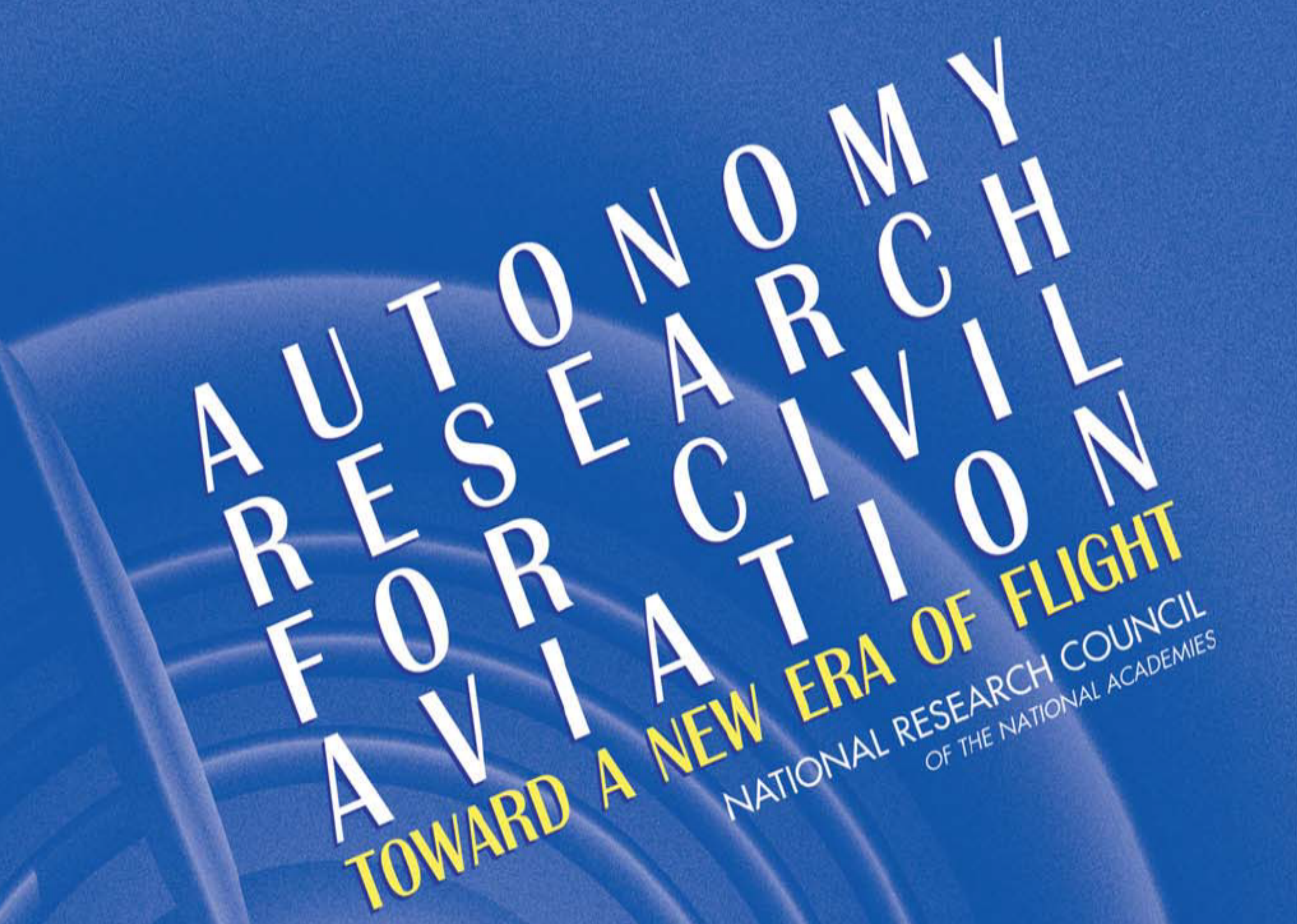

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Agenda

- Background and Context
- Vision and Roles
- Barriers to Implementation
- Research Agenda
- End Notes

