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"ATM Research: Challenges for the Decade Ahead"
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Berkeley, CA
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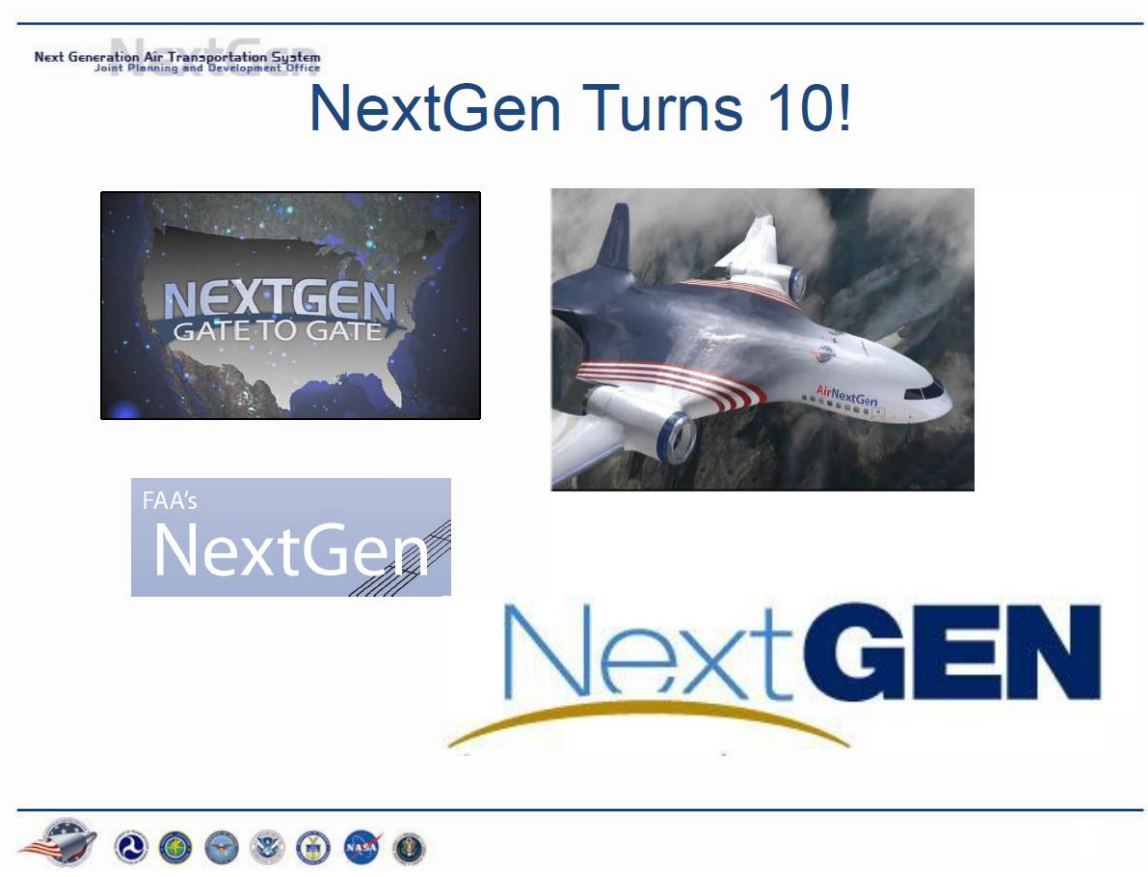
[Remarks as prepared for delivery.]

Good morning! It is a privilege to speak to you this morning because you are the future—you will see and do things that I never dreamed possible. I'd like to talk about how together we will create a global aviation future. And, what better place to have this discussion than Berkeley? I lived just down the road in the South Bay when I was a researcher at NASA Ames. I remember Cal Berkeley as a place for innovative thinking—a place where things were done differently. And that is the spirit I would like to capture at this forum.



As air traffic researchers, how many have heard of the modernization initiatives NextGen or SESAR? Now, how many know that this year marks a decade of research toward NextGen? That's right, NextGen is 10 and SESAR is not much younger.

