National Aeronautics and Space Administration

NASA Aeronautics Strategic Thrust: Assured Autonomy for Aviation Transformation

Vision and Roadmap

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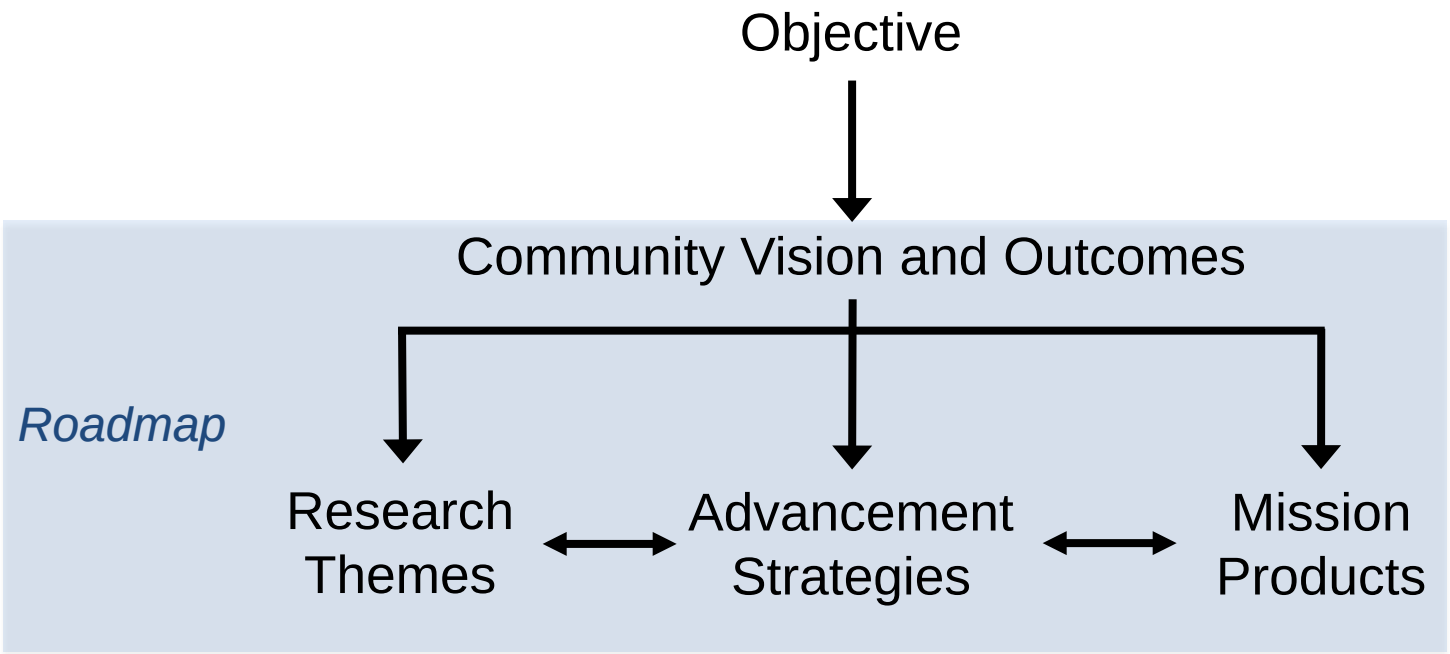
Why an Aviation Autonomy Roadmap?

- The world is on the leading edge of an explosion in machine intelligence, data analytics, high-speed communications, and ubiquitous low-cost hardware
- These capabilities can have large potential payoffs for civil aviation
  - Enabling new aviation uses, users, and mission types
  - Potential to radically transform aviation system capacity, robustness, and flexibility beyond what is possible today

*The **objective** of NASA Aeronautics Research Mission Directorate's Strategic Thrust 6 is to enable autonomous systems that employ highly intelligent machines to maximize the benefits of aviation to society.*

- NASA Aeronautics Strategic Implementation Plan

Roadmap Overview



Vision for the Future of Civil Aviation

- There will be a radical increase in new and cost-effective uses of aviation
- The skies will accommodate thousands of times the number of vehicles flying today
- Travelers will have the flexibility to fly when and where they want in a fraction of the time that it takes today
- All forms of air travel will be as safe as commercial air transport is today
- Aviation will approach overall carbon neutrality