Background and Context

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Statement of Task – Key Elements

- ***Consider***
  - current state of the art in autonomy research and applications
  - current national guidance on research goals and objectives
- ***Describe***
  - forms and applications of autonomy reviewed
  - potential contributions of autonomy to civil aviation
  - technical and policy barriers
  - key challenges and gaps to be addressed by a national research agenda for autonomy in civil aviation
- ***Outline***
  - a prioritized set of research projects that
    - enable development of CONOPS
    - lead to development, integration, testing and demonstration
    - predict system-level effects
    - define approaches to V&V and Cert
  - The outline should be developed with due consideration of required resources and organizational partnerships, and it should describe potential contributions and roles of U.S. research organizations

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Membership of the Study Committee

- JOHN-PAUL B CLARKE , Georgia Institute of Technology, *Co-chair*
- JOHN K. LAUBER, Consultant, *Co-chair*
- BRENT APPLEBY, Draper Laboratory
- ELLA M. ATKINS, University of Michigan
- ANTHONY J. BRODERICK, Consultant
- GARY L. COWGER, GLC Ventures, LLC
- CHRISTOPHER E. FLOOD, Delta Air Lines
- MICHAEL S. FRANCIS, United Technologies Research Center
- ERIC FREW, University of Colorado, Boulder
- ANDREW LACHER, MITRE Corporation
- JOHN D. LEE, University of Wisconsin- Madison
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- LAEL RUDD, Northrop Grumman Aerospace Systems
- PATRICIA VERVERS, Honeywell Aerospace
- LARRELL B. WALTERS, University of Dayton Research Institute
- DAVID D. WOODS, Ohio State University
- EDWARD L. WRIGHT, University of California, Los Angeles

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Increasingly Autonomous Systems

- Advanced autonomy is a further development of work that has been underway for decades
- Report is not focused on fully autonomous aircraft or fully autonomous ATC/ATM systems
- Report is focused on "**increasingly autonomous**" (IA) systems
  - Various locations along the spectrum of system capabilities between current systems and fully autonomous systems

Vision & Roles

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Vision for Increasingly Autonomous Systems

Aircraft and Ground Systems

- New or improved capabilities
  - Function more safely, reliably, and efficiently
  - Expanded array of missions
  - Constrained only by technological limitations and acceptable margins of risk and cost
- Mix of crewed and unmanned aircraft in shared airspace
- ATM systems with distributed responsibilities and authorities
- Designed to minimize failure modes
  - Individual systems
  - NAS as a whole

IA in Civil Aviation

- Air Traffic Management
- Fixed-Wing Transport Aircraft
- Rotorcraft
- General Aviation
- Unmanned Aircraft Systems
- Airport ground systems

- **Monitor data** from all available sources
- **Identify problems** such as equipment anomalies, inconsistencies, mistakes, deviations, conflicts, degradations in capacity, etc.
- **Identify options and recommend course of action** (and act, when action is within the scope of system authority)
- **Communicate** with pilots, controllers, etc.

Potential Benefits

- Safety and Reliability
  - Commercial transports: Very safe—IA systems must not degrade safety
  - General aviation: Substantial room for improvement
  - UAS: no aircrew at risk
  - Small UAS: accidents result in less damage on the ground
- Costs/Efficiency
  - Reduce need for highly skilled operators
  - Enable more efficient operations
  - Replaced crewed aircraft with UAS for some missions
- UAS Operational Capabilities
  - Improve ability of UAS to execute existing missions and to take on new missions

Barriers to Implementation

- Technology
- Regulation and Certification
- Legal and Social

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Technology Barriers

- Communications and Data Acquisition
- Cyber-Physical Security
- Diversity of Aircraft
- Human-Machine Integration
- Decision-Making by Adaptive/Nondeterministic Systems
- Sensing, Perception, and Cognition
- System Complexity and Resilience
- Verification and Validation

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Regulatory and Certification Barriers

- Airspace Access for Unmanned Aircraft
- Certification Process
- Equivalent level of safety
- Trust in Adaptive/Nondeterministic Systems

Additional Barriers

- Legal Issues
- Social Issues

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Key Challenge

“How can we assure that advanced IA systems—especially those systems that rely on adaptive/nondeterministic software—will enhance rather than diminish the safety and reliability of the NAS?”

