



SKY for ALL

USHERING IN A NEW ERA OF AVIATION



Pioneering a better, more sustainable future. Together.

Civil aviation operations transport passengers and goods globally, resulting in **2.3% of the US GDP**, **\$850 Billion in economic activity**, employing **> 4 million people**.¹

AVIATION'S BENEFITS TO SOCIETY TODAY

926 million passengers,² and **>21.3 million tons of freight** were moved by air in the US in 2019.³

In the US, **General Aviation** serves people and businesses, especially in hard to reach communities, stimulating **\$150 billion in economic activity** and creating **7.6 million jobs**.⁴

EXECUTIVE SUMMARY

- Today's aviation system will be unable to keep pace with increasing market demand for new operations that capitalize on advancements in autonomy and other emerging technologies.
- Paradigm shifts are necessary to maintain U.S. leadership in the global aviation market, enhance the sustainability of operations, increase mobility, and provide publicly beneficial services.
- The Sky for All Vision provides an R&D framework that will support national strategic planning for a holistic airspace ecosystem to usher in a new era of aviation.
- NASA is in a unique position to tackle the most difficult R&D challenges and to convene the aerospace community towards a common vision.

TOMORROW

Sustainability-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected...impacts are becoming increasingly complex and more difficult to manage.

IPCC Report, 2022

The global Urban Air Mobility market will grow 30% annually to 2040, reaching USD 1.5 trillion with **[scalable] economic growth** to USD 9 trillion by 2050.

Morgan Stanley, 2022

U.S. market estimated at \$115B annually by 2035, potentially creating more than 280,000 **jobs**.

Aerospace Industries of America (AIA) 2021 / Deloitte

To achieve and sustain the **global leadership role** and successfully realize economic and national security benefits, the United States should establish a comprehensive national [advanced air mobility] strategy.

Deloitte Insights, 2022

We can take the NAS to **the next level of safety and efficiency**... by leveraging the information and connectivity revolution

FAA Info-Centric NAS Vision, 2021

THE VITAL IMPORTANCE OF SKY FOR ALL

The global airspace is experiencing profound change. Progress in this century will be inhibited by paradigms established long ago. Legacy technologies, largely manual processes, and siloed solutions have inadvertently constrained scalability and the ability to integrate new concepts and technologies. Meeting the challenges of tomorrow requires

not only advanced technology but new ways of thinking. The aviation and aerospace communities must contend with rapid industry growth, increased traffic density and complexity, and societal game-changers like climate change.

Over the last 100 years, the United States has built the world's largest, safest,

most complex, and most efficient airspace system. The confluence of NASA research, FAA investments, and industry ingenuity has been key in the ongoing modernization of the national airspace system. NASA innovation has shaped how we fly today and endeavors to usher in a new era of aviation, a Sky for All.



Sky for All: Ushering in a New Era of Aviation

IMAGINING THE MID-21ST CENTURY AIRSPACE SYSTEM

Imagine a Sky for All, a holistic airspace ecosystem that will enhance our quality of life—An ecosystem where aviation innovation provides sustainable solutions and economic opportunities by leveraging highly automated operations that are diverse and resilient.

In this vision of the future, possibilities abound.

- Autonomous aircraft deliver emergency lifesaving medical supplies and efficiently transport patients and doctors, improving access to healthcare.
- Coordinated air vehicles detect, monitor, and respond to all manner of natural disasters, providing emergency support to front line workers, critical information to decision-makers, and aid to survivors.
- Airline transportation is reliable and sustainable, getting people to their destinations on time while minimizing the impact on our planet.
- Zero-emission air taxis carry people between diverse locations, easing congested roadways and maximizing work-life balance.
- High-altitude operations provide new telecommunications services and enhance scientific discovery, advancing our understanding of Earth.
- The global aviation system meets sustainability targets of net-zero emissions by 2050, ensuring the long-term health of our planet for future generations.

Sky for All envisions system-wide paradigm shifts designed to facilitate the integration of diverse new applications, safely and sustainably. New vehicles will have different performance characteristics that will enable them to perform a variety of new missions, operating alongside more traditional aircraft. The current traffic management system, built on technology and constraints of the previous century, will be unable to keep pace with advancements in autonomy, communications, and other emerging technologies. Enter Sky for All, a research and development (R&D) foundation for a future airspace ecosystem that will enable these possibilities and more.

“The increasing volume, diversity, and complexity of air traffic operations is a real challenge. Sky for All is about articulating where we want to be by the mid-21st century and what we need to do, together, to get there.”