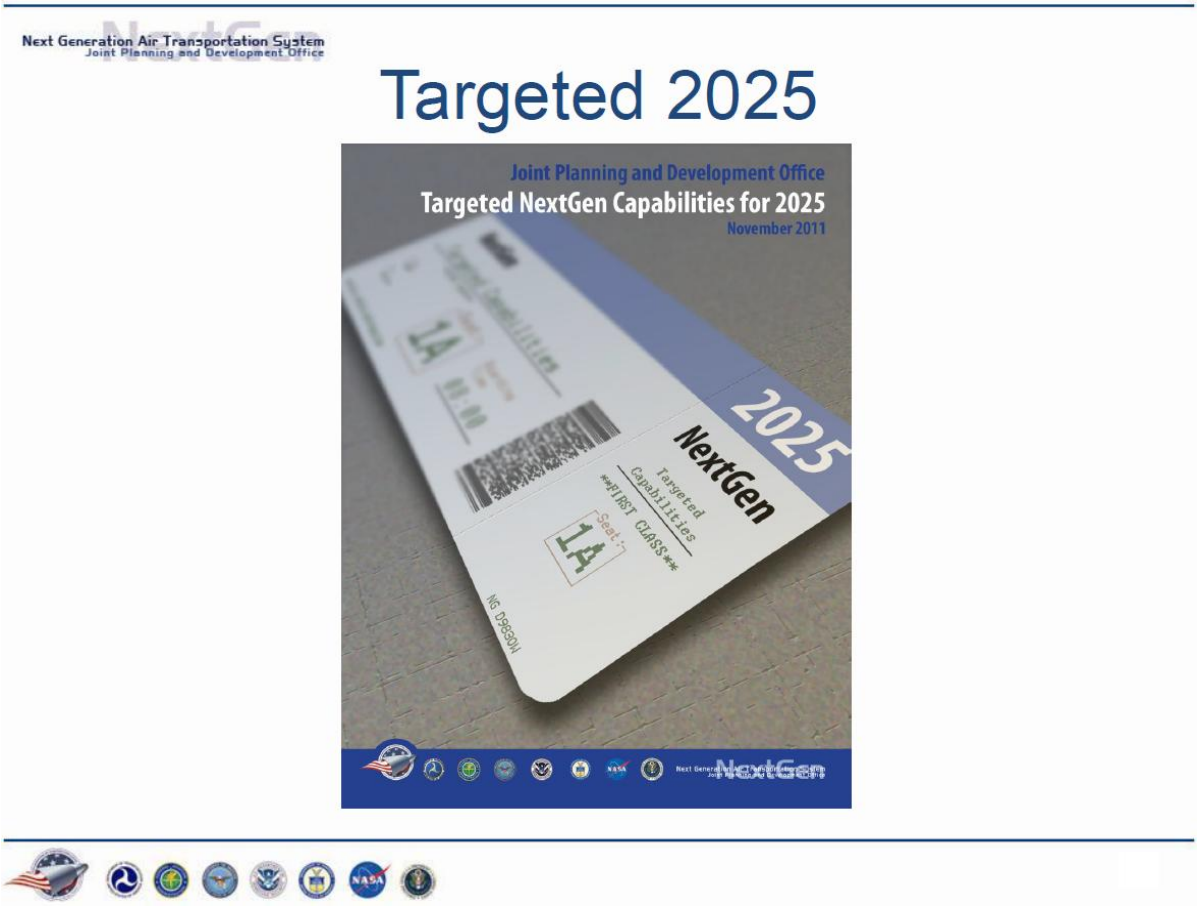
During this time, the NextGen brand has evolved. The NextGen vision called for transformation. Our highways in the sky were jammed. Delivery of goods and services that make the economy strong could not happen without efficient networks. Our country urgently needed one thing: capacity.

I was part of the early visionary team and I worked with colleagues in Europe to formulate new air traffic management (ATM) concepts. In fact, as a researcher, I tried to make sure every interesting idea was in the vision. Perhaps I just wanted job security. Of course, even then I knew that these ideas would all need to be tested and some would end up being discarded.

So, how is NextGen progressing? Are we on the path to transformation?

There has been tremendous progress in getting the infrastructure into place. Air traffic operations are already moving to satellite-based navigation and network-to-network communications. Although the progress is a little behind the initial schedule, that's to be expected because building large, complex systems with many transition steps is a lot harder than the strategic planners envisioned.

The question for us is, "Are we doing the right research and development now to use this infrastructure to reach the far-term vision?”



Last year, my office, the Joint Planning and Development Office (JPDO), analyzed the pace of NextGen implementation and assessed costs, benefits, risks, and policies to understand what the air transportation system might reasonably look like in 2025. We called our report "Targeted 2025." As the steward of the long-term vision, the JPDO took an optimistic (or aggressive) posture. Nevertheless, we discovered that our target system falls far short of the full vision.

This study helped the JPDO identify where development is needed to tie up loose ends for implementation and perhaps, more importantly, to identify where truly fundamental research is needed. The JPDO mapped ongoing U.S. research against this view and found many good projects underway for NextGen. I believe the same is true for SESAR. However, the research, as good as it is, is not complete.

My talk will focus on the far-term, and three particular challenges that I see looming on the horizon:

- Integration of Unmanned Aircraft Systems (UAS)
- Trajectory-based Operations (TBO) and human roles
- Complexity

I will explain why I chose these topics and what should be done. Then, I will close with some of my thoughts on how the ATM research you will be doing in your careers will be different than in it has the past.

UAS Integration

In the 2005-2006 timeframe, when Very Light Jets (VLJ) were multiplying (as it was once said, threatening to blacken the skies), the JPDO did considerable analysis to see how these aircraft could be accommodated. The JPDO looked at what flight plans and airports might be used and what metrics were needed. Was the system flexible enough? Was it scalable to these new traffic patterns? Were new policies needed?

Fast forward to today. Recently, a headline in PCWorld read, "TacoCopter Delivers Tacos by Quadrocopter." Is this a joke or a legit new San Francisco business? Okay, TacoCopter is not an actual service, but people are dreaming new ideas! Imagine: food delivery by flying robots!

