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REPORT IN BRIEF

A Review of the Next Generation Air Transportation System: Implications and Importance of System Architecture

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In 2012, Congress directed the Federal Aviation Administration (FAA) to request an examination of the Next Generation Air Transportation System (NextGen) from the National Research Council. *A Review of the Next Generation Air Transportation System* finds that NextGen currently emphasizes modernizing aging equipment and systems—a shift from its original vision that is not clear to all stakeholders. Nevertheless, modernization is critical, requiring ongoing support. The report explains that NextGen needs an explicit system architecture—in addition to its existing enterprise architecture—to guide its development, manage risk, and cope with change. To create this architecture, FAA should build an architecture community and also strengthen its work force in several technical fields. The report also examines the incorporation of cybersecurity, unmanned aircraft systems, and human factors into the NextGen architecture. Finally, the report considers NextGen's anticipated costs and benefits, noting that airlines are not motivated to spend money on NextGen because they receive few direct benefits and face schedule uncertainty.

Background

The Next Generation Air Transportation System is an effort begun in 2003 whose goals include improving the capacity, efficiency, and safety of the U.S. air transportation system and also enabling reduction in noise, pollution, and energy use. FAA and various stakeholders, including equipment providers, airlines, and contractors, are currently implementing both near-term and mid-term NextGen capabilities. The Federal Aviation Administration Modernization and Reform Act of 2012 calls for the National Research Council to examine NextGen's enterprise software development approach and safety and human factor design. The National Research Council assembled a committee of experts to study the issue.

Aligning Expectations

In the course of the committee's study, it became clear that "NextGen" means different things to different people, ranging from a wide-ranging transformational vision to a much more concrete set of phased incremental changes to various parts of the national airspace system (NAS). In the committee's view, NextGen is a set of programs to implement a suite of incremental changes to the NAS.

An important and necessary part of NextGen is addressing urgent requirements to replace aging equipment. NextGen also includes efforts to further deploy performance-based navigation, to redesign certain aspects of the airspace, to equip aircraft with technology that can form the basis for future capabilities, and an additional broad range of activities. However, NextGen does not set out a series of planned steps toward a fundamentally-transformed end-state. "NextGen" has become a misnomer.

> **Recommendation: The FAA, Congress, and all NAS stakeholders should reset expectations for NextGen. FAA should explicitly qualify the early transformational vision in a way that clearly articulates the new realities.**

Asserting Architectural Leadership

Enterprise Architecture

An enterprise architecture supports and documents existing systems and business processes. The current NextGen enterprise architecture appears to be a set of functional enclaves that are providing individual services, described in a set of documents at the

NAS enterprise architecture level. This tacit architecture is bottom-up and program-driven. This approach to enterprise architecture is not an adequate technical foundation for steering NextGen's technical governance and managing the inevitable changes in technology and operations.

System Architecture

A system architecture models and defines the structure and behavior of a system in a way that supports reasoning about the system and its characteristics. A system architecture for the NAS should help ensure proper operation of the system, allow proper analyses for prediction of system behavior, performance, and so on, and ensure future evolvability. The current NAS system architecture is not well-developed, though this is difficult to discern because of the nearly exclusive focus by the FAA on the enterprise architecture.

Architectural Leadership

Having de facto established the existing baseline architecture as *the* NAS architecture, many opportunities to use the architecture in forward-looking ways have been ruled out. Thus, the FAA has put itself in a position where some important advances are going to be extremely challenging to accomplish.

The most important thing on which the FAA should focus with respect to architecture is building a community of technical leaders within and outside the agency. Architectural leadership should encompass multiple perspectives (including, but not limited to, the enterprise architecture) and provide diversity of thought and approach. To be clear, the report does not urge the premature creation of more detailed specifications and artifacts absent deeper insights and stronger analyses of risks and tradeoffs.

Recommendation: FAA should initiate, grow, and engage a capable architecture community—leaders and peers within and outside FAA—who will expand the breadth and depth of expertise that is steering architectural changes.

Recommendation: The FAA should conduct a small number of experiments among its system integration partners to prototype candidate solutions for establishing and managing a vibrant architectural community.

Recommendation: FAA should use an architecture leadership community and an effective governance approach to assure a proper balance between documents and artifacts and to provide high-level guidance and a capability that 1) enables effective management and communication of dependencies; 2) provides flexibility and evolvability to ensure accommodation of future needs; and 3) communicates changing circumstances in order to align expectations.

Currently, FAA is ill-equipped to perform as a systems integrator. If FAA is to succeed in both the medium and long term, it will require enhancements to its technical expertise.

Recommendation: FAA should nurture workforce talent in the areas of systems engineering, architecture, systems integration, digital communications, and cybersecurity. Significant effort will be required to attract, develop, and retain this talent given high demand outside the FAA.