– Shawn Engelland, Sky for All Lead.

Building on today's trajectory-based operations and harmonizing with the FAA's Info-Centric NAS vision, NASA seeks to enable cooperative and highly automated operations. With this aim, Sky for All emboldens communities to work together towards systemic paradigm shifts that

enable scalability with emerging technology. Together, we will build an ecosystem that advances the entire airspace as a shared national resource—one that meets the public need equitably and sustainably.

As a trusted government advocate, NASA is in a unique

position to convene the aerospace community, charting a common vision and tackling the most difficult R&D challenges.

CHANGING AIRSPACE, SHIFTING PARADIGMS

The next aviation system frontier is a highly automated and cooperative airspace ecosystem that will unleash unprecedented possibilities and provide transformative benefits for humankind and our planet. So what does this transformation look like?

Sky for All envisions highly distributed systems and services that work symbiotically. We anticipate five key paradigm shifts that will transform today's aviation system to a Sky for All airspace ecosystem:

Sustainable Aviation

Eco-friendly aviation that fosters socio-economic prosperity benefiting people and planet, meeting the needs of present generations without compromising our planet's resources for future generations.

Seamless Skies

Integrated and cooperative airspace that supports diverse vehicles and modes of operations.

Ubiquitous Operational Resiliency

Distributed, real-time decision-making and uncertainty management with widely accessible information and tools.

Operator Empowerment

Increased access and flexibility for diverse operations throughout the aviation ecosystem.

Learning-Based System of Systems

A resilient ecosystem that acquires and synthesizes system-wide knowledge, adapts, and evolves at the pace of innovation.



THE SKY FOR ALL VISION

Through a community co-development process, Sky for All has captured the aspirations, goals, and challenges of aviation and aerospace stakeholders across the spectrum. This feedback has informed all aspects of the Sky for All Vision. The Sky for All Vision consists of three important components to chart our successful path to the future.



PRINCIPLES & ASPIRATIONS

The Sky for All Vision is guided by seven Principles and Aspirations, embraced simultaneously and collectively for total system realization.



Principles and Aspirations

Assure Safety as Operations Diversify and Grow

Assure the highest level of aviation safety that exists today, even as new diverse operations emerge and demand grows.

Promote Mobility and Empower Operators

Increase operational flexibility and airspace access to maximize the benefits operators can bring to the public.

Transform the Aviation Ecosystem

Build upon, expand, and transform today's aviation system into a highly automated, highly capable future aviation ecosystem.

Enable Equitable Access for Diverse Operations

Motivate community-based cooperation that promotes equitable access and opportunities for diverse operations and services.

Achieve a Scalable, Secure Digital Aviation System

Develop a scalable digital aviation system that is poised for operational growth and seamless interoperability while leveraging highly automated systems and secure digital information.

Design for Sustainability and Resiliency

Create an aviation ecosystem that addresses ecological, health, social and economic dimensions, recognizing that all must be considered together to achieve adaptable resilience and lasting prosperity for cross generational equity.

Enhance the Quality of Life

Improve mobility and access to aviation services to make people's lives better. Publicly beneficial operations support growth, accessibility, affordability, efficiency, and sustainability for posterity.

RESEARCH & DEVELOPMENT NEEDS: CAPABILITY CORNERSTONES

The R&D Needs are the part of the Sky for All Vision that inform strategic planning and guide the development of NASA and industry roadmaps for R&D. Developing the Sky for All ecosystem will require a phased R&D approach that is aligned with stakeholder needs.

The Sky for All strategy provides a sense of urgency and drive to maintain US global leadership in aviation, encouraging exploration, and nurturing innovation in the application of new technologies and capabilities. The Sky for All strategy defines a long-term, 30-year progression of R&D investment needs in five-year increments that will inform the maturation of R&D roadmaps.

Future Sky for All operations will rely on four Capability Cornerstones.



These four Capability Cornerstones encompass complementary, cross-cutting emerging innovation and new approaches to evolve the current state towards a mid-21st century Sky for All.

COOPERATIVE AND HIGHLY AUTOMATED OPERATIONS

Trajectory based operations > **Cooperative and highly automated operations**

Cooperative practices and automated functions enable operations that are more scalable and sustainable than today's. Capabilities in this cornerstone include an adaptable airspace architecture that supports integration of heterogeneous operations, dynamic airspace management that manages optimal utilization of constrained airspace resources, and cooperative digital flight that serves as a new operating mode founded on digital connectivity, information, and real time computing.