- Many barriers are closely related to this challenge

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Research Agenda

Prioritization Process

- Considerations
  - Degree State-of-the-Art needs to advance
  - Time and resources requirements
  - Time-phased application of research project results
- Criteria
  - Level of difficulty
  - Urgency

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Most Urgent and Most Difficult High-Priority Research Projects

- Behavior of Adaptive/Nondeterministic Systems
- Operation without Continuous Human Oversight
- Modeling and Simulation
- Verification, Validation, and Certification

Additional High-Priority Research Projects

- Nontraditional Methodologies and Technologies
- Roles of Personnel and Systems
- Safety and Efficiency
- Stakeholder Trust

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End Notes

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Coordinate the Research Agenda

- Collaboration among Federal and Private entities to align research efforts
  - Academia
  - Industry
  - FAA
  - DOD
  - NASA

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Develop New Regulations

- FAA will need to
  - develop technical competency in IA systems
  - issue new guidance material and regulations

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Address Breath of Legal & Social Issues

- Recommended research agenda does not fully address legal or social issues
- FAA in best position to lead resolution of legal and social issues
- Resolution of legal issues could involve
  - FAA
  - NTSB
  - Department of Justice
  - State attorneys general
  - Public interest legal organizations
  - Aviation community stakeholders

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Concluding Remarks

- Civil aviation at the threshold of profound changes
- Maintaining or improving safety and efficiency of the NAS will be no easy matter
- Potential benefits are great, but the benefits—and the unintended consequences—will fall on some stakeholders much more than others
- Overcoming the barriers by pursuing the proposed research agenda is a vital next step

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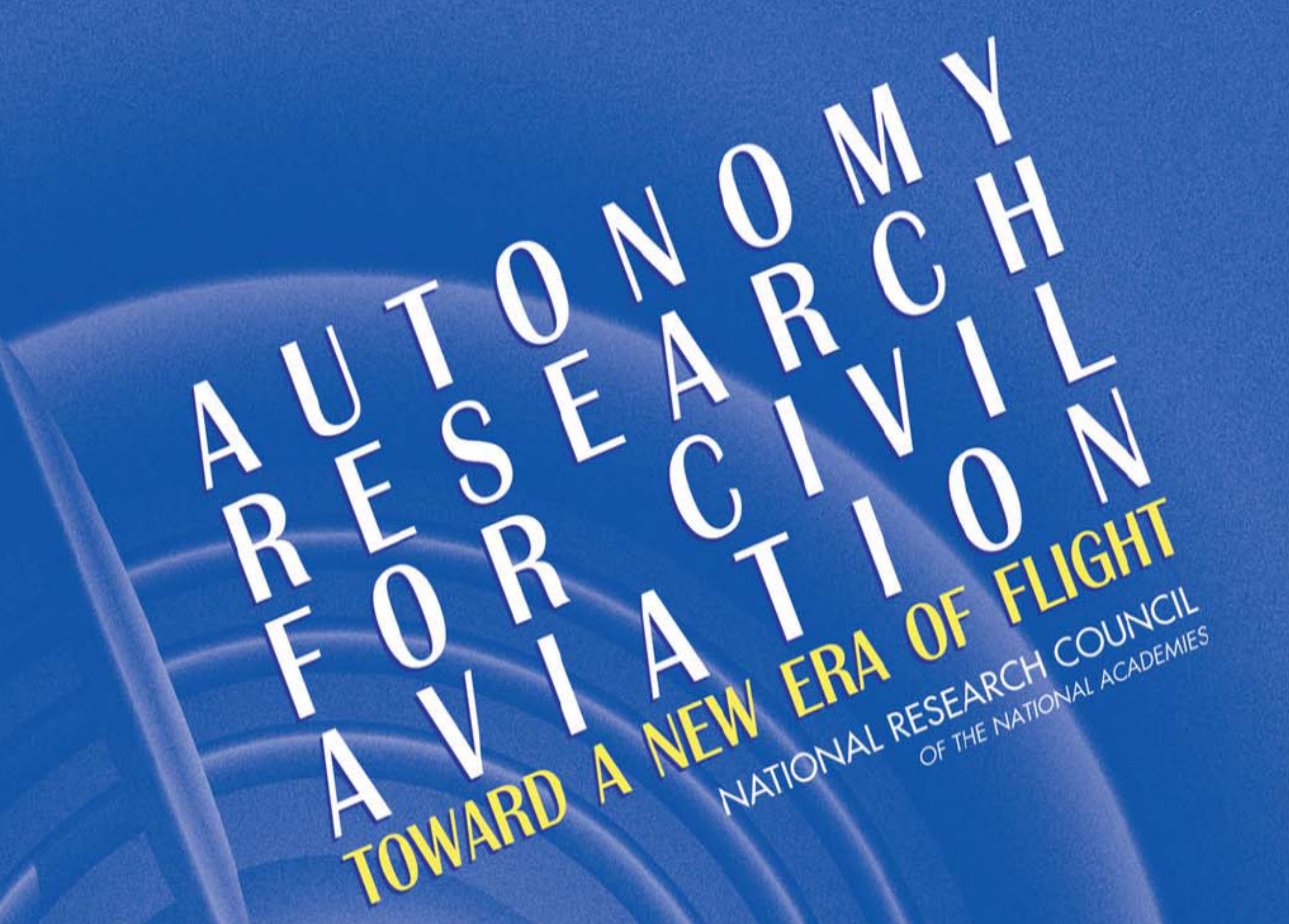