This is a new frontier for aviation—uncharted territory. There are new flight paradigms for small, medium, and large UAS of varying performance. Pilot and controller roles for this widely mixed fleet of remotely piloted and autonomous vehicles must be defined. Can UAS operate efficiently in the National Airspace System (NAS) under the existing airspace policies?

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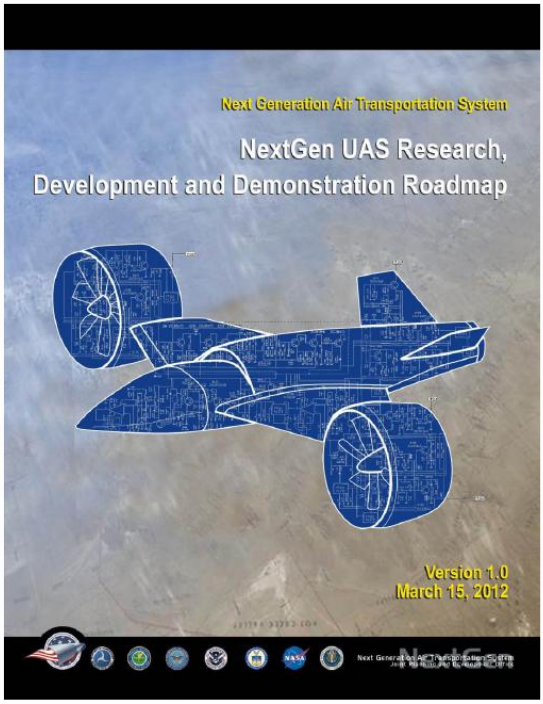
UAS Research



Last year, more than 60 experts from the JPDO and our U.S. government partners created a Research, Development and Demonstration Roadmap to identify technical challenges for Communications, Airspace Operations, Unmanned Aircraft, and Human Systems Integration. This initial Roadmap is a blue print for identifying and addressing technical challenges for routine UAS operations in NextGen. It's not a complete timeline but rather a baseline of government-wide goals for the next five years. Essentially, the Roadmap is a snapshot in time.

Several major challenges stood out:

- Sense and avoid capability for UAS
- Dedicated protected spectrum for control links
- Unmanned aircraft and cockpit certification standards

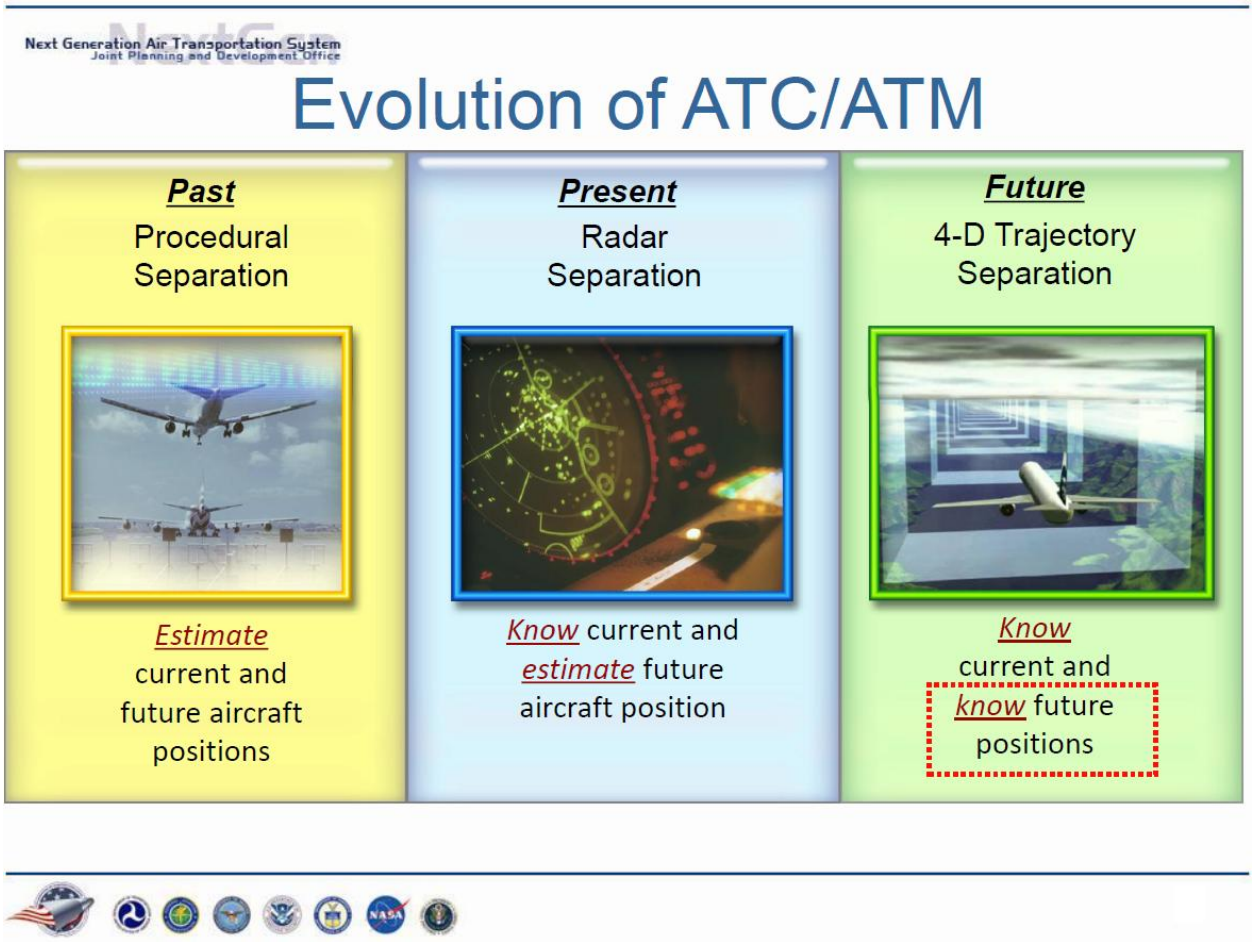
Going forward, the JPDO recommends three parallel phases of activity for UAS integration: accommodate, integrate, and evolve. Research is needed to support each phase.

