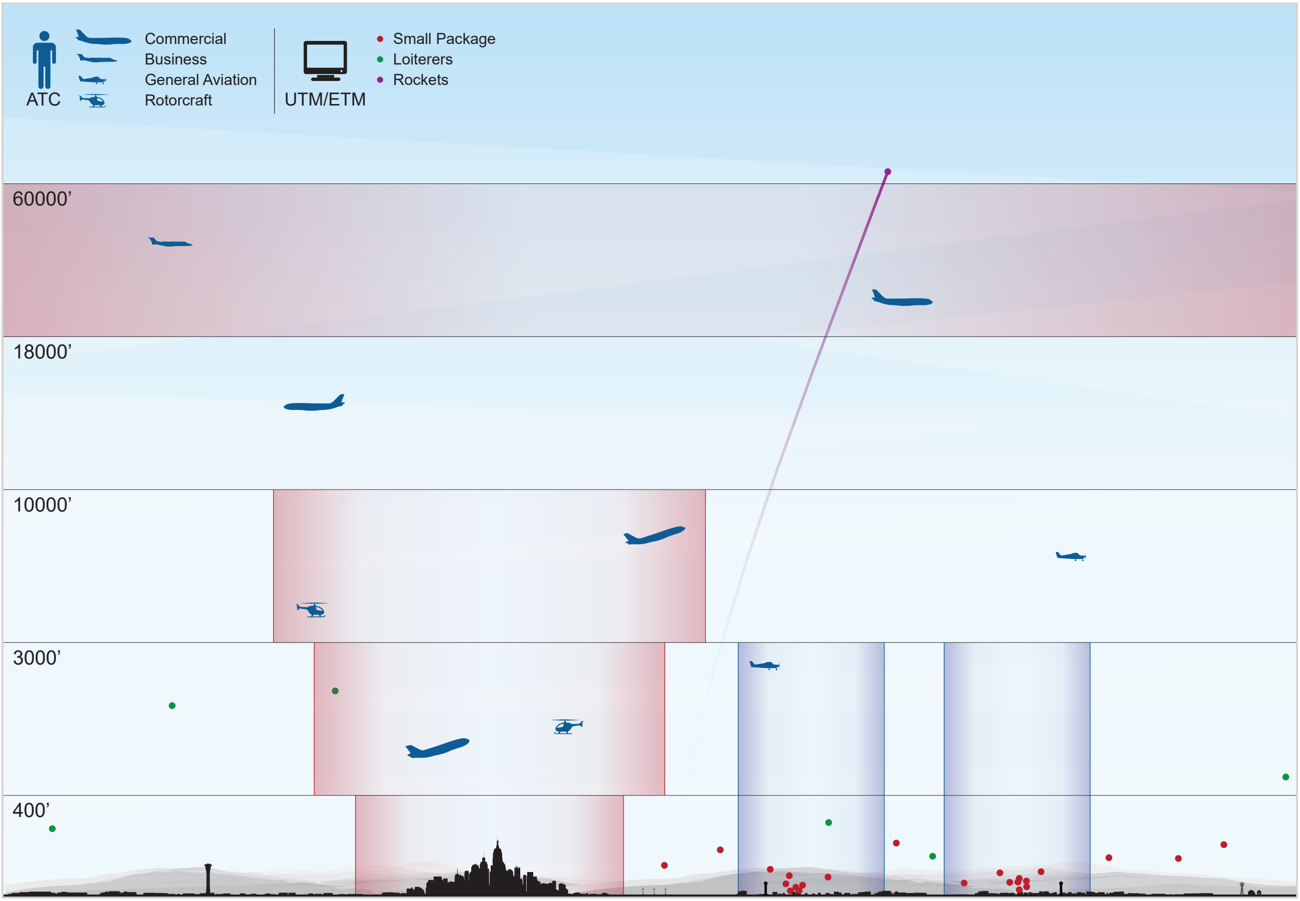


Figure 3. The NextGen Operational View

airspace authorization prior to operating BVLOS in Class B, C, and D airspace. Innovative methods that leverage new advances will be needed to scale to the projected large numbers of new entrants. As these new methods mature, systems and technologies can be incorporated back into traditional ATM.

NextGen technologies, especially information exchange, provide a foundation to incorporate UAS and an increasing number of space launches without needing to fully integrate them into conventional operations. New automation applications are enabling traffic managers, controllers, and operators to respond to off-nominal events in near real time. Improvements in management of special activity airspace protect aircraft from entering airspace where space launches or reentry would potentially pose a hazard. Early instances of UTM support developmental small package delivery operations. Increased access to better information and forecasting helps with both strategic planning and collaboration. Building on the isolated UAS operations depicted in Figure 3, the system is poised to integrate and adapt with an evolution of capabilities provided by operators and third parties.

Next Generation Air Transportation System Information Foundation

NextGen has provided NAS users with access to improved information through SWIM, a network-enabled capability for secure and real-time information dissemination. Globally standardized information exchange models are used to improve interoperability between FAA internal information exchange and international aviation operators as well as other Air Navigation Service Providers by harmonizing the information, independent of implementing technologies.

Through SWIM, a common operational "now-cast" of the NAS emerges through shared weather, flight, flow, aeronautical, and surveillance information. Automation systems make use of such information, together with data from Controller Pilot Data Link Communications (CPDLC) in flight-deck and ground-based automation systems. This includes the development of shared trajectories, central to full TBO implementation.

SWIM provides an essential foundation upon which a ubiquitous, fully integrated information regime can be developed. This environment permits bolder innovation through the pervasive sharing and use of that information for high-performance decision making by the most appropriate stakeholders.

Next Generation Air Transportation System Ground-Based Automation

Increased standardized information sharing through SWIM enables the integration of ground automation and improves collaboration and the quality of decision aids. NextGen automation both uses and provides improved and standardized information (e.g., weather, flight, flow, aeronautical) through SWIM. Aircraft operators are empowered to use this information to develop better plans considering flight-specific constraints provided by automation.