Autonomy is Required to Enable the Vision

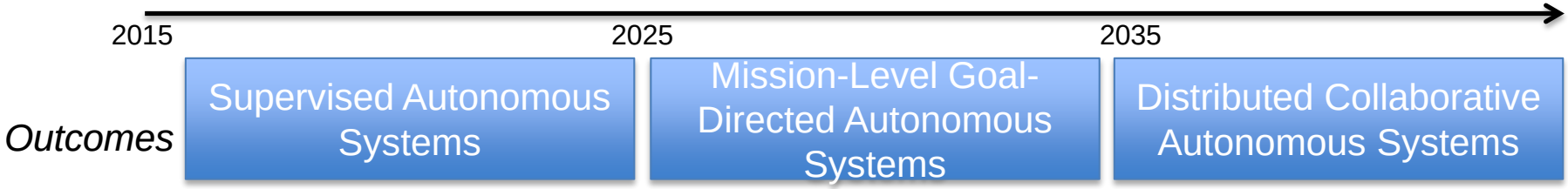
- *Anyone can safely fly…*
- *any time and anywhere, with high confidence…*
- *while sharing the sky with 1000 times more vehicles than today…*
- *as some of those vehicles accomplish new missions…*
- *in close proximity to people and property…*
- *without harming the environment.*

- Autonomy will augment human abilities and make some tasks easier for humans
- Autonomy will foster a radical increase in aviation efficiency, reliability, and dependability through system-wide operational planning and highly responsive replanning to changes
- Configured by autonomous systems, vehicles will continuously operate at peak performance and efficiency
- The aviation system will be so large and complex that it will be unmanageable without machine intelligence
- Machine intelligence will enable new types of vehicles and missions to be possible, unconstrained by the requirements of today's conventional vehicles
- Networked multi-vehicle systems will collaborate to achieve new goals
- Autonomous machines will achieve unprecedented agility through high-bandwidth sensing, replanning, reconfiguration, and control, thereby allowing machines to safely work among us

Community Vision and Outcomes

	2015	2025	2035
Outcomes	Supervised Autonomous Systems	Mission-Level Goal-Directed Autonomous Systems	Distributed Collaborative Autonomous Systems
Capabilities	Advanced prescribed automation and initial goal-directed and adaptive automation	Mission-level goal-directed adaptive automation	Campaign-level goal-directed adaptive automation, embedded within all system elements
	Initial world views from local sensors and limited data exchange	Large-scale detailed world views using advanced sensors and networks	Adaptive collaboration based on extensive shared world views
	Applied to aviation system components and small-scale systems.	Applied to large-scale integrated systems	Highly distributed large-scale collaborative systems that constitute integral parts of larger systems they support
	Predominantly human-supervised; higher levels of machine independence under carefully controlled conditions	Human/machine teams with many levels of control, depending on specific applications and situations; extensive	Human/machine teams, with humans primarily specifying strategic goals; many systems self-protect and self-heal

Community Vision and Outcomes



Benefits

- Efficiency and NAS capacity
- Increased robustness and resilience in operations
- Enhanced vehicle performance
- Initial UAS applications benefits

- Increased NAS system flexibility, efficiency and capacity
- Prognostic safety
- New vehicles designed to leverage autonomy
- Reduced costs at all levels
- Multi-vehicle UAS applications benefits

- Extreme flexibility and adaptability for large-scale systems, with extreme levels of reliability and recovery from disturbances
- Advanced prognostic safety
- Further reduced costs at all levels

Roadmap Elements

Three parallel and interdependent roadmap elements

- Research Themes

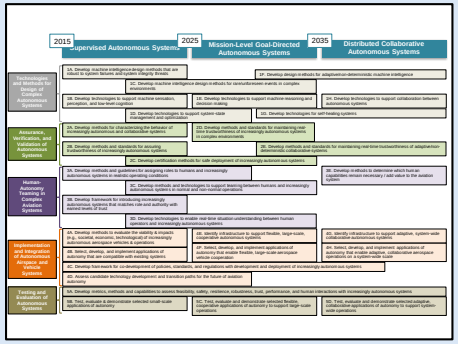
  Technical activities to achieve knowledge breakthroughs and advance aviation autonomy capabilities

- Advancement Strategies

  Approaches employed by NASA to achieve aviation autonomy objectives

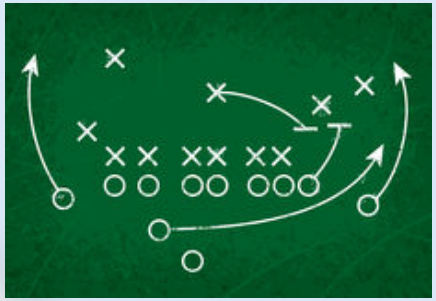
- Mission Products

  Targeted NASA/community capabilities that facilitate a viable path toward mature and widespread aviation autonomy