In the mid-term, coinciding with the FAA's implementation plans for NextGen, how will we define safe integration given the set of airspace technologies, procedures, and standards available? For example, could operations take place in low-density airspace? Will the mixed fleet work in the same airspace?

Our UAS Roadmap work showed that a common concept of UAS operations is missing. It is needed to guide further research prioritization, creating a single point-of-view from where we can decide what needs are most-pressing.

As longer-term NextGen capabilities are deployed, UAS flights will benefit from the added capacity and increased flexibility through precision performance against agreed-to and predictable flight paths.

The recent call for a variety of UAS missions—for defense, homeland security, and civil applications—has not gone unnoticed. UAS will operate together with traditional commercial and general aviation aircraft. These cultures, with different objectives, will have to reach consensus. Both the public and pilots have expressed safety concerns—for technical and social reasons. And, there is a growing concern about UAS invasion of privacy. Despite the huge expected growth—for firefighting, wildlife observation, or pipeline inspection—there is still uncertainty about all the possible applications of UAS. This too complicates the design of a NAS that includes all user missions.



TBO and the Human Role

Quoting from the FAA's NextGen Web site, "It started with bonfires: Immense torches waving from the horizons guided the first pilots from grass runway to grass runway as they delivered the most important commodity of the day: mail." The days of the barnstormers are long gone, with bonfires replaced by beacons and radar towers. With NextGen, satellites will guide manned and unmanned aircraft along their routes.

When I speak about TBO, I am referring to the generation beyond the initial trajectory operations today. The underpinnings of TBO are trajectory planning and re-planning, negotiation and execution. Pilots, controllers, flow managers, and airline operation centers may see their roles change. They will interact with each other and with automation in new ways. The concept expands the value of flight planning and relies on automation to perform separation, based on a combination of the current and future position of each aircraft. Separation must always work. While any change in the approach to separation represents a significant cultural shift, increased collaboration through net-centric operations to improve common situational awareness will increase predictability and reduce variability. This concept is about choices, negotiations, and precision.

Organizations such as NASA and the FAA are performing TBO research today, focusing on selected aspects of the concept. The problem is that we need a systemic approach to resolving key research questions. A little over a year ago, the JPDO completeted a study that laid out the initial TBO concept, identifying more than 40 research topics. An ongoing study may suggest that a systemic approach could focus on less than 10 challenge areas or tall poles that are common problems across the flight profile. A few of the unknowns are:

- What is the nature of the planning and negotiation functions? How would an airline operation center negotiate trajectories to meet their business needs?
- When does a trajectory need re-negotiated? How often and for what cause?
- How resilient is the plan when the system is interrupted by weather, airport acceptance rate change, or unexpected aircraft entering the zone?
- Should aircraft separation be ground-based? If not, what is the best role for the pilot and cockpit automation?

The JPDO's study questioned whether the TBO concept could be safe—what about failure modes, human factors, geometric complexity, and degradation? Experts from government and industry examined this question, concluding that there were no "show stoppers" but that safety research, a public safety policy-setting process involving all stakeholders, and extensive simulation or flight testing were needed.

From my perspective, one of the challenges to safety assurance of TBO is Validation and Verification (V&V). It is a major risk to long-term transformation. Prior JPDO work showed that current V&V tools and techniques will not be adequate to deal with such a complex socio-technical system with new roles for humans and greater automation. Today's tools make assumptions about the independence of different parts of the system—an assumption that falls apart when you consider the many interdependencies of NextGen components. The tools we have now are also insufficient in dealing with people as an integral part of the "system of systems"—again, a fundamental characteristic of NextGen. Validation, throughout the research, development, implementation, and operations lifecycle, must ensure safety, and that the system of systems—including people—works.

