National Aeronautics and Space Administration

NEW AVIATION HORIZONS INITIATIVE
and Complementary Investments

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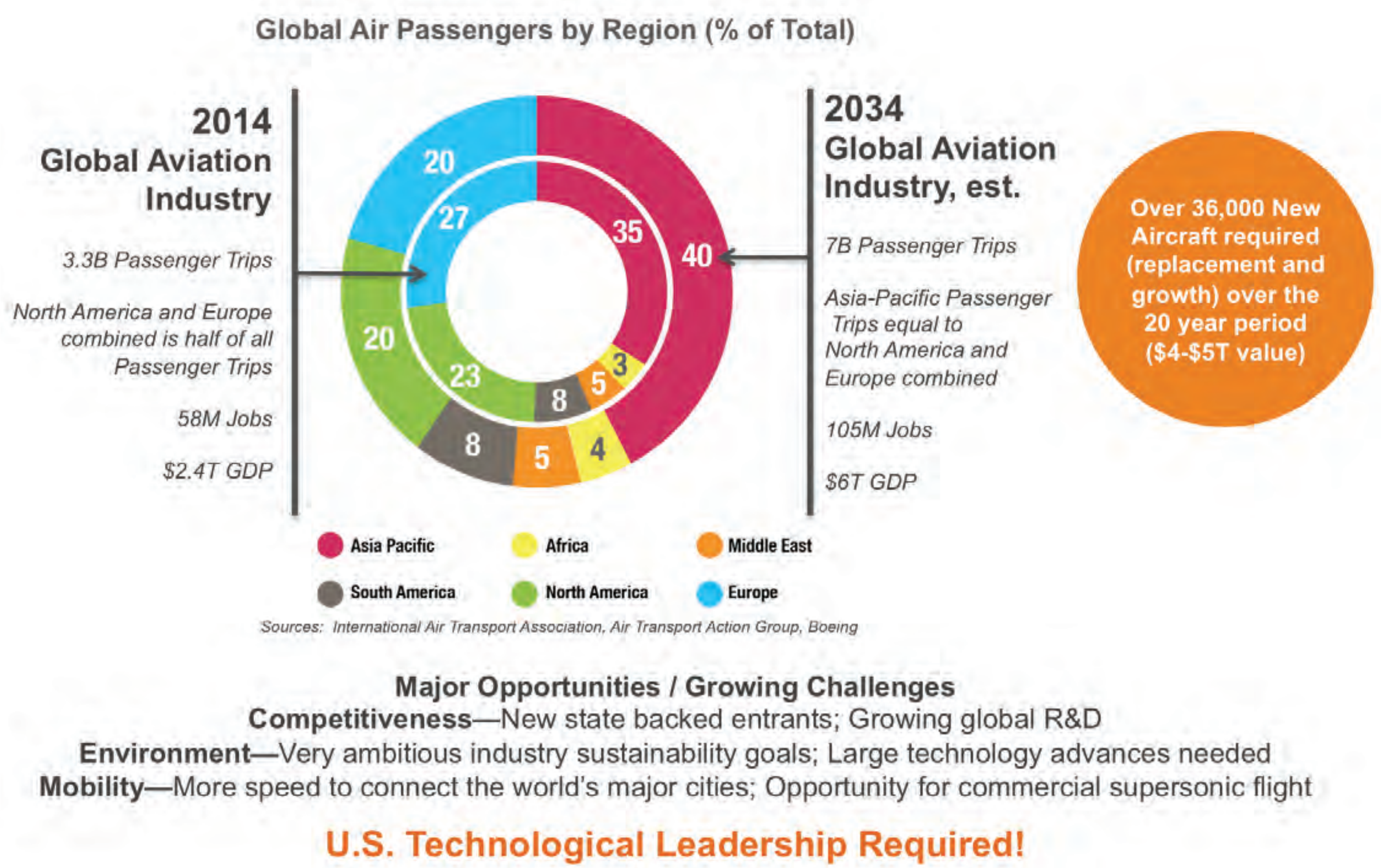
GLOBAL CHANGES CHALLENGE U.S. LEADERSHIP IN AVIATION

The aviation system is the high-speed transportation backbone of the United States and global economies. Global aviation is forecast to grow from today's 3.5 billion passenger trips per year to 7 billion passenger trips by the mid-2030s, and to 11 billion passenger trips by mid-century. Such growth brings with it the direct economic potential of trillions of dollars in the fields of manufacturing, operations and maintenance, and the high-quality jobs they support.

At the same time, international competition for leadership of this critical industry is growing, as more nations invest in developing their own aviation technology and industrial capabilities.

Such massive growth also creates substantial operational and environmental challenges. For example, by mid-century the aviation industry will need to build and fly enough new aircraft to accommodate more than three times as many passenger trips while at the same time reducing total emissions by half from that new hardware. Moreover, large reductions in emissions and aircraft noise levels will be needed, if not mandated. To meet those demands, revolutionary levels of aircraft performance improvements – well beyond today's technology – must be achieved. In terms of air traffic control and the National Airspace System, maintaining safe and efficient operations is a continuing and growing

Global Growth in Aviation: Opportunities and Challenges



challenge as the system expands, and especially as new business and operational models – such as unmanned aerial systems – are introduced. Enabling aircraft (with pilots aboard or not) to fly optimized trajectories through high-density airspace with real-time, system-wide safety assurance are among the most critical operational improvements that must be achieved.