Full TBO provides automation capabilities that help develop, exchange, and manage flight trajectories among air and ground systems. Flight operators collaborate with traffic management to obtain a well-defined trajectory. The trajectory provides the agreed upon path of flights and the basis of negotiation for a new flight path considering both constraints and flight-operator preferences. The trajectory allows automation systems to be on the same page regarding the plan and the effect of decisions on each flight in the NAS. With the trajectory as a common expression of flight intent and the incorporation of that trajectory in multiple automation systems, NextGen provides an essential building block for the integration of new operations in 2035.

Aircraft Systems in a Next Generation Air Transportation System Environment

A NextGen environment supports mixed operations for aircraft of the past as well as new aircraft, with varying levels of equipage. This is supported by providing ATC services in managed airspace for all NAS users.

NextGen investments in ground automation and procedures have leveraged aircraft technologies and avionics, improving safety, efficiency, and predictability. Flight-deck electronic capabilities, displays, and electronic data communication are used to efficiently manage the flow spacing and enable flight operators to respond to ATC initiatives (e.g., rerouting) easily.

The connected aircraft provides a necessary starting point for the ubiquitous information sharing with the flight deck. Electronic Flight Bags leverage connectivity to deliver airborne SWIM access and enable flight deck decision-making participation (e.g., flow management and trajectory planning). CPDLC provides the ability to deliver electronic clearances to the flight deck reflecting the planned trajectory. Aircraft-derived information is incorporated through ADS-B surveillance and may include the synchronization of trajectory parameters obtained via the connected aircraft.

Most operations in this timeframe are performed using PBN, providing safer and more precise navigation delivering the trajectory. Arrival and departure procedures are area navigation (RNAV) or required navigation performance (RNP). RNAV and RNP approach procedures are preferred. Point-to-point navigation can be utilized to provide flexibility for the operator unless structure is necessary (e.g., PBN Air Traffic Service routes or Q [High] and T [Low] altitude routes). These are provided more frequently, allowing for the issuance of convenient clearances. As an alternative navigation source, Distance Measuring Equipment (DME) improves PBN resilience in the en route environment during Global Navigation Satellite System (GNSS) interference events, both localized and space-based. In the time domain, precision for flow synchronization is obtained by leveraging improved time scheduling.

NextGen delivers the ability to collaboratively plan, monitor, control, and deliver a precise trajectory by leveraging flight-deck capabilities. These provide an indispensable starting point for the integration of new operations using the trajectory as a key element of the common information approach.

VISION FOR THE FUTURE OF AIR TRAFFIC MANAGEMENT

Principles

The 2035 NAS is built around a combination of existing and modernized principles[1]. Fundamental principles for achieving the 2035 NAS vision include the following:

- Maintain and improve safety, security, and resiliency
- Enable negotiation among affected communities to establish:
  - Strategic planning through rules for tactical operation
  - Extent of user freedom to pursue their business and mission objectives
  - Appropriate access to resources enabling their mission
- Distribute decision making to enable stakeholders to best meet their objectives
- Incorporate performance-based standards throughout the enterprise
- Leverage public/private partnerships and manage services to achieve economic viability and provide resiliency
- Build in scalability to rapidly expand capabilities to meet operational challenges
- Ensure adaptability and agility to keep pace with unanticipated changes

Overview

The vision for the future NAS addresses the key drivers of change in a manner that respects the principles of aviation while taking advantage of opportunities brought on by innovation and societal change. The vision is described through attributes[2] of the fundamental changes that occur in three key areas: **operations**, **supporting infrastructure**, and **safety assurance**.

1. **Operations** in the 2035 NAS are characterized by collaboration among and within diverse traffic management services enabling the increased variety and number of new vehicles, missions, and operations. This collaboration is made possible through the fully integrated information regime with common representation and full sharing of information. This can be leveraged to improve the accuracy of the now-cast of the NAS, allowing confident assessments of the future system state. Increased agility in systems and services accommodates changing needs and constraints as system needs evolve in unanticipated ways.
2. **Infrastructure** increasingly leverages commercial assets, services, and new technologies in support of operations across diverse traffic management services. The combined public/private infrastructure delivers ubiquitous coverage of traffic management services across the expanded operations space, resilience in the face of a changing environment, and an evolving capability to respond to expanding user needs. Where necessary, public/private partnerships are established to help ensure any unique government

1. Principle: Fundamental rule or proposition that provides the foundation for or guides the development and operation of the 2035 NAS.
2. Attribute: A quality or feature regarded as a characteristic or inherent part of something.

