Autonomy Research for Civil Aviation: Toward a New Era of Flight

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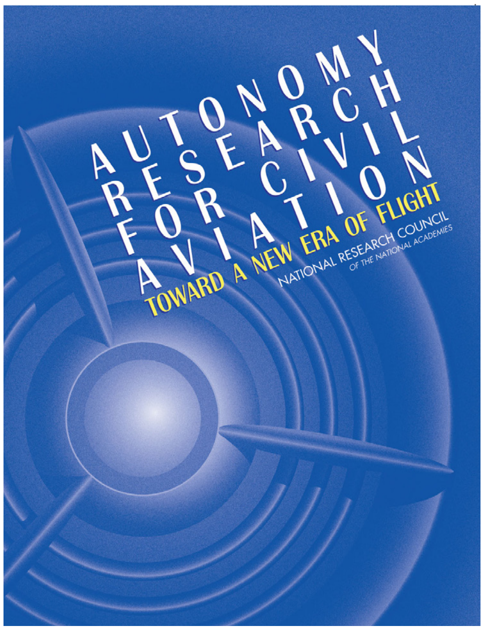

Civil aviation in the United States and elsewhere in the world is on the threshold of profound changes in the way it operates because of the rapid evolution of increasingly autonomous (IA) systems. IA systems encompass a wide array of system capabilities that range from the abilities of current automatic systems, such as autopiloted and remotely piloted unmanned aircraft, to the highly sophisticated systems that would be needed to enable aircraft and air traffic management systems to perform complex mission-related tasks with little or no human intervention for extended periods of time. The development and application of IA systems for civil aviation are proceeding at an accelerating pace, driven by the expectation that such systems will return significant benefits in terms of safety, reliability, efficiency, affordability, and previously unattainable mission capabilities. However, many substantial barriers, including technical issues, certification and regulation changes, and legal and social concerns, must be surpassed before widespread use of advanced IA systems in civil aviation is possible. This report suggests major elements of a national research agenda to address these barriers and inform and support the orderly implementation of IA systems in U.S. civil aviation.

Background

Aircraft automation began less than a decade after the Wright brothers first flew with the invention of a rudimentary autopilot system. Throughout the remainder of the 20th century, aircraft automation became increasingly capable with the advent of navigation systems, unmanned aircraft systems, digital technology, and many other innovations. Today, IA systems are used throughout military and government applications, particularly in unmanned aircraft. Unlike the United States, some countries, such as Japan, allow commercial use of unmanned aircraft, which provides a wide range of opportunities for the use of IA systems.

In the United States, a wide variety of organizations are contributing to the advancement of IA systems for civil aviation. Accordingly, NASA's Aeronautics Research Mission Directorate requested that the National Academies convene a committee to develop a national research agenda for autonomy in civil aviation in the United States.

Barriers to Increased Autonomy in Civil Aviation

Before widespread implementation of advanced IA systems throughout the national airspace system (NAS), numerous challenges must be overcome. The most critical of these can be described in terms of the question "How can we assure that advanced IA systems—especially those systems which adapt their behavior over time or those with little human control—will enhance rather than diminish the safety and reliability of the NAS?" These challenges break into three categories: technology barriers, regulation and certification barriers, and legal and social barriers. The following list offers some examples of each category:

- *Technology*: decision-making by advanced IA systems, cyberphysical security, verification and validation, human-machine integration, and sensing, perception and cognition.

- *Regulation and Certification*: airspace access for unmanned aircraft, development of new certification processes and safety standards, and stakeholder trust in IA systems.

- *Legal and Social*: laws, regulations, and public concerns about privacy and safety.

Elements of a National Research Agenda for Autonomy in Civil Aviation

The report identifies eight high-level research projects that would address these barriers to implementation.

> **Recommendation: Agencies and organizations in government, industry, and academia that are involved in research, development, manufacture, certification, and regulation of IA technologies and systems should execute a national research agenda in autonomy that includes the following high-priority research projects, with the first four being the most urgent and the most difficult:**

Behavior of Adaptive/Nondeterministic Systems

> **Develop methodologies to characterize and bound the behavior of adaptive/nondeterministic systems over their complete life cycle.**

Adaptive systems have the ability to modify their behavior in response to their external environment and learn from their experience. *Nondeterministic systems* do not always respond in precisely the same way even when presented with identical inputs or stimuli. Because these properties often enable improved performance, many advanced IA systems are expected to be adaptive and/or nondeterministic. The built-in adaptability of advanced IA systems will create challenges for assessing and setting the limits of their resulting behaviors.

As advanced IA systems take over more functions traditionally performed by humans, there will be a growing need to incorporate autonomous monitoring and other safeguards to ensure continued appropriate operational behavior. There is tension between the benefits of incorporating software with adaptive/nondeterministic properties in IA systems and the requirement to test such software for safe and assured operation. Research is needed to develop new methods and tools to address the inherent uncertainties in airspace system operations and thereby enable more complex adaptive/nondeterministic IA systems with the ability to adapt over time to improve their performance and provide greater assurance of safety.