Recommendation: Should FAA continue to act as the systems integrator of NextGen programs, FAA should maintain architectural leadership and not delegate architecture definition and control to contractors.

Operations and Maintenance

Although Congress has been supportive of FAA efforts, the report finds a specific need for support of ongoing maintenance and modernization (upgrades), including modernizing both the hardware and software so as to provide reliable, cost-effective operation.

Finding: As a large-scale, software-intensive system, NextGen and the NAS will benefit if ongoing maintenance of the NAS and its hardware and software systems are supported—in addition to programmatic investments; such an approach will make the most of past and ongoing investments.

Managing Risk

The challenge for complex systems such as NextGen is not how to eliminate risks but rather how to manage them successfully. This usually means understanding the consequences of risky decisions as early in the project's life cycle as possible, lest the costs of unwinding previous bad decisions become prohibitive. An effective architecture can be a basis for risk assessment and mitigation and can also be used as a tool to support decision-making. The risks to NextGen are not clearly articulated and quantified in order of importance, making it difficult to make sound decisions about how to prioritize effort and allocate resources.

Recommendation: The FAA should use an architecture leadership community and a system architecture, with input from specialists in probability and statistics, as a key tool in managing and mitigating risks and in assessing new value opportunities.

Coping with Change

In concert with revising the architectural approach for NextGen, planning to cope with unanticipated change is needed. Cybersecurity and unmanned aircraft systems (UAS) are two examples that illustrate why planning for resilience in NextGen is so important.

Cybersecurity

Cybersecurity, by its very nature, demands constant adaptation to a dynamic threat environment. FAA has acknowledged cybersecurity as an issue and has some efforts underway to address it. However, it is the report committee's impression that cybersecurity has not been fully integrated into the agency's thinking, planning, and efforts. As new technologies and procedures are rolled out and long-stable technologies are used in different ways, new vulnerabilities will arise. So threat analyses are needed both on existing systems with any expected changes and on new components.

> **Recommendation: The FAA should incorporate cybersecurity as a systems characteristic at all levels of the architecture and design. The FAA should begin by developing a threat model followed by an appropriate set of architectural and design concepts that will mitigate the associated risks, support resilience in the face of attack or compromise, and allow for dynamic evolution to meet a changing threat environment. The FAA should inculcate a cybersecurity mindset complementary to its well-established safety mindset throughout the organization, its contractors, and leadership.**

Unmanned Aircraft Systems

Several NextGen technologies are essential to the safe integration of UAS into the NAS. However, NextGen planning and architecture did not explicitly anticipate the introduction of UAS and thus does not readily lend itself to incorporating these new types of aircraft. Thus, the integration of UAS is an example of a rapidly emerging requirement that could provoke disruptive changes, to both technology and to roles and responsibilities. The report urges that FAA use UAS as a use case for developing a better approach to system architecture (and associated technical and procedural designs).

> **Recommendation: The FAA and its architecture leadership community should look for and apply lessons from the challenge of integrating UAS into the NAS as it develops an effective system architecture. The FAA and its architecture leadership community should incorporate measures in the NAS system architecture to address UAS integration.**

Incorporation Human Factors

The medium-term plans for the NAS will not fundamentally change the roles and activities of human pilots and controllers. However, even with modest changes, misunderstandings and errors can result. Just like technical factors, human factors are an important ingredient in—and potential bottleneck to—successful changes. When human factors are not included at the outset of design, products and services may need to be modified subsequently to meet the human factors' requirements, delaying release and increasing cost.

> **Recommendation: The FAA should recognize and incorporate in early design phases the human factors and procedural and airspace implications of stated goals and associated technical changes. In addition, FAA should ensure that a human factors specialist, separate from the research and certification groups, have sign-off authority within the NextGen approval process.**

Assessing Costs and Benefits

NextGen plans require a substantial investment, both by the taxpayer via FAA for infrastructure, and by carriers and aircraft owners for equipage and training. At best, benefits—however quantified—to carriers will lag deployment costs. Benefits that accrue to the carriers will be less than the projected social benefits to the system as a whole (quantified in the form of reduced delays to passengers). Furthermore, for airlines to gain significant benefit, NextGen capabilities will need to be deployed at sufficient scale. Although modernization efforts are important and can bring significant benefits, it remains a challenge to incentivize uptake for equipage, training, or changes in procedures absent clear benefits.

> **Recommendation: Preceding any further equipage mandate, FAA should provide an estimated statement of costs and benefits, mutually reviewed and agreed with the relevant stakeholders. It should be based upon a mature and stable technical specification, and a committed timeline for FAA deliverables and investment (for procedure and airspace design, infrastructure deployment, training, and so on). On this basis, industry could responsibly invest as required, given a reasonable expected return.**

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