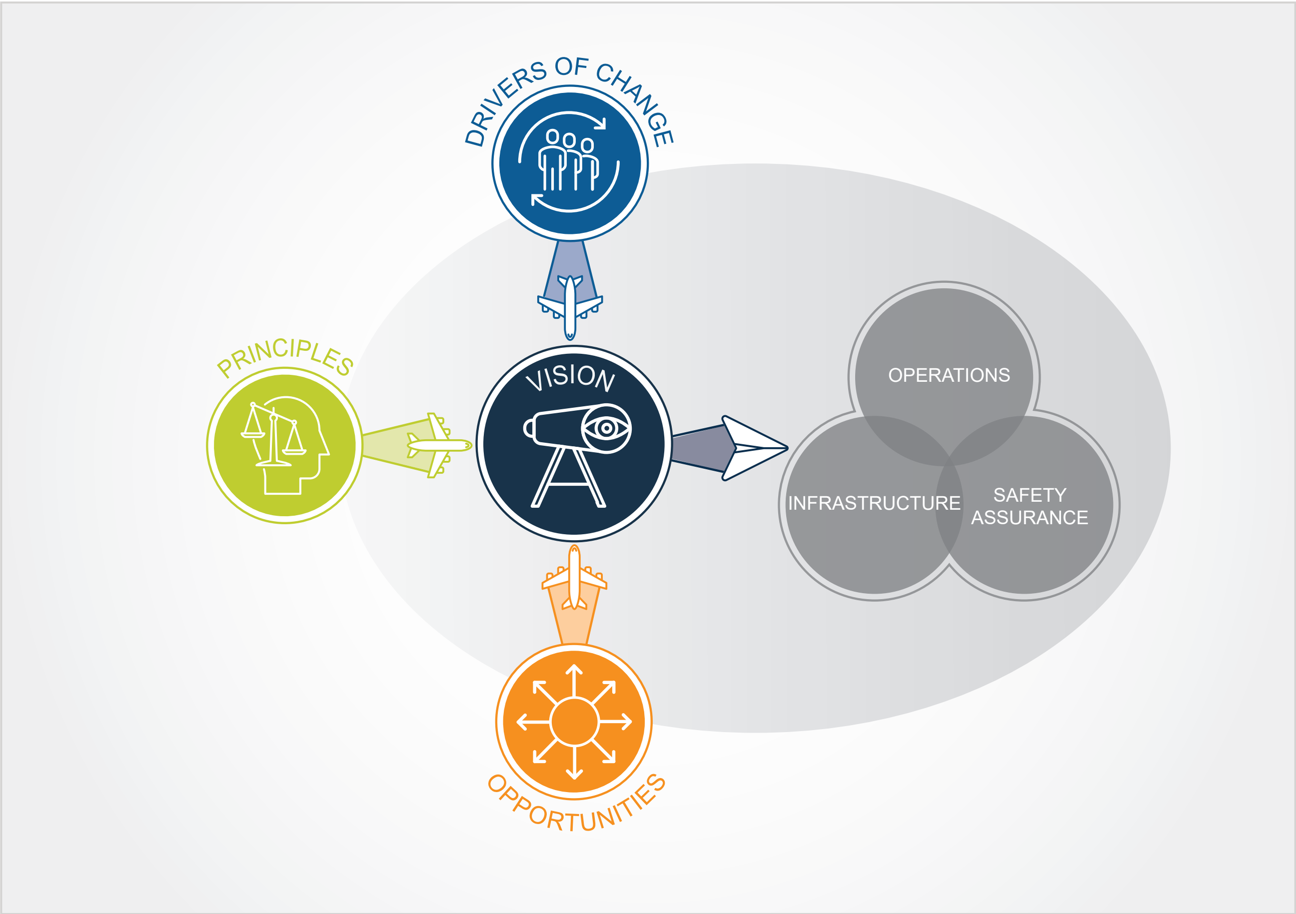


Figure 4. Vision Framework

requirements can be met through commercial services and technologies.

3. **Safety Assurance** for traffic management is characterized by the safety continuum that establishes tailored operations and flight rules to achieve acceptable safety based on operational characteristics. With the ubiquitous information, the NAS assures real-time safety through continuous monitoring, modeling, and verification to detect anomalies and correct for real-time spikes in risk. The compliance philosophy including the use of the Safety Management System assures each organization accounts for interoperability in a system-of-systems of public and private services, air and ground systems, and automated and manual control functions that support the diversity of operations.

Operations

A significant increase in the variety of airborne vehicles, missions, and operations wishing to operate from surface to space is beginning to materialize. Projections indicate that these diverse new entrants will represent substantial economic value. For the United States economy to realize the projected economic value, the NAS must affordably accommodate this variety while providing improved performance to conventional operations. Beyond economic value, these new airborne vehicles and technologies are being applied to fulfill changing national security missions. Successful execution relies on successful accommodation.

Accommodation of new entrants does not imply full participation within the entire ATM system. Rather, the simultaneous co-existence and interoperability of diverse collaborating traffic management services with conventional Air Traffic Services (ATS) is expected to cost-effectively enable these future operations. Achieving such interoperability drives the need for common interactions that are made possible with a fully integrated information regime. Further, the volume of information provided in such an environment will require agile systems and services, affordable and on pace with economic drivers, to support decision making for ATM services.

DIVERSE COLLABORATING TRAFFIC MANAGEMENT SERVICES

New traffic management services address the operation of select new entrants within dynamically segregated airspace, which is not an operationally sterile airspace[3]. Examples include services for UTM and E Above A Traffic Management for high-altitude operations that provide for operations in certain volumes without the need to engage in traditional ATC. Within all Extensible Traffic Management (xTM) services, decisions are distributed, allowing stakeholders to best manage their operations. New xTM services manage operations for entrants with differences in performance expectations compared to classical operations

New traffic management services address the operation of select new entrants.

with ATM services. Through the tailoring of requirements in line with desired performance expectations of the served operations, xTM services cost less than ATC services. Scalability is also provided through these highly automated and third-party managed xTM services that can technically and financially deliver service growth in line with demand.

Future ATC services continue to support the current base of airspace users and will interoperate with these diverse traffic management systems without requiring pre-defined airspace allocation to each xTM system. Rules for access to shared resources (e.g., airspace and aerodromes) are collaboratively negotiated across the diverse set of participants. Rules for interactions between the xTM services are defined in a collaborative fashion and supported and enforced through information, systems, services, and procedures. Operations, in accordance with their needs, are not limited to the use of one xTM system for the entire duration of flight (e.g., a flight may operate using UTM services, switch to ATC services, and back to UTM). All xTM services provide required levels of performance for participating operations. These performance requirements depend on operational circumstances and may be met through the combined use of multiple technologies and public/private infrastructure.

Operations under xTMs organize to allow ATC services to deliver tactical functions without having to consider other individual operations using other xTM services. This independence allows interoperation without imposing a burden on ATC operations, enabling affordable scalability of xTM operations. While tactical functions between ATC services and other xTM services are independent, coordination