For more than a century the nation has confidently turned to NASA and its predecessor organization, the National Advisory Committee for Aeronautics, for solutions to aviation's biggest challenges in the air and on the ground. The resulting technology developed through the years by NASA's world class aeronautical innovators today finds itself aboard every U.S. aircraft and inside every air traffic control tower in the country. Much of this success also is the upshot of one of the most productive public-private partnerships in U.S. history, as NASA has and continues to team with industry, academia and other government agencies including the Federal Aviation Administration (FAA) and the Department of Defense. Now with NASA and its rich research heritage at the heart of this ongoing collaboration, the stage is set to enable a new era in aviation as revolutionary to the world as the introduction of the commercial jet age during the 1960s and the invention of flight itself in 1903. Only vigorous and sustained investment in this pursuit will ensure the United States maintains its continued technological leadership.

In FY 2017, NASA plans to begin a major 10-year research effort to accelerate aviation energy efficiency, transform propulsion systems, and enable major improvements in air traffic mobility.

NASA has made decades of contributions to aviation. Every U.S. aircraft and control tower uses NASA-developed technologies.

NEW AVIATION HORIZONS INITIATIVE

The centerpiece of NASA's 10-year acceleration for advanced technologies testing is called New Aviation Horizons, or NAH. It is an ambitious plan to build a series of five mostly large-scale experimental aircraft – X-planes – that will flight test new technologies, systems and novel aircraft and engine configurations.

X-planes are a key piece of the "three-legged stool" that characterizes aviation research. One leg represents computational capabilities – the high-speed super computers that can model the physics of air flowing over an object – be it a wing, a rudder or a full airplane.

A second leg represents experimental methods. This is where scientists put what is most often a scale model of an object or part of an object – be it a wing, a rudder or an airplane – in a wind tunnel to take measurements of air flowing over the object. These measurements help improve the computer

One exciting piece of NASA's 10-year research acceleration plan is an ambitious undertaking to design, build and fly a variety of flight demonstration vehicles as a way to test advanced technologies and revolutionary designs — all to reduce the time it takes for those technologies to be adopted by industry and moved into the marketplace.

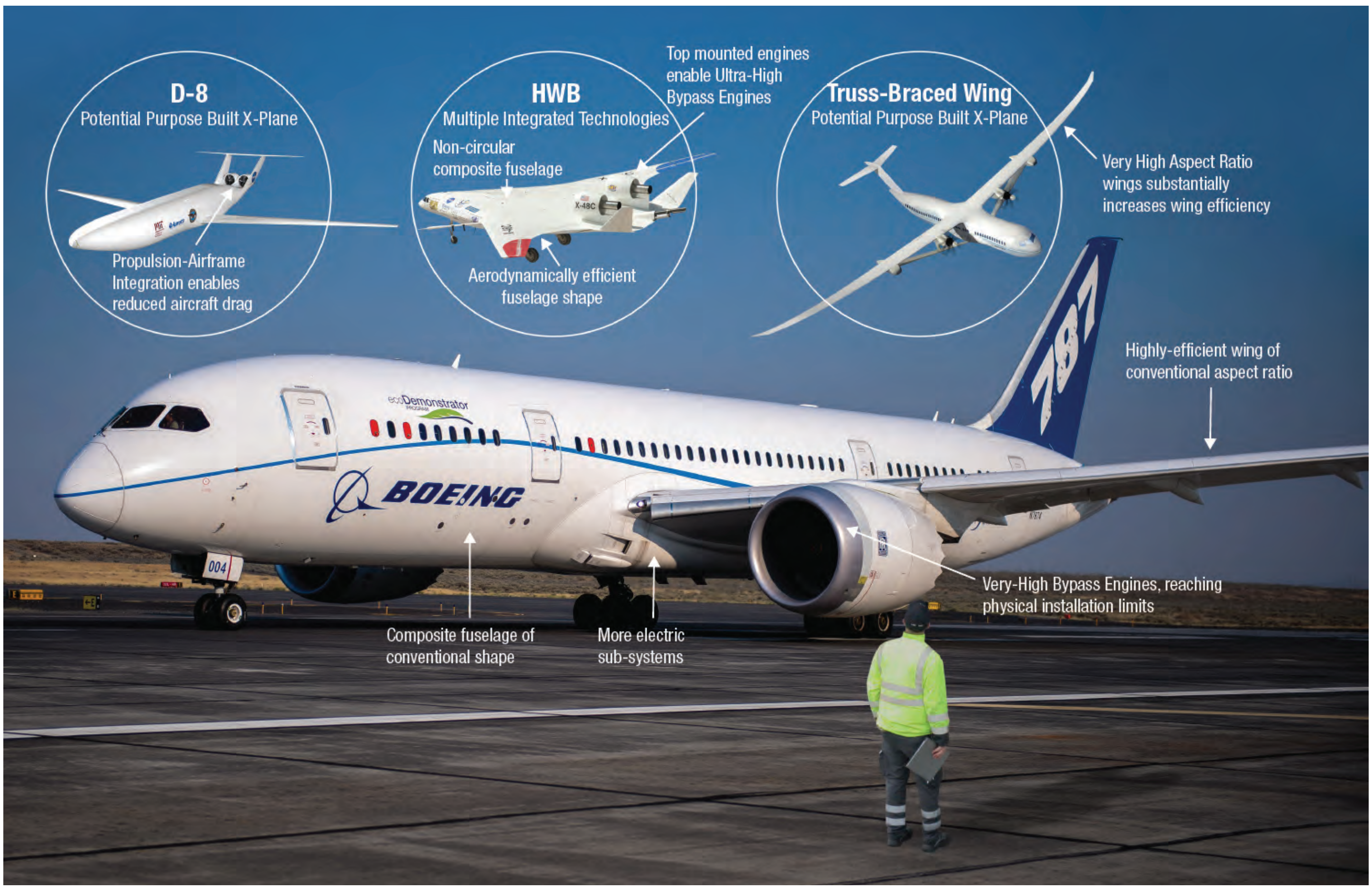
model, and the computer model helps inform improvements to the airplane design, which can then be tested again in the wind tunnel.