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.**

While crewed aircraft already employ varying levels of automation today, these systems still require continuous human supervision and human control over the aircraft as a whole. Advanced IA systems could allow unmanned aircraft to operate for extended periods of time without the need for human operators monitoring aircraft systems in real time. This could increase human safety, reduce costs of operation, and decrease human error. However, realizing these benefits depends on understanding how humans perform their roles in the present system and how these roles are translated to the IA system, particularly for high-risk situations.

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.**

Modeling and simulation capabilities will play an important role in the development, implementation, and evolution of IA systems in civil aviation because they enable researchers, designers, regulators, and operators to get information about how something performs without actually testing it in real life, forgoing the expense and risk associated with actual operations. For example, modeling and simulations enable designers to test some IA systems in literally millions of scenarios in a short time, evaluate design alternatives, and train adaptive (i.e., learning) IA systems through repeated operations. The committee envisions the development of a distributed suite of modeling and simulation modules by disparate organizations with the ability to be interconnected or networked, as appropriate, based on established standards.

Verification, Validation, and Certification

> **Develop standards and processes for the verification, validation, and certification of IA systems, and determine their implications for design.**

The high levels of aviation system safety achieved in the operation of the NAS largely reflect the formal requirements imposed by the Federal Aviation Administration (FAA) for verification, validation, and certification of hardware and software and the certification of personnel as a condition for entry into the system. However, current standards do not adequately address advanced IA systems. As was done in the past during the introduction of major new technologies, such as fly-by-wire and composite materials, the FAA will need to develop technical competency in IA systems and issue guidance material and new regulations. Furthermore, the broad range of aircraft sizes, masses, and capabilities envisioned in future civil aviation operations may present opportunities to reassess the current safety and reliability criteria for various components of the aviation system.

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.**

Open-source hardware and software are being widely used in the rapidly evolving universe of IA systems. This is particularly, but not uniquely, true in the active and growing community of hobbyists and prospective entrepreneurs who are developing and operating small unmanned aircraft. Many potential safety and economic benefits might be realized in the civil aviation environment by developing suitable methodology that would permit reliable, safe adoption of hardware and software systems of unknown provenance.

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 advanced IA systems.**

Effectively integrating humans and machines in the civil aviation system has been a high priority for decades. Although the reliance on high levels of automation today has increased the overall levels of system safety, problems arise when operators lack an appropriate mental model of what the automation is doing at any given time, particularly in dynamic situations. Not only are there significant issues surrounding responsibilities of humans in such systems, but there are also important new questions about the properties and characteristics of the human–machine interface posed by the adaptive/nondeterministic behavior of these systems. While some of these issues can be addressed by examining duties, responsibilities, and skills and training required for pilots, air traffic controllers, and other humans in the system, implementing advanced IA systems may require new roles and radical realignment of the more traditional roles of such human actors.

Safety and Efficiency

> **Determine how IA systems could enhance the safety and efficiency of civil aviation.**

As with other new technologies, poorly implemented IA systems could put at risk the high levels of efficiency and safety that are the hallmarks of civil aviation, particularly for commercial air transportation. However, done properly, advances in IA systems could enhance both the safety and the efficiency of civil aviation. For example, IA systems have the potential to reduce reaction times in safety critical situations, especially in circumstances that today are encumbered by the requirement for human-to-human interactions.

Stakeholder Trust

> **Develop processes to engender broad stakeholder trust in IA systems for civil aviation.**

IA systems can fundamentally change the relationship between people and technology, and one important dimension of that relationship is trust. Although closely related to verification, validation, and certification, trust warrants attention as a distinct research topic because formal certification does not guarantee trust and eventual adoption. Stakeholder trust is also tied to cybersecurity and related issues; trustworthiness depends not only on designers' intents but also on the degree to which the design prevents either inadvertent or intentional corruption of system data and processes.

Coordination of Research and Development

All of the research projects described above can and should be addressed by multiple organizations in the federal government, industry, and academia. The roles of academia and industry would be essentially the same for each research project because of the nature of the role they play in the development of new technologies and products. While the scope of this study does not include organizational recommendations, the FAA, Department of Defense, and NASA all have interests that coincide with the recommended research agenda. Effective coordination among relevant organizations in government, academia, and industry would help execute the recommended research projects more efficiently, in part by allowing lessons learned from the development, test, and operation of IA systems to be continuously applied to ongoing activities.

The recommended research agenda would directly address the technology barriers and the regulation and certification barriers. In the absence of any other action, resolution of the legal and social barriers will probably be quite lengthy, as court cases are filed to address various issues in various locales on a case-by-case basis. A more timely and effective approach for resolving the legal and social barriers could begin with discussions involving the Department of Justice, FAA, National Transportation Safety Board, state attorneys general, aviation community stakeholders, and others. Given that the FAA is the federal government's lead agency for establishing and implementing aviation regulations, it is in the best position to take the lead in initiating a collaborative and proactive effort to address legal and social barriers.

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