3. Airspace within which select types of operations are permitted while others are precluded.

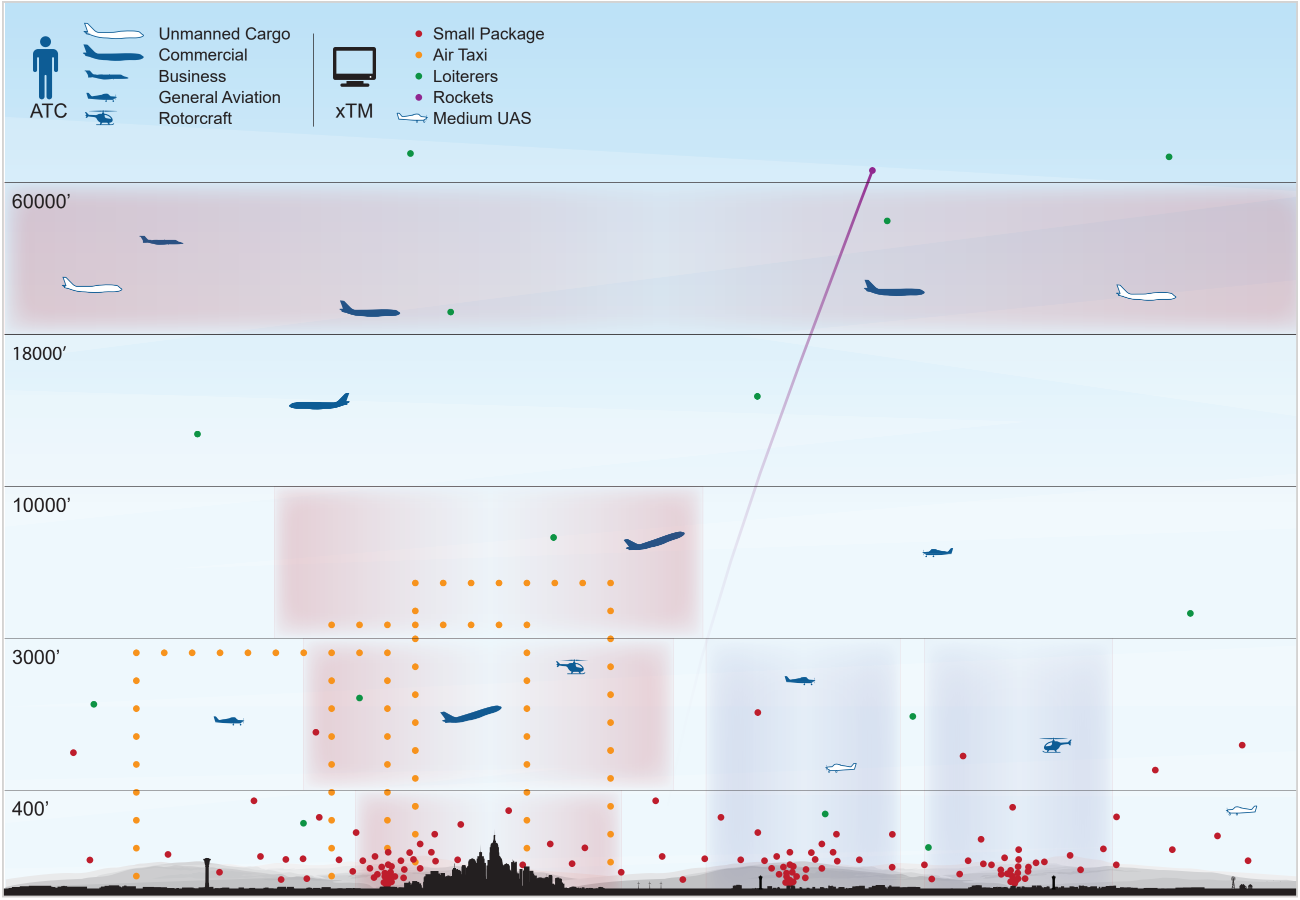


Figure 5. Diverse Collaborating Traffic Management Services - 2035 Joint Use Airspace with Mature UAS Ops

across planning functions, leveraging the fully integrated information regime, ensures well-organized operations across all xTM services.

The resulting operation has softer boundaries for operations and the use of joint use airspace with large cargo UAS operating in Class A airspace and UAS applications, including passenger transport in controlled airspace, as depicted in Figure 5.

FULLY INTEGRATED INFORMATION REGIME

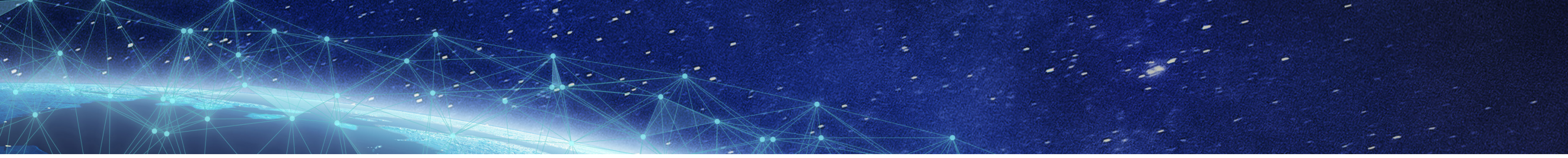
Collaboration among diverse traffic management services and the integration of their operations is made possible through a fully integrated information regime. At a minimum, this involves acquiring and sharing state data for all vehicles and trajectory data for potentially interacting vehicles. The full integration of information allows decision making to be shifted to the most appropriate participants, not restricted by lack of access to information needed to fulfill their missions. Interacting distributed decisions can be made in real time without requiring guesswork or

hedging. This real-time, integrated information regime allows migration towards a dynamic Aeronautical Information and Services cycle, providing changes when needed for all operations. Consumers of shared information are aware of the quality of the information being provided, including uncertainty. Information services are provided with differing performance levels, appropriate to the information and services. Performance attributes of individual operations are also known to the relevant xTM, enabling the determination and application of eligibility rules.

The exchange of such information informs a continuous planning process during which operations using the ATC and xTM services are organized and dynamically segregated subject to established rules of access and interaction considering risk tolerances. ATC services deliver full TBO. As a result, a trajectory-based continuous planning process with full information exchange is already in place for flights using ATC services. The trajectory-based ATC planning process is extended to incorporate airspace organization and flow planning required to support xTM operations in accordance with established rules.

The exchange of information with full integration enables a collaborative distribution of decisions without requiring inference of coupled decisions made by other parties; the impact of interacting decisions is known as they are being made. Distribution of decisions occurs organizationally, spatially, and temporally. The structure and allocation of decision making is dynamically selected for improving performance outcomes, based upon operational circumstances, supported by ongoing data analytics, and constrained by rules of engagement.

Under the fully integrated information regime, decision making can be distributed optimally, not restricted by lack of access to information.