The third leg of the stool is to actually fly the design. Whether it's flying an X-plane or a full-scale prototype of a new aircraft, the data recorded in actual flight can be used to validate and improve the computational and experimental methods used to develop the design in the first place. This third leg makes it possible to lower the risk enough to completely trust what the numbers are saying.

With NAH, NASA will:

- Demonstrate revolutionary advancements in aircraft and engine configurations that break the mold of traditional tube and wing designs.
- Support accelerated delivery to the U.S. aviation community of advanced verified design and analysis tools that support new flight-validated concepts, systems and technologies.
- Provide to appropriate organizations and agencies research results that inform their work to update domestic and international aviation standards and regulations.
- Enable U.S. industry to put into service flight-proven transformative technology that will solve tomorrow's global aviation challenges.
- Inspire a new generation of aeronautical innovators and equip them to engineer future aviation systems.

Of the five X-planes, NASA has determined that three subsonic aircraft will be enough to span the range of possible configurations necessary to demonstrate in flight the major enabling fuel, emissions and noise reducing technologies.



During the late 1950s and early 1960s the introduction of key technologies — jet engines, swept wings, pressured fuselages — created the modern jet transport and transformed aviation into the indispensable transportation system that moves the world today. The Boeing 787 is the state of the art for commercial aircraft, with efficient and Earth-friendly performance that was unimaginable at the dawn of the jet age. But NASA believes the full potential of advanced "green aviation" technologies is bumping up against the limitations of traditional tube-and-wing designs. With NAH, the testing and adoption of a new set of foundational technologies would be accelerated.

The NASA Aeronautics budget, including the NAH initiative and complementary investments, are guided by the NASA Aeronautics Strategic Implementation Plan. Within the plan are six strategic research thrust areas that guide the selection and execution of specific research activities, and their integration throughout the entire aeronautics research portfolio.