INTEGRATED AND DISTRIBUTED INFORMATION INFRASTRUCTURE

Stove piped data > **Common view of the NAS**

Data and information infrastructure will provide a common view of the NAS to support cooperative and highly automated operations. This cornerstone includes scalable, adaptive communication, navigation, and surveillance systems and a robust, digital, ubiquitous information ecosystem.

AUTOMATION AND ECOSYSTEM PERFORMANCE

Prescriptive technology adoption > **Agile on-ramping of innovation and performance gain**

Identifying how new concepts and technologies will interoperate with the existing airspace system takes a long time because of the complexities of the airspace system. New systems modeling and agile analysis approaches can help shorten that time, enabling quicker integration of Sky for All capabilities. This cornerstone includes intelligent adaptive automation and ecosystem performance assurance. They employ novel systems of systems integration methods and digital twin models of airspace operations to accelerate the on-ramping of innovations that continually push overall ecosystem performance to new levels.

INTEGRATED SAFETY ASSURANCE

Protective, retrospective safety > **Productive, proactive safety**

Airspace operations will become more complex with the introduction of cooperative and highly automated operations. To sustain aviation's excellent safety record, this cornerstone leverages the integrated and distributed information infrastructure to monitor, assess, mitigate, and assure integrated safety in real time by identifying hazards, managing risk, facilitating mitigation actions, and designing in safety at every level.

RESEARCH & DEVELOPMENT NEEDS: ADVANCEMENT TIMELINE

The Sky for All strategy provides a flexible framework to guide R&D investment in five-year time increments, or epochs. Aligning R&D and incremental capability development maximizes investment productivity across the government and industry to yield integrated, synchronized outcomes and measurable progress. This strategy also allows the vision to evolve and adapt in response to discoveries within each previous epoch. For example, updates may be based on new or modified challenges, shifting community needs, technology innovation, or projected regulatory changes.

The Sky for All R&D Needs will inform the NASA Aeronautics Research Mission Directorate portfolio and community roadmaps by providing a common vision that identifies barriers, research questions, technological and operational capabilities, and research investments that must be prioritized to achieve a Sky for All.

**ARCHITECT & IMPROVE
(2025-2030)**

The initial focus is on architecting the Sky for All foundation and defining the performance requirements necessary for increasingly cooperative and automated capabilities. This epoch begins to demonstrate and deliver early improvements that produce more sustainable and efficient operations.

**OPTIMIZE & LEARN
(2040-2045)**

This epoch proliferates highly automated operations throughout the airspace as user and system-wide optimization improvements enhance operational resiliency.

**CONNECT & INTEGRATE
(2030-2035)**

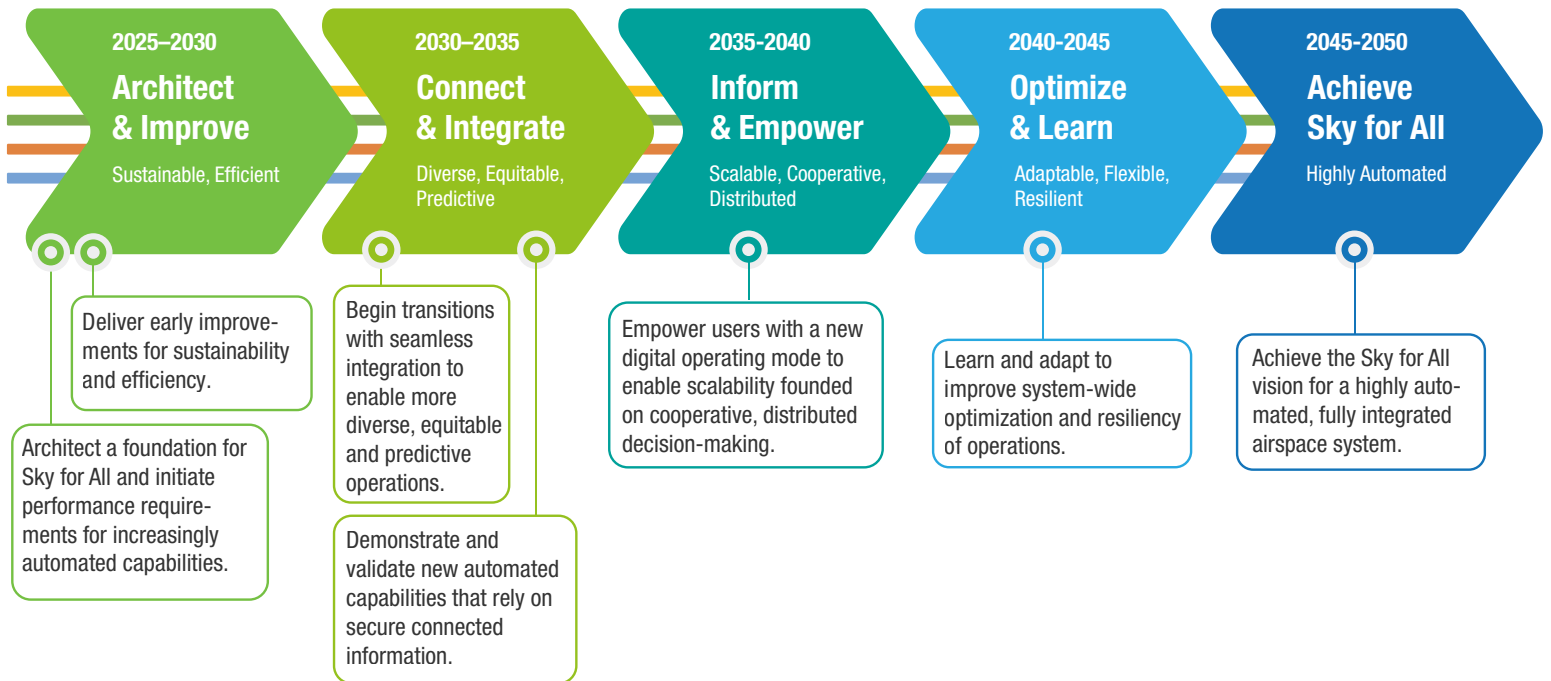
Demonstrations will continue to validate new automated capabilities as they become more connected and integrated through increasingly mature information services. Diverse, high-performing vehicles will integrate seamlessly with traditional operations in this epoch.