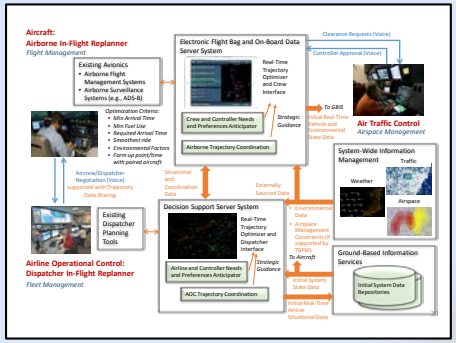


Research Themes

Vision



Advancement Strategies



Mission Products

TCs (Developed by Programs and Projects)

Research Themes

1. **Technologies and Methods for Design of Complex Autonomous Systems**

   Develop methods and technologies for design of intelligent machine systems capable of operating and collaborating in complex environments. Technologies include, among others, machine sensing, cognition, and reasoning.

2. **Assurance, Verification, and Validation of Autonomous Systems**

   Develop methods for certification and assuring trustworthiness in the design and operation of autonomous systems

3. **Human-Autonomy Teaming in Complex Aviation Systems**

   Develop optimal and safe human-machine role assignments and teaming strategies that can evolve with machine autonomy and earned levels of trust

4. **Implementation and Integration of Autonomous Airspace & Vehicle Systems**

   Develop, implement, and integrate novel real-world autonomy applications into existing systems, and develop transition paths for future systems with higher levels of autonomy.

5. **Testing and Evaluation of Autonomous Systems**

   Develop and apply metrics, models, simulation capabilities, and testbeds for assessment and evaluation of autonomous systems in both laboratory and operational settings. Includes demonstrations and field tests of developed technologies and applications.

Research Themes

	2015	2025	2035
	Supervised Autonomous Systems	Mission-Level Goal-Directed Autonomous Systems	Distributed Collaborative Autonomous Systems
Technologies and Methods for Design of Complex Autonomous Systems	1A. Develop machine intelligence design methods that are robust to system failures and system integrity threats	1F. Develop design methods for adaptive/non-deterministic machine intelligence	
	1C. Develop machine intelligence design methods for rare/unforeseen events in complex environments		
	1B. Develop technologies to support machine sensation, perception, and low-level cognition	1E. Develop technologies to support machine reasoning and decision making	1H. Develop technologies to support collaboration between autonomous systems
	1D. Develop technologies to support system-state management and optimization	1G. Develop technologies for self-healing systems	
Assurance, Verification, and Validation of Autonomous Systems	2A. Develop methods for characterizing the behavior of increasingly autonomous and collaborative systems	2D. Develop methods and standards for maintaining real-time trustworthiness of increasingly autonomous systems in complex environments	
	2B. Develop methods and standards for assuring trustworthiness of increasingly autonomous systems	2E. Develop methods and standards for maintaining real-time trustworthiness of adaptive/non-deterministic collaborative systems	
	2C. Develop certification methods for safe deployment of increasingly autonomous systems		
Human-Autonomy Teaming in Complex Aviation Systems	3A. Develop methods and guidelines for assigning roles to humans and increasingly autonomous systems in realistic operating conditions	3E. Develop methods to determine which human capabilities remain necessary / add value to the aviation system	
	3D. Develop methods and technologies to support teaming between humans and increasingly autonomous systems in normal and non-normal operations		
	3B. Develop framework for introducing increasingly autonomous systems that matches role and authority with earned levels of trust		
	3C. Develop technologies to enable real-time situation understanding between human operators and increasingly autonomous systems		
Implementation and Integration of Autonomous Airspace and Vehicle Systems	4A. Develop methods to evaluate the viability & impacts (e.g., societal, economic, technological) of increasingly autonomous aerospace vehicles & operations	4E. Identify infrastructure to support flexible, large-scale, cooperative autonomous systems	4G. Identify infrastructure to support adaptive, system-wide collaborative autonomous systems
	4B. Select, develop, and implement applications of autonomy that are compatible with existing systems	4F. Select, develop, and implement applications of autonomy that enable flexible, large-scale aerospace vehicle cooperation	4H. Select, develop, and implement applications of autonomy that enable adaptive, collaborative aerospace operations on a system-wide scale
	4C. Develop framework for co-development of policies, standards, and regulations with development and deployment of increasingly autonomous systems		
	4D. Assess candidate technology development and transition paths for the future of aviation autonomy		
Testing and Evaluation of Autonomous Systems	5A. Develop metrics, methods and capabilities to assess feasibility, safety, resilience, robustness, trust, performance, and human interactions with increasingly autonomous systems		
	5B. Test, evaluate & demonstrate selected small-scale applications of autonomy	5C. Test, evaluate and demonstrate selected flexible, cooperative applications of autonomy to support large-scale operations	5D. Test, evaluate and demonstrate selected adaptive, collaborative applications of autonomy to support system-wide operations