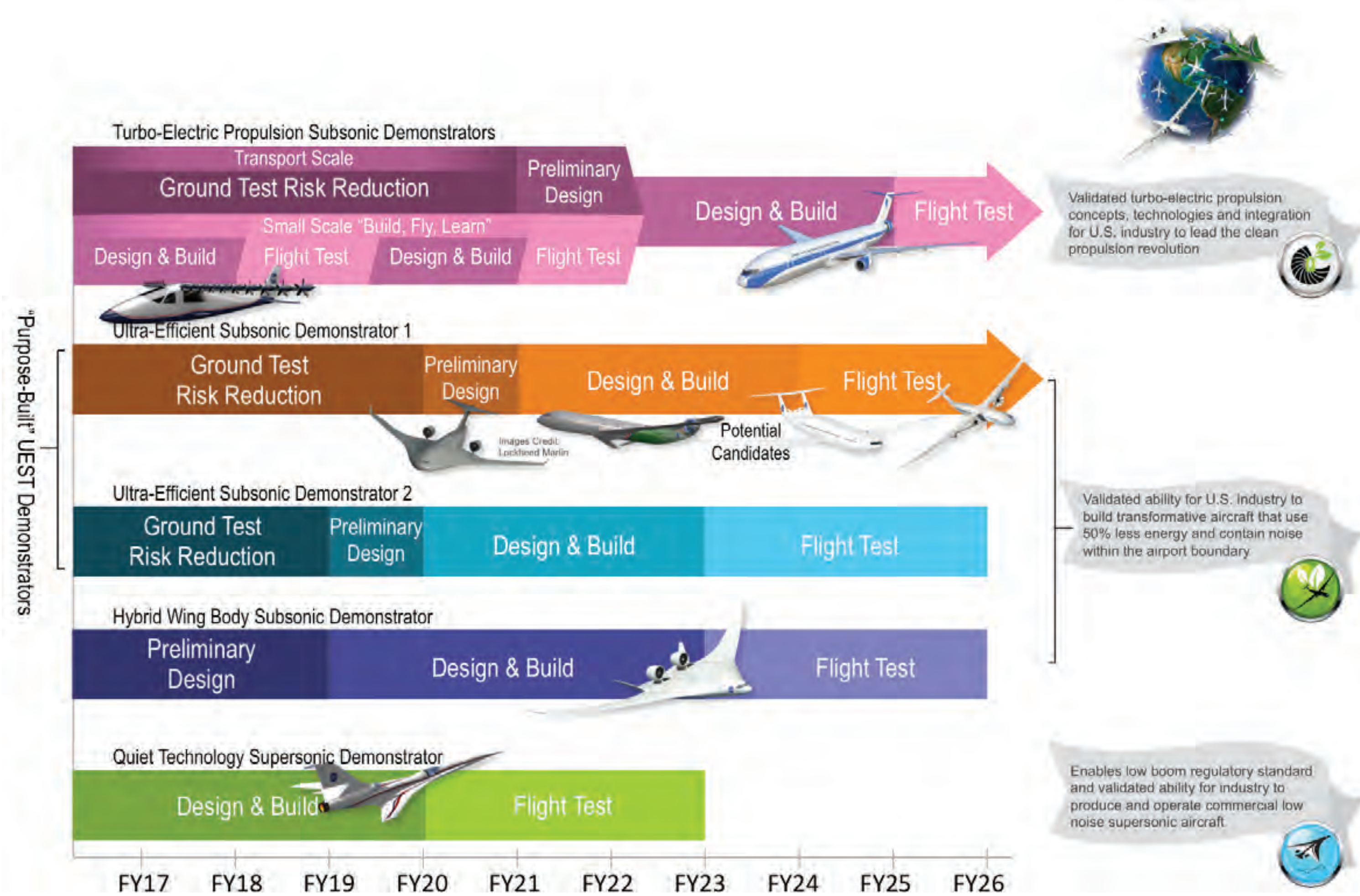
An even more ambitious reduction in aviation's environmental impact could be possible with a transformation in aircraft propulsion technology. Turbo-electric propulsion is the leading candidate.

NASA envisions flying a fourth large-scale, transport-class X-plane with turbo-electric propulsion during the mid-2020s. Given the wide range of design concepts for such a vehicle, and the need to gain experience with integration and experimentation, NASA will build a small-scale, general aviation-sized X-plane, fly it in 2017 and apply what is learned to designing a larger vehicle.

A fifth X-plane will seek to validate NASA research that shows major hurdles to efficient, low noise supersonic flight can be overcome. Analysis and ground testing of advanced supersonic aircraft configurations have shown it is possible to dramatically reduce sonic boom noise. In this case, in order to generate the data necessary for regulators to consider creating a noise standard targeted to lift the current prohibition against commercial supersonic flight over land, a full-scale demonstrator X-plane is required. With a new noise standard and the design tools to enable industry to build aircraft to meet that standard, U.S. industry can open a new era of global commercial supersonic transportation. Work on this X-plane began in February 2016 with NASA's awarding a contract for the preliminary design of the Quiet Supersonic Technology (QueSST) X-plane, which is expected to get airborne in the 2020 timeframe depending on funding.

NAH X-Plane Flight Demonstration Plan

NAH will implement a phased deployment of the five X-planes during the next 10 years. This approach enables early development and flight tests for technologies and concepts that are mature enough for integrated flight experimentation, while ground test and analysis continue on those that need additional maturation. Phasing also allows for a full competition of ideas among U.S. companies to achieve the highest impact payoffs. Key decision points will occur at the end of each preliminary design phase to ensure readiness for detailed design and build of the X-planes.



This graphic illustrates NASA's plan for phased development and flight tests of the X-planes. NASA's approach is based on the full FY 2017 budget request including the 10-year budget profile.

NASA has developed a flight demonstration plan that will deliver:

- X-planes that integrate advanced concepts and technologies.
- Advanced technologies proven through ground and flight tests.
- Full understanding of complex, transformational flight systems including structures, aerodynamics, propulsion, controls (including human factors and autonomy) and flight dynamics interactions.
- Transformational research aligned with NASA Aeronautics' Strategic Plan. New approaches for NASA-industry resource-sharing partnerships.