Further, with TBO, we will no longer be able to depend on the traditional redundancies that made the ATM system robust. Think about this as the independence of the communications, navigation and surveillance systems, and the controller's ability to keep traffic moving when automation failed. The design of TBO has to ensure that the system is resilient to all kinds of system perturbations and failures, and that the V&V tools for NextGen must validate the resilience of that system design.

There is another kind of resilience to consider: concept resilience to different futures. The shift to the TBO I described is more than 20 years away. I remember being asked in the 1980's what I would do if this new DARPA technology, called the Internet, were available on my desktop computer. How would I use it? I just figured I wouldn't need to take as many trips to the library. I was amazingly short-sighted.

Predicting the future is hard, if not fully impossible.

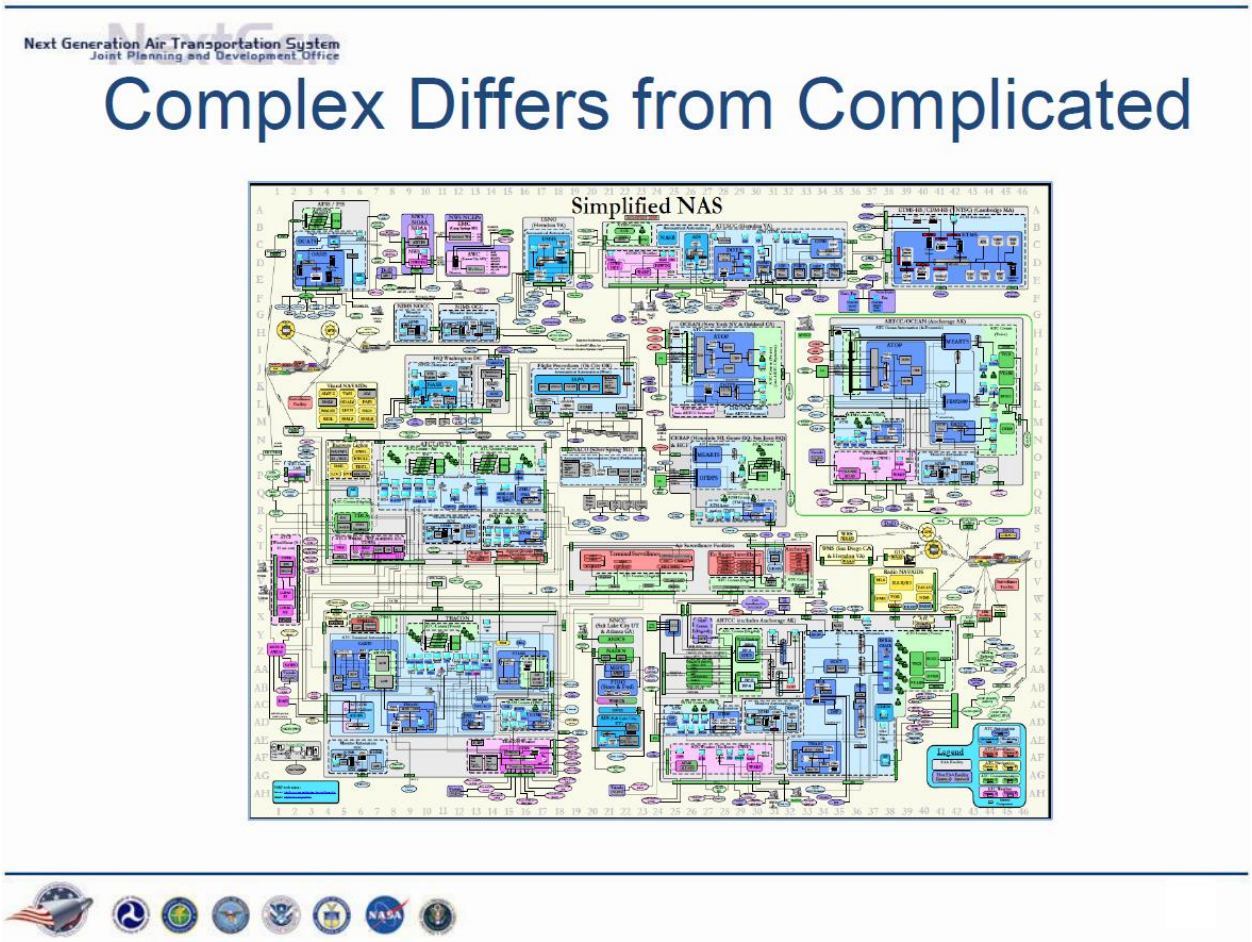
The F-22 Raptor in this picture is a fantastic airplane—America's most advanced fighter for the 20th century. ABC Television’s Brian Ross had a different take saying, "The truth about the F-22 is that it's never flown in combat because it was built to fight an advanced Soviet jet fighter that doesn't exist." There have been calls to end F-22 production after cost overruns and delays.

Since the F-22 was designed, the world has changed. The F-22 is no longer really needed. This should be an important lesson for us.

In just 10 years since we started NextGen, there are different driving requirements. In 2003, our concern was primarily capacity. Today, we are also concerned about the environment and UAS integration.

I challenge you to imagine the world 20 years from now. How will your concepts work in the many possible worlds of the future? Air transportation system design needs a second kind of resilience: it must be able to respond to changing requirements.