The information management approach allows multiple parties conducting advanced data analytics to obtain and maintain voluminous amounts of historical data. These are applied toward continually learning and evolving systems and services driving performance improvements across all systems and individual operations.

AGILE SYSTEMS AND SERVICES

Gone are the monolithic automation systems of the past. Automation is a system-of-systems composed of learning, adaptable, and lightweight interacting systems delivering microservices through a combination of private and public entities. In such an architecture, safety-critical services are provided in a small stable core while all other services are provided through a combined public/private microservices architecture that evolves on pace with economic needs.

Gone are the monolithic automation systems of the past.

Advances in machine learning, artificial intelligence, and analytics, coupled with abundant observed data, enable systems to continually refine predictive models supporting decision making. With more and more data, these models become increasingly tailored to the specific operation and circumstance being addressed. Decision making can apply interacting predictive models to rapidly evaluate a number of choices against performance objectives given the current state and the forecast of operational circumstances. With increased volumes of information, coupled with advances in data analytics, the "now-cast" of the NAS, together with more accurate future-state predictions, can be incorporated into decision making. Quality of information, including uncertainty, is incorporated into predictive models, allowing performance outcomes to consider increased robustness and predictability.

The continuous planning process among xTM and ATC services occurs through system-to-system interactions made possible through pre-defined rules and the fully integrated information regime. In such an environment, humans guide the objectives, while automation collaborates to reach solutions best meeting the objectives.

Infrastructure

UBIQUITOUS

Advances in communications technology will offer the aviation community a broader range of alternatives for the next generation of aviation information exchange. The major telecommunications carriers will have completed their transition to the next-generation network, which will fully converge on the use of internet protocol (IP) for supporting services at all performance levels. Another major aspect of the telecommunications revolution will be the move away from using wired access infrastructure for all but the largest customers, to high-performance terrestrial wireless services.

Terrestrial wireless services will have evolved to the Nth generation[4]. Most access connections will be implemented with the Nth generation of terrestrial wireless services. These wireless services will offer the bandwidth, reliability, and quality of service that today is delivered by wired access. There will be full support for the IoT with service

No gaps: Infrastructure delivers needed services everywhere, always, securely.

4. Nth generation represents whatever level wireless communications have evolved to in the subject timeframe.

coverage across the Continental United States (CONUS). Wireless services offering high bandwidth, low latency, and widespread coverage will make it feasible to use these services for fixed and mobile aviation applications. Nth generation terrestrial wireless will be capable of coverage for typical manned and unmanned aircraft altitudes. Quality of Service appropriate for the required performance level will enable cost-effective use of wireless for aviation.

Adding to the communications considerations for aviation will be the deployment of vast constellations of low-Earth orbit (LEO) satellites of various sizes and payloads. Communications services offered by LEO providers will rival terrestrial wireless and provide an entirely separate communications medium for aviation to consider. While potentially less capable in terms of bandwidth and low latency, these technologies will nevertheless provide an acceptably diverse medium to augment terrestrial wireless coverage in CONUS while providing primary service to oceanic and other relevant domains.

Commercial services, infrastructure, and technologies are leveraged to the maximum extent practical. With a diversity of providers and infrastructure, this allows for the more ubiquitous delivery of services and infrastructure where available for both aviation and non-aviation applications.

Fully defined information assurance protocols and credential management for aviation will allow secure information transfer over international and domestic security boundaries.

The increasing demands of air traffic volume, diversity, and complexity make ATM automation services ever more critical. The need for automation services will be met by combinations of technology advancements such as cloud-based services, edge intelligence, and certified remote operations enabling cost-effective ATM automation capabilities to be provided wherever needed. This evolved automation architecture is inherently scalable, supporting the expansion of UTM operations, space and near-space operations, and non-traditional passenger transport services. Any data supporting operations and analysis is available through access-managed common data services. When not managed by third-party service providers, better alignment with information technology marketplace trends ensures that FAA-managed physical infrastructure can be introduced, expanded, or changed as needed.

RESILIENT

Native IP applications will support full connectivity between and within ATC and xTM systems at all locations. This connectivity will enable reconfiguration, as appropriate, in response to operational- or infrastructure-related contingencies such as loss of a major facility. In the case of the latter, adjacent or backup facilities can be readily connected to remote assets or service providers. That will allow the seamless handover of airspace control between facilities. Less catastrophic outages will result in self-healing behavior but with full information on service status and operations always available in real time for the situational awareness of operations personnel. Self-healing behavior is made possible through the virtual operational redundancy provided by leveraging pervasive commercial infrastructure. Traditional roadblocks to reconfigurability, such as dedicated hub and spoke voice communications architecture, will have been replaced by any-to-any connectivity with all voice communications assets and providers. The extent of reconfiguration capabilities can either be limited to pre-planned scenarios or extended to "on-the-fly" command decisions based on operational conditions and agency policy.

Leveraging multi-purpose commercial infrastructure provides a more resilient, cost-effective NAS.

Use of software defined networking (SDN), edge-security, adaptive security controls, and centralized monitoring and control of assets will help to ensure that reconfiguration will be safe from cyber threats and misconfiguration. SDN and network virtualization will allow full network management and operations capabilities to be implemented on mobile devices, eliminating the need for costly, large-scale dedicated control and centers. Full information on communications services and infrastructure status will be immediately available to authorized personnel. This infrastructure is delivered through diverse infrastructure and service providers, allowing for increased resiliency across both communications, navigation, and surveillance (CNS) and automation systems.

High-accuracy Positioning, Navigation, and Timing (PNT) is provided through GNSS. A second form of PNT allows for normal operations to continue when GNSS is unavailable. A nationwide backup timing infrastructure allows for both ground and airborne systems to remain fully synchronized. The current GNSS systems, such as the Global Positioning System, provide performance that far exceeds what is needed for an alternative PNT system. It is not realistic to expect any alternative to offer the gold-standard performance that is currently afforded by GNSS. The exact performance standards required of any alternative will depend on expectations of its continued operations. Policies and procedures evolve to allow for these alternative PNT systems to be fully embraced by all parties. Each CNS component has robust backup systems that allow for nearly seamless operation during a GNSS outage event and are robust against cybersecurity attacks.