COMPLEMENTARY INVESTMENTS

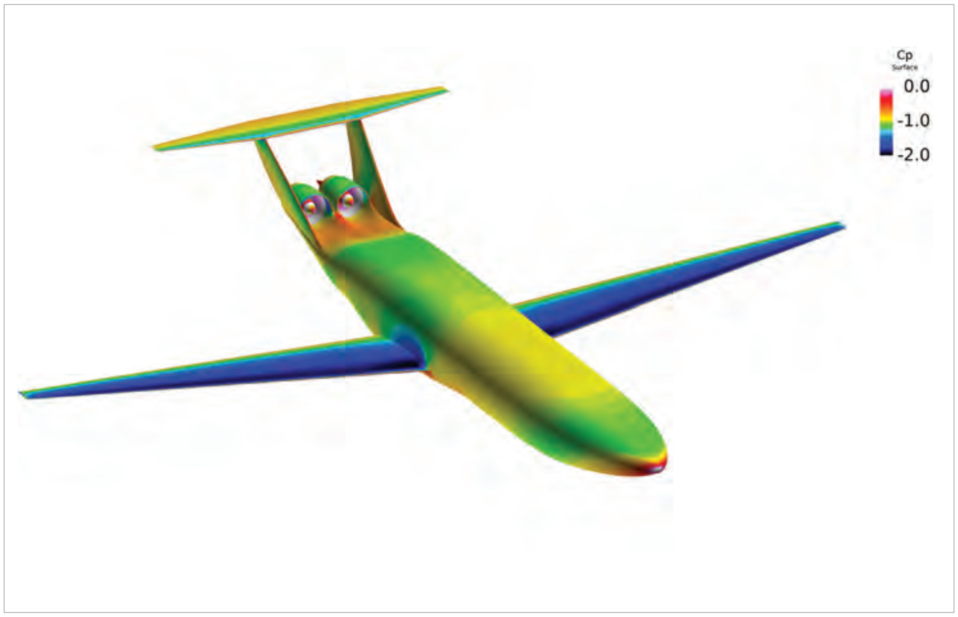
In addition to the NAH initiative, NASA's 10-year research acceleration plan includes a set of complementary investments that help to fully realize its dramatic benefits.

Enabling Tools and Technologies

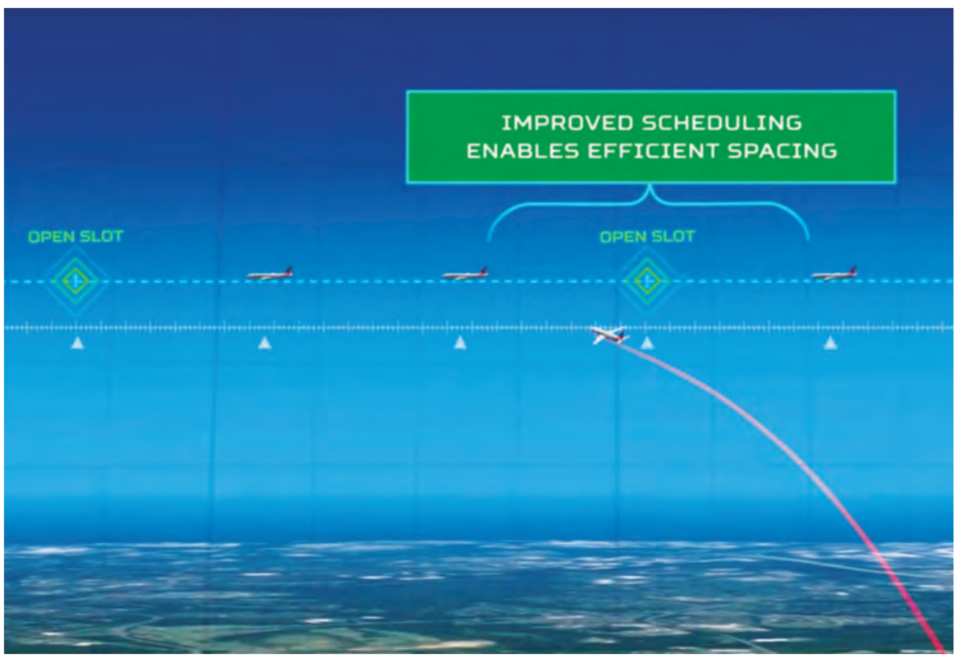
- Large-scale ground experiments will advance readiness for flight experimentation, and then ensure that complementary ground and flight data sets are available for each major technology.
- Advanced high-power-density jet engine core technology will be developed and demonstrated to achieve ultra-high bypass engines and as an enabling technology for turbo-electric propulsion.
- Next generation physics-based methods for analysis and design will be validated to enable high-fidelity modeling of the advanced configurations and technologies being demonstrated in flight.

Optimizing Operational Efficiency

- Development and implementation of complex field tests will accelerate validation of full gate-to-gate Trajectory Based Operations (TBO) – a key concept for achieving the NextGen air traffic management system. TBO will also help to fully realize the operational benefits of advanced technologies and configurations being demonstrated through New Aviation Horizons' X-planes.
- Validated technology that automates some tasks, assisting controllers and flight crews in decision-making, will be delivered to the FAA for implementation.



The ability to simulate airflow over aircraft with non-traditional designs is a challenge for aeronautical innovators. Advanced computational fluid dynamics tools are key enablers in the design and analysis of non-traditional aircraft concepts.



NASA – in partnership with the FAA, airports, airlines and industry – is conducting complex field tests of technologies that improve air traffic flow on the ground and into the air, which ultimately reduces delays and fuel use.