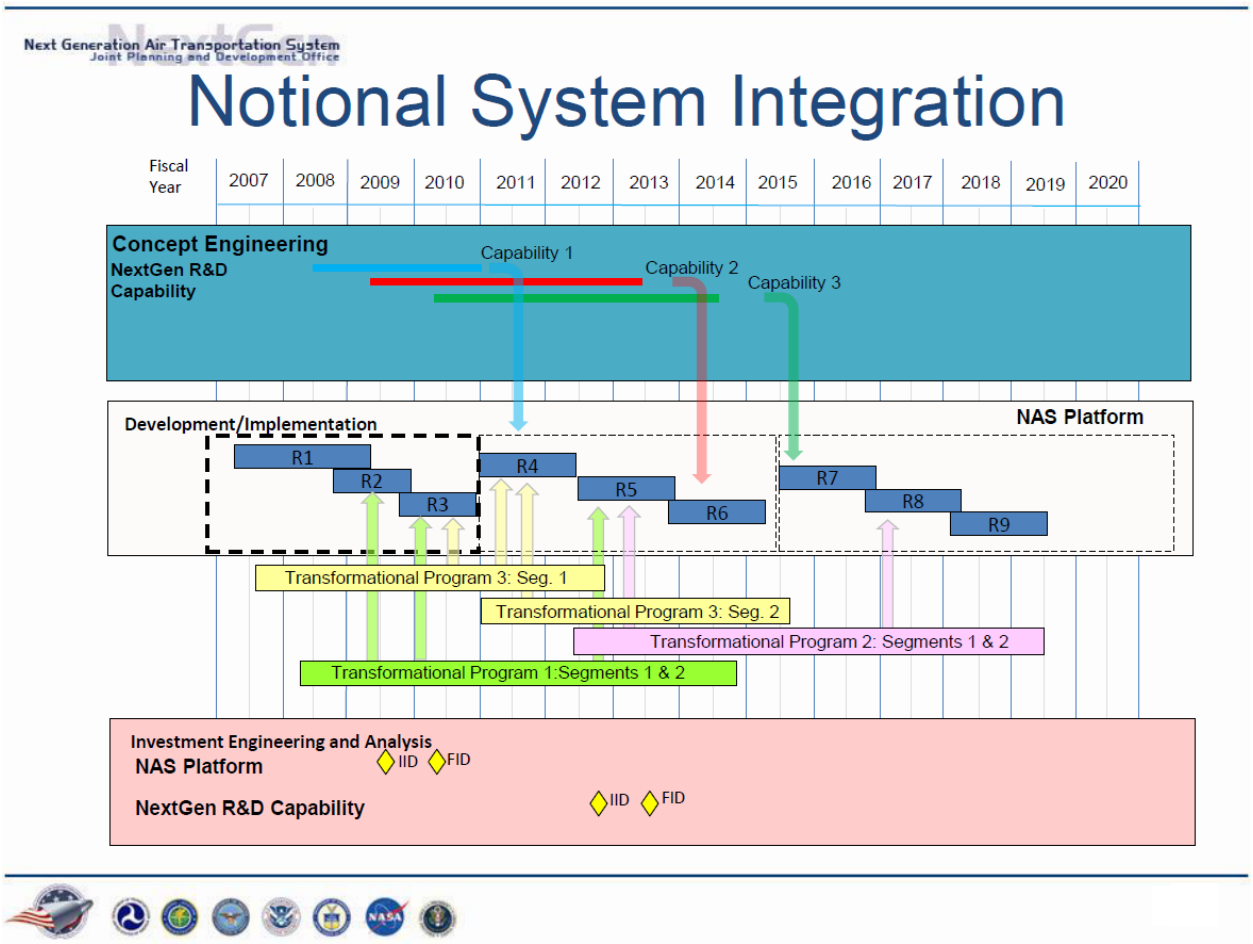
Complexity



As an engineer, I am always intrigued by technology. That said, I think it should be clear by now that the challenges for UAS and TBO go far beyond technology alone. NextGen is a complex system requiring a whole new set of R&D.