The technologies that make automation services and network infrastructure more capable can also make those services more resilient and more efficient to operate. For example, reconfigurable infrastructure enables network topology and automation services to adapt to status changes in real time. Through SDN, data traffic is routed to respond to dynamic changes in network status, demand, or security status. Cloud-related technologies allow automation services to scale dynamically in response to added workload or component failure. Machine intelligence enables continuous monitoring of status and degrees of freedom, together with projections of response, to respond to failures or demand spikes with or without human intervention. Similarly, machine-learning approaches enable effective prediction of potential failures and preventive maintenance application. Service overlaps enable required resilience and cost-effective application of operations and maintenance policies. In many circumstances, a specific outage does not diminish operational capability because of available redundancies, allowing maintenance to be scheduled for greater efficiency.

EVOLVING

Commercial services, infrastructure, and technologies are leveraged in key industries. Public/private partnerships make contracting possible for managed services in enterprise capabilities such as communications, aeronautical information, and weather services. Beyond managed services, services and infrastructure meeting necessary requirements may be fully leveraged for aviation applications. The use of shared infrastructure and services allows both to evolve on pace with technology and the commercial markets in accordance with the needs of the most demanding users or providers.

Advances in secure cloud-computing capabilities and continued build-out of cloud services infrastructure will offer the potential to implement automation and decision-support processes in the cloud. Ubiquitous cloud capabilities, coupled with the use of shared services communications infrastructure, will support high-performance and cost-efficient cloud services that enable the agile systems and services previously described.

Shared infrastructure and services evolve on pace with technology and the needs of the most demanding users or providers.

Initiatives such as IoT and autonomous vehicle infrastructure implementation will fuel research into advanced concepts like fog and edge computing. Continued progress in reducing the size and increasing the density/complexity of electronic hardware will support these concepts. These technology developments will enable a shift to a distributed decision-making paradigm, with many decisions being made at the edge using the capabilities afforded by the new technologies, rather than the centrally based approach

seen in the system today. Edge-based decision making will allow for more context-specific decisions to be made in less time than a central approach.

Technology developments enable the FAA to envision and pursue new automation architectures. A prominent element is the increasing integration of cloud services. Micro-segmentation and edge security in the network architecture will support logical partitioning of information flows that will allow cloud implementation of non-safety-critical applications to Federal Information Security Management Act high-level security (already available in Amazon Web Services [AWS] GovCloud U.S. Region, https://aws.amazon.com/govcloud-us/fedramp/). Cloud services and other shared-use infrastructure enable the FAA to better keep pace with technology developments. An application framework and standardized infrastructure services enable more discrete and competitive acquisition and development of applications and services that can be more readily integrated than today.

Safety Assurance in Extensible Traffic Management

The system relies on the same layers of safety assurance, with a greater emphasis on integration and interoperability to account for the increasingly distributed nature of control decisions. The ATM system regulator is accountable for the overall design assurance, establishing the expectations and architecture for how the layers of xTM provide separation and navigation services appropriate to every class of airspace. The design assurance addresses how ATC and the xTM service providers maintain interoperability. The SMS for each service provider and major operator details how they integrate, adapt, and manage their operations and role, enabling the collective xTM air operations to work as designed.

Safety-critical performance indicators are monitored to support airworthiness, detect operational emergencies, and evaluate information assurance. Operational safety analysis identifies trends or conditions in the system-of-systems for prognostic evaluations. These provide feedback, correct issues at system boundaries, and adapt the overall system to shifting risks or environments.

New entrants introduce additional dimensions to the traditional role of ATM. They employ user management and control information to:

- Understand and identify risk
- Enable interoperability across air vehicle operations with diverse performance and mission requirements

Beyond the enhancements for management of the integrated system there are three specific changes to safety assurance: tailored operations and flight rules, interoperability, and real-time safety risk management. These are described in subsequent sections.

TAILORED OPERATIONS AND FLIGHT RULES

In the 2035 NAS, a combination of ATC service providers and xTM providers deliver services tailored to operator needs across all types of operations. Flight rules deliver acceptable risk to each party in joint use airspace and employ segregated airspace only where that risk is unacceptable. Elements of xTM and ATM require system certification and assurance that the integrated operation accounts for differences in the safety performance expectations from all associated systems.

Services are tailored to meet the needs of operations in all airspace.

VFR continues to place the responsibility for see/detect and avoid (DAA) on the operator. While nearly everyone is connected, providing a continuous now-state expression of traffic, operations with aircraft that do not provide position information must be considered. VFR aircraft execute basic avoidance maneuvers when they detect traffic for which intent and position are not known. In the 2035 NAS, most of the airspace will require position reporting in operations, and non-reporting VFR may be relegated to designated airspace for legacy general aviation operations.

Collaboration between xTMs at a minimum involves sharing position data to enhance the ability to detect all traffic, including VFR. This information may inform DAA systems, much like traffic advisories inform VFR today. Services, including safety alerts, traffic advisories, and limited navigation assistance, can then be provided by xTM when requested by the flight. Further collaboration and services are essential to adjusting the flow in mixed airspace, such as in the vicinity of UAS or manned aircraft airports. These advanced traffic information services improve conflict management over that of VFR alone.

Cooperative separation includes sharing of intent/trajectory data, performance envelopes, and constraints to support newly defined tailored flight rules (TaFR). An extension to traditional IFR, this information would allow xTM providers to provide strategic separation services. With this information, pilots can perform tactical separation as a DAA procedure under TaFR. Optionally, this may include exchanging proposed resolutions or constraints. These concepts are like advanced collision avoidance systems, with knowledge of the flight procedure the other aircraft intends to execute, to reduce false alarms. The xTM service provides traffic advisories to allow aircraft operators to separate in accordance with TaFR. ATC continues to provide all traditional IFR separation services for manned and unmanned aircraft where operators need assurance that positive separation is provided between aircraft.