Leveraging Convergent Technologies, and Inspiring and Developing the Future Workforce

NASA's 10-year research acceleration plan will stimulate key investments to rapidly assess the feasibility of advanced technology concepts. Convergent technologies that bring together advanced concepts from aviation and non-aviation industries – such as high energy density batteries for potential use in turbo-electric propulsion – will be supported through challenge prizes to incentivize commercial innovation. NASA's internal innovation framework will also be augmented to accelerate feasibility assessment of breakthrough concepts.

Perhaps most importantly, in executing this plan NASA will emphasize university leadership and direct involvement of students in every element of research, design, development and testing, which is crucial to ensuring the future U.S. workforce is positioned for global leadership.

OPPORTUNITIES INVOLVE NASA, INDUSTRY AND UNIVERSITIES

The NAH initiative and its complementary investments will offer opportunities to, and rely on, many others who are interested in solving problems, working on developing advanced technologies, experiencing the unique excitement of flight campaigns, and helping to make aviation more Earth-friendly.

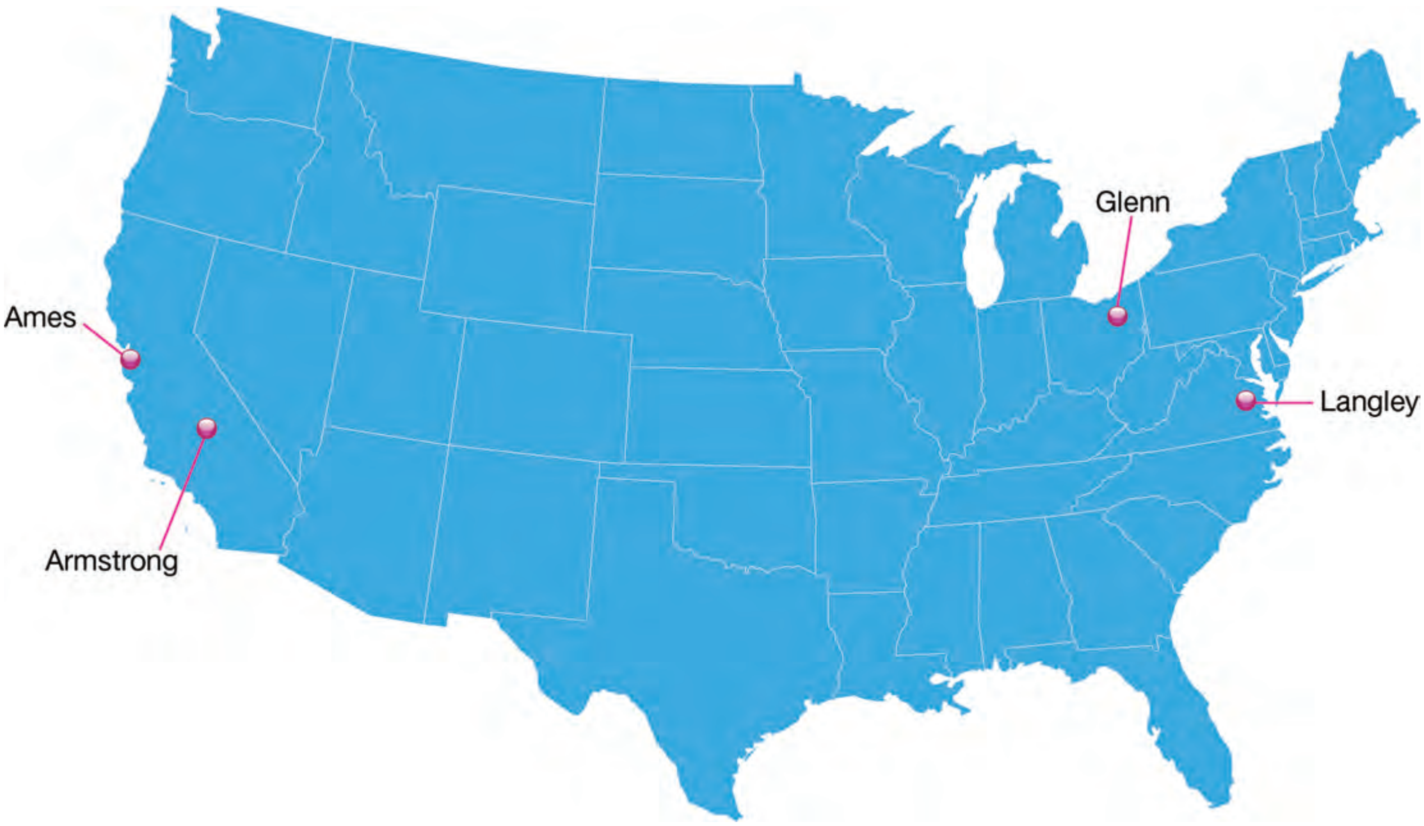
NASA RESEARCH CENTERS

Ames Research Center
(Mountain View, California)
Ames plays an important role for NAH, including wind-tunnel tests and computational fluid dynamics analysis in support of the design, development and flight testing of the X-planes. Ames also is integral to the development of the advanced physics-based models that will be pursued in close coordination with the X-planes, taking advantage of flight data to solve complex open issues in flow modeling. Finally, Ames has the leadership role in accelerating the demonstration and validation of optimized trajectory based operations for NextGen. In support of NAH, NASA anticipates needed capability improvements in Ames wind tunnels, supercomputing capabilities, and NextGen simulation facilities.