**ACHIEVE SKY FOR ALL
(2045-2050)**

Highly automated operations will be ubiquitous, fully integrated, and mature, achieving sustainable, adaptive operations that will continuously acquire and synthesize system-wide knowledge.

**INFORM & EMPOWER
(2035-2040)**

Building from FAA's Info-Centric NAS, this epoch formalizes a new digital operating mode that allows users to scale and diversify their operations, enabled by emergent automated capabilities, cooperative practices, and distributed decision-making.



POSSIBILITIES

Sky for All will unlock a myriad of new aviation possibilities that will revolutionize transportation and aerial services, transform transportation, enhance our economy and improve people's lives. These possibilities, and those yet to be imagined, will require an aviation ecosystem that breaks free from the constraints of today's system and:

- leverages automation and cooperation to ensure interoperability of diverse operations
- harvests the benefits from an integrated and distributed infrastructure to seamlessly share information and enable those cooperative operations
- improves the ability to rapidly validate and integrate new concepts based on the latest technological innovations
- enhances safety using automation to predict hazards and implement mitigations in-time before safety is degraded.

Imagine what we could accomplish with a Sky for All.

Visit the Sky for All Portal to learn more about the possibilities below.

“Sky for All is about growing sustainably and intentionally. It will enable aviation to continue connecting people safely and even more efficiently while protecting our planet and the quality of life for all generations.”

—Jeanne Yu, Chief Strategist

Air Mobility and Access Everywhere



Airline Industry Takes Off

Airline operations will become more reliable and sustainable, minimizing the impact on our planet.



On-Demand Urban Air Travel

Agile on-demand air transportation will save commuting time, enhancing how we live and work.



General Aviation Soars

General aviation will be more accessible, enhancing transportation, services, and recreation.

Aid and Services from Above



Relief from Above

Diverse types of air vehicles collaborate in their response to natural disasters and provide emergency services, saving lives and property.



Aerial Imagery

Autonomously collected aerial data will improve scientific discovery and detect infrastructure problems early, preventing environmental disasters.

Autonomous Transport of Goods



Autonomous Delivery to Your Door

Automated air delivery of packages will make products and vital supplies accessible to everyone.



Future of Freight

Automated aircraft will rapidly transport freight through the supply chain, driving our economy.

Flight at New Heights



Cruise at Supersonic Speeds

Expedient supersonic travel will reduce travel time, bringing our world closer together.



Ascend Above and Beyond

Space launches will be seamlessly coordinated, reducing the impact on aviation operations as the commercial space industry grows.



High Altitude Operations & Services

High altitude vehicles will sustainably provide sensing and telecommunication services on platforms that can be upgraded as technology advances.