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Technology Barriers

- **Communications and Data Acquisition:** Civil aviation wireless communications are fundamentally limited in bandwidth, and the operation of unmanned aircraft in the NAS could substantially increase bandwidth requirements.
- **Cyber-Physical Security:** The use of increasingly interconnected networks and increasingly complex software embedded throughout IA air- and ground-based system elements, as well as the increasing sophistication of potential cyber-physical attacks, threaten the safety and reliability of IA systems.
- **Diversity of Aircraft:** It will be difficult to engineer some IA systems so that they are backward-compatible with legacy airframes, ATM systems, and other elements of the NAS.
- **Human-Machine Integration:** Incorporating IA systems and aircraft in the NAS would require humans and machines to work together in new and different ways that have not yet been identified.
- **Decision-Making by Adaptive/Nondeterministic Systems**: The lack of generally accepted design, implementation, and test practices for adaptive/nondeterministic systems will impede the deployment of some advanced IA systems and aircraft in the NAS.
- **Sensing, Perception, and Cognition:** The ability of IA systems to operate independently of human operators is fundamentally limited by the capabilities of machine sensory, perceptual, and cognitive systems.
- **System Complexity and Resilience:** IA capabilities create a more complex aviation system, with new interdependencies and new relationships among various operational elements. This will likely reduce the resilience of the civil aviation system, because disturbances in one portion of the system could cause the performance of the entire system to degrade precipitously.
- **Verification and Validation:** Existing verification and validation (V&V) approaches and methods are insufficient for advanced IA systems.

Regulatory and Certification Barriers

- **Airspace Access for Unmanned Aircraft**: Unmanned aircraft may not operate in nonsegregated civil airspace unless the FAA issues a certificate of waiver or authorization (COA).
- **Certification Process**: Existing certification criteria, processes, and approaches do not take into account the special characteristics of advanced IA systems.
- **Equivalent level of safety:** Many existing safety standards and requirements, which are focused on assuring the safety of aircraft passengers and crew on a particular aircraft, are not well suited to assure the safety of unmanned aircraft operations, where the primary concern is the safety of personnel in other aircraft and on the ground.
- **Trust in Adaptive/Nondeterministic Systems:** Verification, validation, and certification are necessary but not sufficient to engender stakeholder trust in advanced adaptive/nondeterministic IA systems.