Armstrong Flight Research Center
(Edwards, California)
Armstrong has the leadership role for NAH X-plane flight operations. All X-planes will be operated out of Armstrong, and the center will coordinate flight tests of many of the key technology experiments. In addition, Armstrong's role includes assurance of airworthiness, X-plane instrumentation, design of experiments, and the collection and analysis of flight data. NASA anticipates needed capability improvements in Armstrong hangars, flight simulation and flight loads capabilities, control rooms, and the Dryden Aeronautical Test Range.

Glenn Research Center
(Cleveland, Ohio)
Glenn has the lead role for research and technology development, including analysis and ground testing, for the NAH Turbo-Electric Propulsion X-plane, and provides propulsion technical support for all of the X-planes. In addition, Glenn leads the complementary research and technology development for advanced "small core" turbofan technologies, including analysis, ground test and demonstration. Finally, Glenn wind tunnels and other facilities support ground tests for all X-planes. NASA anticipates needed capability improvements in Glenn wind tunnels, as well as the development of specialized capabilities for very high power electric propulsion testing.

Langley Research Center
(Hampton, Virginia)
Langley has the lead role for research and technology development, and systems engineering including analysis and ground tests, for the NAH Quiet Supersonic Technology and the Ultra-Efficient Subsonic X-planes. Langley is integral to the development of the advanced physics-based models that will be pursued in close coordination with the X-planes, taking advantage of the flight data to solve complex open issues in aero-sciences modeling. Finally, Langley has a support role in accelerating the demonstration and validation of optimized trajectory based operations for NextGen. NASA anticipates needed capability improvements in Langley wind tunnels, structural test facilities, and NextGen simulation facilities.