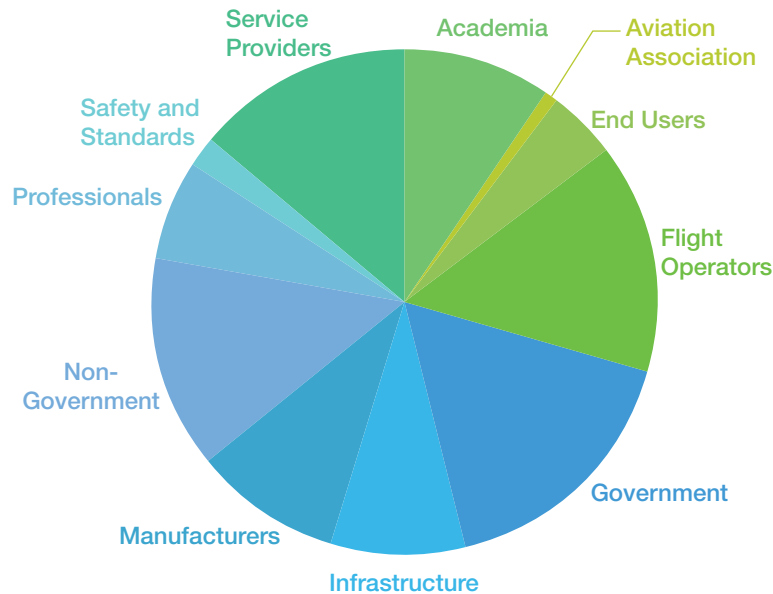
STAKEHOLDER COMMUNITIES

NASA Aeronautics Research Mission Directorate, the national technology leader in aeronautics, is a uniquely positioned and well-established convener of the aviation community. NASA co-developed the Sky for All Vision and R&D Needs in collaboration with a broad stakeholder community consisting of over a thousand community participants. Stakeholder engagement included the interactive web portal and more than a dozen virtual use case, capability, and validation sessions. Through this engagement, NASA compiled hundreds of barriers, research questions, and capabilities necessary to bring Sky for All to life.

The interactive exploratory and validation sessions brought together representatives from across the aerospace community, including traditional, non-traditional, and emerging airspace actors, for hours of specialized group discussions and in-depth conceptualization and analysis.

NASA will continue to engage with the FAA and other government agencies, representatives from the aviation industry, and community participants. The collective effort between the entire aviation and aerospace community will create a sustainable and transformative aviation future.

The Sky for All Portal has received thousands of comments from diverse communities.



“It’s important that we collaborate on this vision we’re developing for the mid-century National Airspace System (NAS) and understand how the NAS needs to transform in order to enable operations that are flexible, sustainable, secure, and connected.”

– Kurt Swieringa, Sky for All Deputy Lead

Sky for All engages with stakeholder communities in every area of aviation, including:



Flight Operators
New entrants and incumbent operators of aircraft for commercial, public, or private use.



Infrastructure Providers
Entities involved in development and maintenance of physical and digital infrastructures supporting space, airborne, and ground-based systems.



Service Providers
Commercial and government service providers that collect and disseminate operational data and manage air navigation, functional, and monitoring services for flight operators.



Manufacturers
Companies that design, develop, manufacture, and maintain aircraft and related products and services.



End Users
Consumers of aviation value, including passengers.



Safety and Standards Bodies
Organizations that conduct research, develop standards, and promote aviation safety.



Government Orgs
Federal, tribal, state, and local government agencies that ensure operational safety and efficiency, establish regulations and policy, and work with communities.



Non-Government Orgs
Nonprofit organizations that operate independently of any government, with the purpose of addressing the societal and political aspects of aviation.



International Associations
International institutions focused on improving interoperability and harmonization across airspaces.



Aviation Associations
Organizations that convene, support, represent, and/or advocate for special interests, including unions and workforce groups.



Aviation Workforce
Individuals who work within the aviation industry.



Academia & Research Orgs
Organizations and individuals involved in aviation-related education, research, and development.



Students
Students of any age with an interest in how the future of aviation will improve their world.



Public
All others interested in how aviation can create better outcomes for all.



THE FUTURE OF AVIATION IS OURS TO TRANSFORM TOGETHER

NASA's mission is to innovate for the benefit of humanity. NASA's Aeronautics Research Mission Directorate, is poised to be both a premier research leader and convener of a diverse set of stakeholder communities, all invested in the future of aviation and aerospace.