Other Barriers

- **Legal Issues**: Public policy, as reflected in law and regulation, could significantly impede the degree and speed of adoption of IA technology in the NAS.
- **Social Issues:** Social issues, particularly public concerns about privacy and safety, could significantly impede the degree and speed of adoption of IA technology in the NAS.

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Most Urgent and Most Difficult High-Priority Research Projects

- **Behavior of Adaptive/Nondeterministic Systems:** Develop methodologies to characterize and bound the behavior of adaptive/nondeterministic systems over their complete life cycle.
- **Operation without Continuous Human Oversight:** Develop the system architectures and technologies that would enable increasingly sophisticated IA systems and unmanned aircraft to operate for extended periods of time without real-time human cognizance and control.
- **Modeling and Simulation:** Develop the theoretical basis and methodologies for using modeling and simulation to accelerate the development and maturation of advanced IA systems and aircraft.
- **Verification, Validation, and Certification:** Develop standards and processes for the verification, validation, and certification of IA systems, and determine their implications for design.

Additional High-Priority Research Projects

- **Nontraditional Methodologies and Technologies:** Develop methodologies for accepting technologies not traditionally used in civil aviation (e.g., open-source software and consumer electronic products) in IA systems.
- **Roles of Personnel and Systems:** Determine how the roles of key personnel and systems, as well as related human–machine interfaces, should evolve to enable the operation of IA systems.
- **Safety and Efficiency:** Determine how IA systems could enhance the safety and efficiency of civil aviation.
- **Stakeholder Trust:** Develop processes to engender broad stakeholder trust in IA systems for civil aviation.

Relationship of Technology Barriers to High-Priority Research Projects

High Priority Research Projects

Barriers	1. Behavior of Adaptive and Non-Deterministic Systems	2. Operation without Continuous Human Oversight	3. Modeling and Simulation	4. Verification, Validation, and Certification	5. Non-Traditional Methodologies and Technologies	6. Roles of Personnel and Systems	7. Safety and Efficiency	8. Stakeholder Trust
Technology Barriers								
Communications and data acquisition			●	●		■		
Cyber-physical security			●	●	■	■		●
Diversity of vehicles			●		■	■		
Human machine integration		■	■				■	
Non-deterministic decision-making	■	■	■	■	■			■
Sensing, perception, and cognition		■					■	
System complexity and resilience		●	■	■	■	■		■
Verification and validation	■	●	■	■	■	■		■
Regulation and Certification Barriers								
Airspace Access for Unmanned Aircraft		■	●		●	●	●	●
Certification process	■	■	■	■	■	■	■	■
Equivalent level of safety	■	■	■	■	■	■	■	■
Trust in non-deterministic IA systems	■	●	●	■	■	■		■
Additional Barriers								
Legal issues						■		■
Social issues	●					■		■

Note: The number of barriers addressed by a particular project does not indicate priority, which is based on (1) level of difficulty and (2) urgency.

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Advanced Automation and Autonomy

Distinguishing Characteristics	Advanced Automation	Advanced Autonomy
Exhibits emergent behavior	Sometimes	Usually
Adapts behavior to feedback (learns)	Sometimes	Usually
Responds differently to identical inputs	Sometimes	Usually
Addresses situations beyond the routine	Rarely	Usually
Reduces cognitive workload for humans	Sometimes	Usually
Replaces human decision makers	Rarely	Potentially
Robust to unanticipated situations	Limited	Usually
Behavior determined by experience rather than design	Never	Usually
Adapts to unforeseen environmental changes	Rarely	Potentially
Makes value judgments (weighted decisions)	Never	Usually
Makes mistakes in perception and judgment	N/A	Potentially