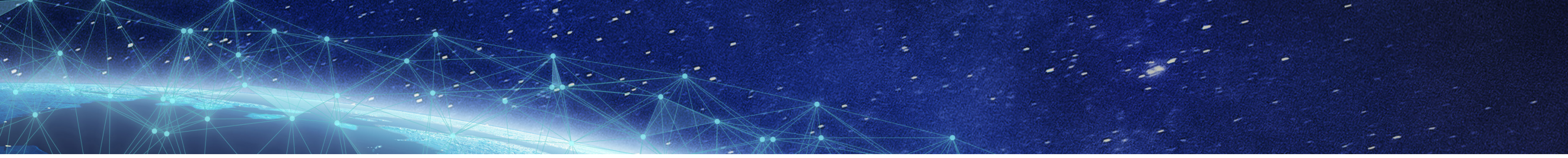
A variation of this is joint use airspace (e.g., E above A) where operations are sharing information at different levels, including those not sharing at all and operating via a "due regard" principle. Those with service providers have the benefit of strategic separation with all reporting traffic. However, tactical resolution is left for the flight operators following flight rules applicable to their capability, the separation timing, and performance envelopes. The flights operating "due regard" will detect all other traffic directly or through their service provider and follow TaFR procedures to remain separated. These advanced traffic information services provide operators the means to self-assure separation.

The airspace will be joint use where possible using interoperable flight rules (e.g., TaFR and IFR, TaFR and due regard, and TaFR with VFR services), and segregated where that is not possible through means such as a mesh of available routes and scheduling windows. The flight rules overlap with compatible approaches, allowing different air operators and service providers working in the same airspace to deliver safety appropriate to that class of airspace. Flights may transition between flight rule regimes and switch between xTM providers. A variety of xTM service providers, DAA, navigation, and flight control systems will be in use to execute according to the flight-rule regime. The system certification can then focus on key performance, ensuring compliance of flight systems with the relevant flight rules associated with separation assurance and other navigation services.

INTEROPERABILITY

The SMS for the service provider focuses on the interoperability with its operators and its suppliers, including how they manage the evolution or adaptation of their products and services. Each service provider and operation follows specific flight-rule regimes, which state how flights must respond to situations. With performance-based standards, how an operator complies with the rule may differ (e.g., use of DAA, strategic conflict resolution, etc.) from operator to operator or between xTM providers. However, the means must be interoperable, with the key being the information sharing and information assurance that will support the flight rules. The system-of-systems interoperability depends on those information assurance standards under specific assumptions and interactions of public and private services, air and ground systems, and automated and manual control functions that support the diversity of operations. Performance-based regulations and interoperability standards are stated for common components.

Diverse service providers interoperate safely.



Another level of interoperability is implied by the diversification of service delivery organizations. Each organization (operator, service provider, manufacturer) addresses interoperability within its SMS. These processes must consider the implications for safety assurance and interdependent system mitigations. Interoperability is defined either in operational specifications for interdependent practices/procedures, or reliance on the ATC or xTM services in a service-oriented architecture. New standards for developmental assurance help to detect incompatibility between interoperating systems early in the development and integration process. Such standards include software development and update practices, regression practices, and system configuration management. Agile updates across system-of-system applications will add compatibility checking, especially at the boundaries between systems. As an additional safety layer, the health monitoring and real-time safety systems will find interoperability issues that escape the other safety layers.

REAL-TIME SAFETY RISK MANAGEMENT

The NAS assures real-time safety through continuous monitoring, modeling, and verification to detect anomalies and alert for real-time changes in risk. Supported by models and live data, the risk in the system is affected continuously by airspace, service provider, individual flight, or high-concern hazards. Prognostic models will project potential unsafe conditions and alert service providers. With health monitoring and real-time risk modeling for undesirable flight conditions, more operators will have advanced indications of state changes that would indicate the need to deviate from the intent before a situation becomes an emergency. Such models should work for risks that arise from nominal behavior pushing outside the safe operating envelope.

Multiple systems and regimes will cooperate. Data is available from multiple sources onboard many aircraft, including surveillance of surrounding aircraft. This is based on a continuous joint process of verifying live data from multiple sources. Monitoring of any and all means of independent information is used to confirm data integrity in near real time.

> ***Continuous modeling, monitoring, and verification provide real-time safety risk assessment and alerting.***

The other major risk monitored in real time is the complexity arising from anomalous operations (e.g., emergencies, non-compliant aircraft). In these cases, models can no longer extrapolate trajectories or assume flights behave according to flight rules. Monitoring must detect such anomalies and model the new range of risk (based on the likelihood of different flight behaviors going forward), predicting where other aircraft might be at greatest risk. Similarly, constant change in components and the use of learning systems and outside service data as extensions of the system mean real-time conditions will arise that could not have been planned for or tested. The information assurance monitoring must detect these anomalous behaviors as well and assess if the cause is likely a system failure or an interoperability issue due to a recent change.

Post-operation modeling can reconstruct unsafe conditions or anomalies and support causal analysis. This type of continuous auditing and monitoring will inform corrective actions across the system-of-systems. As an additional layer of safety assurance, this continuous monitoring will highlight shifts in key performance areas that will allow an operational response to the current risk level. The results are fed back into the system-of-systems design assurance and standards for components and interoperability.

Example Operations

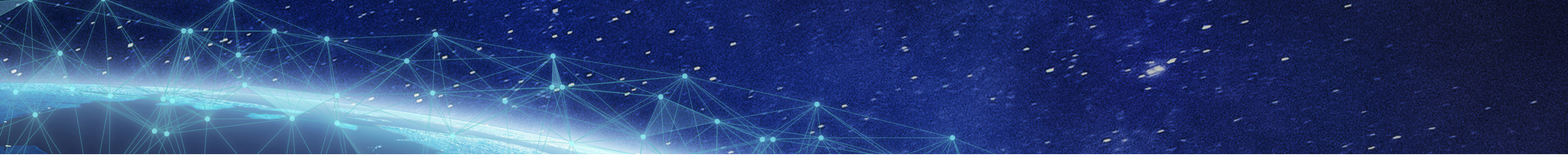
As new operations are being planned, a request for service is provided to the appropriate xTM, subject to known rules and constraints. Rules may include the need to submit such a request with enough lead time, depending on the nature of the requested operation (e.g., space launches require more lead time than small UAS missions). Traffic Flow Management personnel interact with automation systems to identify objectives. ATS and xTM automation systems may then dynamically interact with the collection of operational intent and requests to organize and structure plans to meet the desired objectives. At a flow level, these plans ensure xTM operations are sufficiently segregated from individual ATS operations to allow ATC to be unencumbered by the specific xTM operations.