Our vision is to transform today's aviation system to an adaptable, scalable, highly automated aviation ecosystem that can keep pace with the unprecedented growth and need for sustainable solutions

in the mid-21st century. Through rigorous community engagement, we are beginning to illuminate a Sky for All R&D pathway to pioneer this new era of aviation operations.

Community cohesion to support, harmonize and leverage FAA's Info-Centric NAS, will accelerate progress towards the Sky for All Vision of the mid-century.

Transformation to a more highly automated digital airspace ecosystem will provide public benefit and

enable gains in overall airspace performance while meeting the challenges of resource efficiency and climate change.

Sky for All sets the course beyond the mid-21st century for a better, more sustainable tomorrow for us and for future generations on earth.

Imagine what we will do. Together.

ENDNOTES

- 1 "The Economic Impact of Civil Aviation on the U.S. Economy," January 2020 https://www.faa.gov/about/plans_reports/media/2020_jan_economic_impact_report.pdf
- 2 Bureau of Transportation Statistics, <https://www.transtats.bts.gov/DataElements.aspx?Data=2>, Accessed Sept. 2, 2022.
- 3 Bureau of Transportation Statistics, <https://www.transtats.bts.gov/freight.asp?20=D&qv52ynB=qn-6nF>, Accessed Sept. 2, 2022.
- 4 "State of General Aviation," 2019 https://download.aopa.org/hr/Report_on_General_Aviation_Trends.pdf#:~:text=More%20than%2090%25%20of%20the,States%20are%20general%20aviation%20aircraft.&text=More%20than%2080%25%20of%20the,the%20U.S.%20fly%20GA%20aircraft.&text=*General%20Aviation%20generates%20more%20than,and%20creates%207.6M%20jobs.

APPENDIX: RESEARCH AND DEVELOPMENT NEEDS – CAPABILITY CORNERSTONES DEVELOPMENT BY 5 YEAR PHASE



	2025–2030 Architect & Improve Sustainable, Efficient	2030–2035 Connect & Integrate Diverse, Equitable, Predictive	2035–2040 Inform & Empower Scalable, Cooperative, Distributed	2040–2045 Optimize & Learn Adaptable, Flexible, Resilient	2045–2050 Achieve Sky for All Highly Automated
Cooperative and Highly Automated Operation	Develop adaptable, scalable, service-oriented airspace architectures, standards, performance requirements and practices. Deliver early improvements.	Demonstrate, integrate, implement and transition early autonomy capabilities for performance-based, cooperative flight operations with oversight.	Empower users with a new digital operating mode to enable scalability founded on cooperative, distributed decision-making.	Grow automated, cooperative operations with distributed responsibility and dynamically managed airspace for optimal resource utilization.	Achieve ubiquitous, cooperative, and highly automated operations with collaborative continuous learning.
Integrated, Distributed Information Infrastructure	Develop requirements and innovate for Communication, Navigation and Surveillance. Establish architecture for open, secure, software infrastructure, providing tools, protocols and governance.	Leverage adaptable spectrum, mesh networks and multi-link services for more connected, secure, vehicle to vehicle to ground data sharing.	Enable dynamic, trusted data communications management with privacy standards. Learn from adjacent industries, advance forecasting, probabilistic analysis.	Adapt further to ensure scalable information architecture, multi-sourced data for guidance of navigation for automated operations and vulnerability scanning.	Common view and understanding of the NAS
Automation and Ecosystem Performance	Establish requirements and standards for increasing automation in safety-responsible roles. Develop systems of systems architecture and methodology to accelerate integration, optimization and performance.	Demonstrate seamless integration, validate automation and cooperation by test and analysis for interoperability, certification, policy and lifecycle benefits in increasingly safety-critical applications.	Continue to grow human and autonomy teaming. Scale, model and verify interoperability requirements for systems of systems. Accelerate performance-based transition to automation of critical functions.	Grow system resiliency, using data analytics for system behavior characterization. Model optimization techniques for automated systems.	Automation and digital twin modeling enable optimization of NAS operations.
Integrated Safety Assurance	Establish standards and metrics of safety data architecture and management, including risk analysis and risk management maturity models for validating safety of autonomy.	Integrate hazards monitoring for situational awareness. Develop simulation test suite to validate systems and performance-based airspace functional requirements and guidance for new operations.	Empower users with predictive modeling employing early MI/ AI for safety analysis. Regional implementation of evolving design for safety standards.	Cooperative in-time crowd-sourced information utilizing AI/ML automated systems identification of risks and actions.	Safety for All – seamless, integrated and highly autonomous safety mitigation



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