NASA Aeronautics Strategic Thrust: Assured Autonomy for Aviation Transformation

Vision and Roadmap

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March 9, 2016
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
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

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<th>Capabilities</th>
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<td>Supervised Autonomous Systems</td>
<td>Advanced prescribed automation and initial goal-directed and adaptive automation</td>
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<td>Mission-Level Goal-Directed Autonomous Systems</td>
<td>Mission-level goal-directed adaptive automation</td>
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<td>Distributed Collaborative Autonomous Systems</td>
<td>Campaign-level goal-directed adaptive automation, embedded within all system elements</td>
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- **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

Outcomes
- Supervised Autonomous Systems
  - Efficiency and NAS capacity
  - Increased robustness and resilience in operations
  - Enhanced vehicle performance
  - Initial UAS applications benefits
- Mission-Level Goal-Directed Autonomous Systems
  - 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
- Distributed Collaborative Autonomous Systems
  - 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

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
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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

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

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
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
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
1G. Develop technologies for self-healing systems
1H. Develop technologies to support collaboration between autonomous systems
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1H. Develop technologies to support collaboration between autonomous systems

Assurance, Verification, and Validation of Autonomous Systems

2A. Develop methods for characterizing the behavior of increasingly autonomous and collaborative systems
2B. Develop methods and standards for assuring trustworthiness of increasingly autonomous systems
2C. Develop certification methods for safe deployment of increasingly autonomous systems
2D. Develop methods and standards for maintaining real-time trustworthiness of increasingly autonomous systems in complex environments
2E. Develop methods and standards for maintaining real-time trustworthiness of adaptive/non-deterministic collaborative systems
3A. Develop methods and guidelines for assigning roles to humans and increasingly autonomous systems in realistic operating conditions
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
3D. Develop methods and technologies to support teeming between humans and increasingly autonomous systems in normal and non-normal operations
3E. Develop methods to determine which human capabilities remain necessary / add value to the aviation system

Human-Autonomy Teaming in Complex Aviation Systems

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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
4B. Select, develop, and implement applications of autonomy that are compatible with existing systems
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
4E. Identify infrastructure to support flexible, large-scale, cooperative autonomous systems
4F. Select, develop, and implement applications of autonomy that enable flexible, large-scale aerospace vehicle cooperation
4G. Identify infrastructure to support adaptive, system-wide collaborative autonomous systems
4H. Select, develop, and implement applications of autonomy that enable adaptive, collaborative aerospace operations on a system-wide scale

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
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2015

Supervised Autonomous Systems

2025

Mission-Level Goal-Directed Autonomous Systems

2035

Distributed Collaborative Autonomous 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
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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