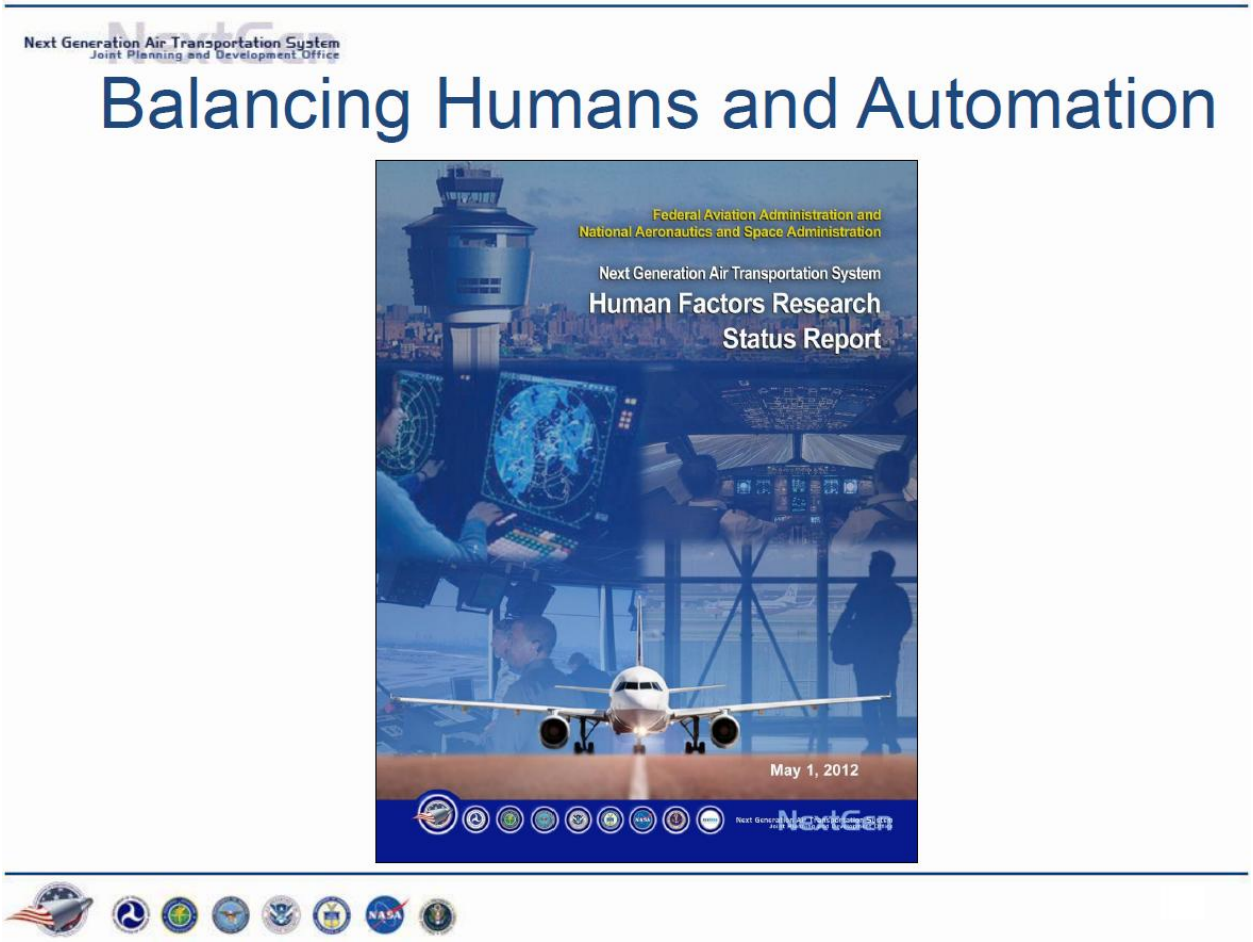
Wikipedia defines a complex system as "a system composed of interconnected parts that as a whole exhibit one or more properties (behavior among the possible properties) not obvious from the properties of the individual parts."

The wiring chart on this slide, called "the Simple NAS," shows a very complicated system. Don't confuse a complicated system with a complex one.