Research Themes

Technologies and Methods for Design of Complex Autonomous Systems

1A. Develop machine intelligence design methods that are robust to system failures and system integrity threats

1B. Develop technologies to support machine sensation, perception, and low-level cognition

1C. Develop machine intelligence design methods for rare/unforeseen events in complex environments

1D. Develop technologies to support system-state management and optimization

1E. Develop technologies to support machine reasoning and decision making

1F. Develop design methods for adaptive/non-deterministic machine intelligence

1H. Develop technologies to support collaboration between

1G. Develop technologies for self-healing systems

Advancement Strategies

1. Address critical autonomy barriers that require unique NASA contributions and leadership
2. Leverage initial technologies and early adopters to insert autonomy into operational environments, and then build on operational experience (Evolutionary Autonomy)
3. Develop and demonstrate feasibility-driven autonomy concepts, technologies, and mission products to generate breakthrough capabilities (Revolutionary Autonomy)
4. Advance autonomy technologies and overcome barriers by developing mission products that leverage the high demand for Unmanned Aerial Systems and their rapid development cycles
5. Leverage large investments in non-aviation autonomy technologies by developing mission products that repurpose those technologies for aviation where appropriate
6. Establish mechanisms to achieve stakeholder consensus. Provide community coordination and leadership to achieve research advances and implement selected applications.

2025 Community Vision

Community Needs

Disaster Relief

Environmental Protection

Infrastructure Inspection

Increased mobility

Transportation congestion solutions

Increased access to medical services

Assured Autonomy Role

Decision support systems

Risk assessment & management

Situational awareness

Information management

Expert knowledge provider

Critical thinking

Perception

Local actions

Mission Product Categories

Enhance Aviation Safety

Address Increased Demand for Air Transportation

Increase Operational Efficiency In Aviation

Enhance Aviation Vehicle Performance

Accommodate New Users and Missions

Community Coordination and Leadership
Getting Started

Establish mechanisms to achieve stakeholder consensus. Provide community coordination and leadership to achieve research advances and implement selected applications.

- Identify community stakeholders, their different needs and objectives, and their potential roles in civil aviation autonomy
- Establish approach for achieving community goals and objectives
  - Set agenda and identify participants for community meetings
  - Establish appropriate partnership agreements with community stakeholders
  - Form and lead workshops on specialized topics within civil aviation autonomy
- Determine appropriate roles and relationships for NASA/Community to participate
- Provide strawman research agenda (i.e., this Roadmap) as precursor to developing a national research agenda

Autonomy in Civil Aviation

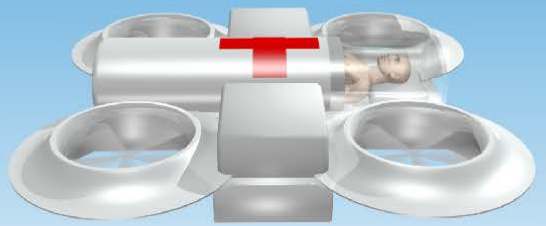


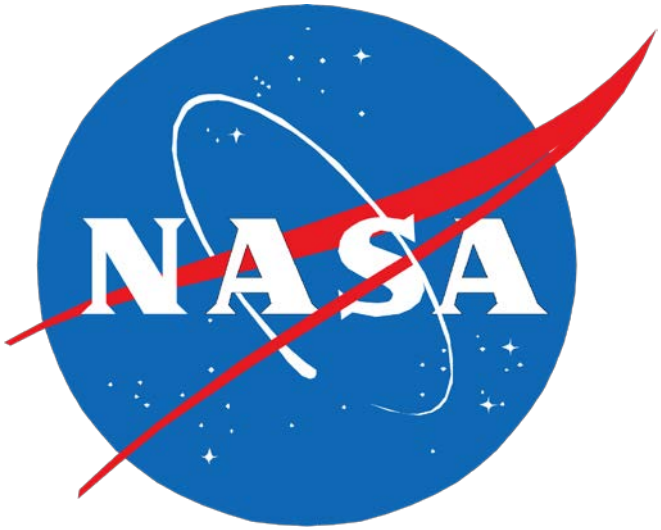










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