The information-rich learning environment is also leveraged to deliver improvements in ATC automation for tactical flow and separation provision. Within ATC, decisions are supported by automation, but operations are largely managed by exception, as the integrated flow plan has tailored decisions to individual operations and mitigated the need for tactical actions with knowledge of uncertainty.

CONSTANT ADAPTATION OF THE SYSTEM

The NAS is characterized by continual adaptation of the system. New vertiports and aerodromes enter service frequently to support UAM and a variety of UAS operations. NAS adaptation tools rapidly assess the impact to traditional ATM airspace, incorporate noise impacts, and coordinate with other UTM operations. This is facilitated by a more agile adaptation for all the ATM systems, including coordination with UTM systems.

Each operator selects the set of services and systems to support their operation. The combination of air and ground systems, public (ATC) and private (xTM) services, capabilities, and flight rules creates a dynamically changing mixture of operations. The system will have to tailor expectations to this level of change.



LIKELY OFF-NOMINAL EVENTS

Nominal flight events are defined as trajectories, plans, and related assumptions for flights that hold true except for normal statistical variance due to known perturbations. These perturbations could include wind impact, weather avoidance, or other minor NAS variations.

Off-nominal events are characterized by a break in assumptions or plans, where the planned trajectory becomes void, such as rocket flight termination (self-destruction), mechanical failures, or unexpected entry into mixed-use airspace by unsuitable vehicles, occurring for any reason.

Off-nominal events impact ATC services by requiring the separation of vehicles that use ATC services for their operations from the off-nominal traffic operating under xTM. Examples include:

- UTM co-existing with ATC and a UTM vehicle or vehicles experiences an off-nominal event. (Co-existing UTMs are assumed to provide state and intent to ATC automation.)
- Space vehicles, balloons, or supersonic (>FL600) aircraft experience an off-nominal event and unexpectedly descend into airspace providing ATC services.
- Pilot operating using ATC services reports unexpected UTM in proximity—undetected by ATC or UTM systems.

OTHER MODES OF OPERATION

Classic VFR operations continue to be accommodated; however, VFR rules in 2035 may require equipage and connectivity to coexist in portions of the airspace. One pilot may operate many remotely piloted aircraft systems (RPAS) using ATC services. Large cargo RPAS require airports using ATC services for operations. When operating using ATC services, these types of UAS remain visible to ATC services and follow rules for ATC services. Special UAS flight paths may be required. Control of these UAS includes various degrees of autonomy, from fully autonomous with an interface to ATC separation services to remote pilot operation.

NEXT STEPS

A successful achievement of the vision results in the safe, cost-effective delivery of capacity and access to new vehicles and operations while simultaneously improving performance delivered through ATS. This future NAS embraces diversity in vehicles, operations, infrastructure, and service delivery. These diverse elements interoperate to provide safe, scalable access that ensures projected growth in new vehicles and operations can be attained. Safe, scalable access is provided cost-effectively in the face of an unanticipated future by:

- Enabling expeditious airworthiness approvals and interoperable traffic management services using a safety-assurance process
- Allowing for fit-for-purpose constraints on operations with tailored operations and rules
- Monitoring, modeling, and correction of real-time safety for dynamically adapting systems
- Leveraging multi-use infrastructure providing:
    - Cost-effective, ubiquitous coverage for greater access and predictability
    - Resilience to disruptions
    - Timely adoption of technologies cost-shared across infrastructure users
- Using an integrated information regime with integrated security and performance-based standards
- Ensuring collaboration among traffic management services to benefit the serviced operations
- Implementing agile services that accommodate changing operations

Attaining an outcome of collaborating traffic management across diverse participants requires a collaborative beginning. First, the projected diversity and its evolution must be understood through continuous communication of plans, projections, and initial concepts by all stakeholders. These provide input to the airspace regulator to ensure timely readiness of required safety assurance processes.

On its own, this process is not enough for convergence, since vehicles, operations, infrastructure, or service delivery could potentially develop along different courses. The evolution will proceed at industry's pace, directed by business requirements. Therefore, the role of the vision and its principles is to guide the emerging architecture, detect incompatibilities, and bring them to stakeholder attention for resolution. Stakeholders, including the existing ATM service provider, must work together to ensure concepts are compatible, access rules are negotiated, available infrastructure is leveraged, and information standards are developed, all in a timely manner. Working together, all stakeholders can evolve to the vision and usher in a future era of growth in aviation.

ACRONYM LIST

Acronym	Definition
ADS-B	Automatic Dependent Surveillance-Broadcast
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
AWS	Amazon Web Services
BVLOS	Beyond Visual Line of Sight
CNS	Communication, Navigation, and Surveillance
CONUS	Continental United States
CPDLC	Controller Pilot Data Link Communications
DAA	Detect and Avoid
FAA	Federal Aviation Administration
GNSS	Global Navigation Satellite System
IFR	Instrument Flight Rules
IoT	Internet of Things
IP	Internet Protocol
LEO	Low-Earth Orbit
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NGN	Next Generation Network
PBN	Performance Based Navigation
PNT	Positioning, Navigation, and Timing
RNAV	Required Navigation
RNP	Required Navigation Performance
RPAS	Remotely Piloted Aircraft System
SDN	Software Defined Networking
SMS	Safety Management Systems
SPD	Small Package sUAS - Delivery
SWIM	System Wide Information Management
TaFR	Tailored Flight Rules
TBFM	Time Based Flow Management
TBO	Trajectory Based Operations
TFDM	Terminal Flight Data Manager
UAM	Urban Air Mobility
UAS	Unmanned Aircraft Systems
USS	Unmanned Aircraft Systems Service Supplier
UTM	UAS Traffic Management
VFR	Visual Flight Rules
xTM	Extensible Traffic Management

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