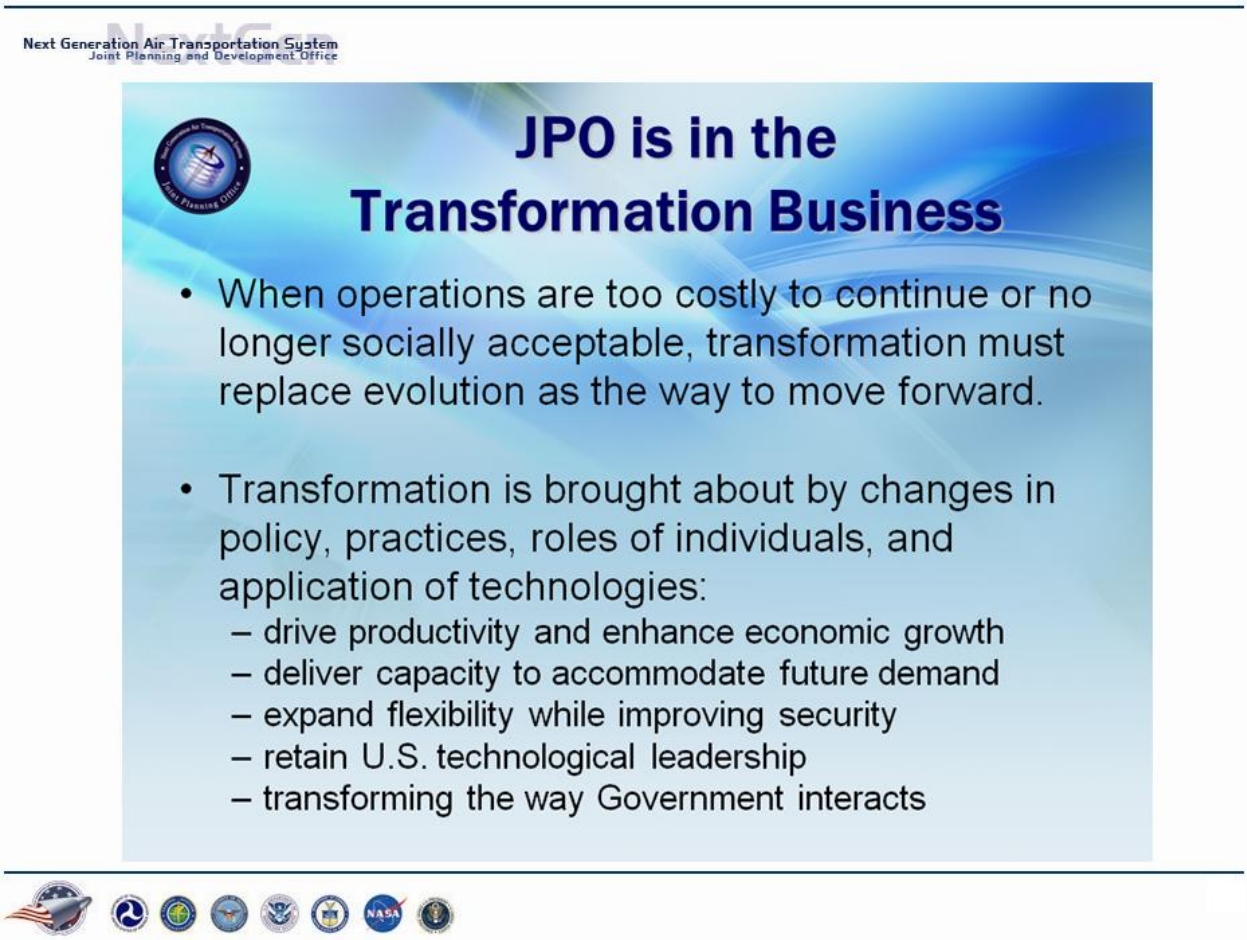
Similarly, this notional chart illustrates the tiny windows of opportunities where new capabilities can be integrated into software or hardware platforms in the NAS. This requires careful systems engineering to bring the pieces together.

NextGen and SESAR have many organizations and agents (both people and machines) that must all work together. It is a very complex system, where technology must be considered along with public policy. In the past, engineers decomposed systems into parts, designed the individual parts and recombined the parts to make the whole.



Given the many interactions of people and equipment, which may lead to emergent behavior, it may not be possible to understand how the whole system will work as the parts are designed. Our R&D community is starting to pay attention. For example, SESAR Work Package-E, ComplexWorld EU, and the work Bruce Sawhill spoke about yesterday begin to consider how the pieces need to fit together. Past practices of looking separately at surface, terminal, and en route solutions won't be the norm for TBO research.

I have shared a few thoughts on UAS, TBO, and complexity. So what does all this tell us about the research you will be doing in the coming decade?



When we started NextGen 10 years ago, we were driven by a bold vision of transformation. We said that when operations are too costly to continue or are no longer socially acceptable, transformation must replace evolution as the way forward. That transformation is brought about by changes in policy, practices, roles of individuals, and new technology.

Today, looking out 10 to 15 years, I see that we may not be able to afford the cost of safe system operation without doing things smarter, with more automation, and changing roles. This requires immediate research attention. The R&D of the past that addressed the hard technical problems will continue to play a very large role. But success will require a broader scope that entails understanding of complex system engineering issues, integrating social science and public policy with traditional engineering to understand the system of systems aspects for NextGen.

To succeed in this, you will need to be willing to be bold and think and work in new ways.

I was energized by a TED talk by Regina Dugan, the former Director of DARPA, given in March of this year. She said, "Failure is part of creating new and amazing things. We cannot both fear failure and make amazing new things."

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DARPA's Hummingbird Nano Air Vehicle

http://www.ted.com/talks/regina_dugan_from_mach_20_glider_to_humming_bird_drone.html

She explained how DARPA developed a hummingbird drone. The hummingbird is the only animal that can fly forward, hover, fly backward, and upside down—and so can the drone. At first, the artificial bird crashed repeatedly; then it flew for only a few seconds. But the researchers didn't give up until the hummingbird finally flew. This could never have happened without accepting and learning from the repeated failures.

Don't ever let anyone tell you that you can't do something you believe possible. Dream big. Aim high. It's the hallmark of aviation.

What would have happened if the Wright brothers got discouraged? They suffered from physical and mental illnesses—not easily treatable in those days—before they started a bicycle repair shop, which led to experimenting with powered flight. After many attempts at creating a working aircraft, years of hard work, and hundreds of failed flights, they finally made a plane that could get airborne, stay in the air for 12 seconds, and travel a distance of 120 feet.

I began the morning by telling you that NextGen has made a great deal of progress in building the NextGen infrastructure. My challenge to you is to find ways to build on this infrastructure and move Air Traffic Management into the next century of flight.

And, as Regina Dugan said in her TED talk, "Don't be afraid to fail. Ask yourself what you would do if you knew you could not fail!"

Thank you.