AMES

ARMSTRONG

GLENN

LANGLEY

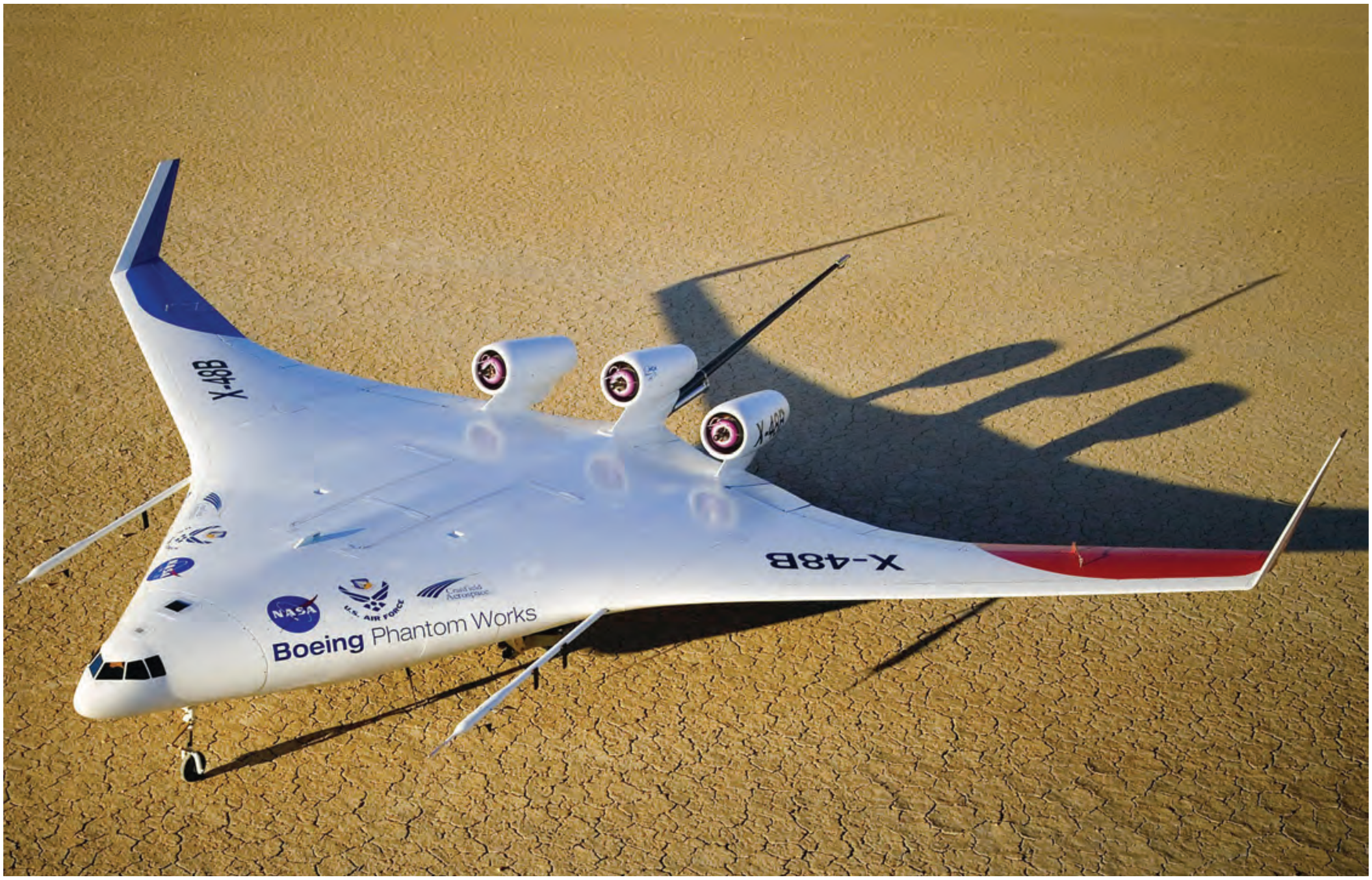
Industry

U.S. industry plays an integral role in the NAH initiative, leading the design, development and building of all X-planes under contract to NASA.

Industry will be a research partner in the ground test and analysis, as well as the flight tests of the X-planes. Industry also partners in the advancement of the physics-based design and analysis capabilities.

Through the lead and partnering roles, U.S. industry will be fully capable of confidently taking the next steps in commercializing the transformational configurations and technologies. The Lockheed Martin Aeronautics Company has already been awarded a preliminary design contract for the Quiet Supersonic Technology demonstrator.

As indicated in a white paper published by the Aerospace Industries Association and the American Institute of Aeronautics and Astronautics, "The U.S. government must support robust, long-term Federal civil aeronautics research and technology initiatives funded at a level that will ensure U.S. leadership in aeronautics. Congress should support NASA's ten-year Strategic Implementation Plan at least at the levels recommended in the fiscal year 2017 NASA Budget request to sustain a strong economy, maintain a skilled workforce, support national security, and drive a world-class educational system."



The Boeing-built X-48 Blended Wing Body demonstrator sits on Rogers Dry Lake near NASA's Armstrong Flight Research Center. The 20-foot wingspan remotely piloted test vehicle flew for nearly six years, providing a valuable ground-to-flight database for controllability of the unique design through the flight environment.

Universities

NASA has already launched the University Leadership Initiative, which provides U.S.-based universities the opportunity to take full independent leadership in defining and solving key technical challenges aligned with the NASA Aeronautics strategy. Solicitations and proposals are managed through the NASA Research Announcement process; the first round of awards will be made in Fall 2016.

These awards could lead to new experiments that would fly onboard one or more X-planes. In addition, NASA is formulating new mechanisms for direct university and student participation in the X-plane design, development and flight test process. The objective is to ensure U.S. universities remain the leading global institutions for aviation research and education, and to ensure the next generation workforce has the vision and skills needed to lead aviation system transformation.

Students and faculty from the Massachusetts Institute of Technology (MIT) were part of the team that developed the “double bubble” D8 airliner concept several years ago. The design was one of a number of studies funded by NASA Research Announcements that required industry to partner with at least one university. Pictured (l to r): Alejandra Uranga, research engineer and aeronautics MIT technical lead, and Mark Drela, professor of aeronautics and astronautics at MIT.

Other Government Agencies

NASA has ongoing research partnerships with regulatory agencies such as the FAA. Through Research Transition Teams and other mechanisms, NASA supplies data or technologies to the FAA to assist with rule making, or with modifying standards and certification processes.

For example, the FAA and International Civil Aviation Organization's Committee of Aviation Environmental Protection have developed the schedule and initiated the process for an overland sonic boom noise rule, which will be based on the results of the Quiet Supersonic Technology demonstrator community noise research and data collection process. The FAA also is participating with NASA on turbo-electric propulsion development to inform standards, basis of certification and other rules with regard to electric propulsion systems.

NASA expects FAA interest in other aspects of NAH in the future. The FAA also is a direct partner and customer for NASA's NextGen trajectory based operations optimization research, demonstration and validation.

The Department of Defense is a partner in developing and testing technologies of interest for military application.

NEW AVIATION HORIZONS INITIATIVE AND COMPLEMENTARY INVESTMENTS BUDGET

NASA's aeronautics research proposed budget from FY 2017 to FY 2026 is $10.7 billion. This is a $3.7 billion augmentation to the baseline aeronautics research budget that will serve to fund New Aviation Horizons and complementary investments.

The 10-year investment horizon is necessary to fully achieve the five projected New Aviation Horizons X-planes as scheduled in the Flight Demonstration Plan (see page 8).

The full budget is aligned with the NASA Aeronautics Strategic Implementation Plan and Roadmaps (see page 17).



Wind-tunnel testing of subscale models of possible future aircraft configurations is still a vital tool in the R&D process. (left to right) A model of the transonic truss-braced wing design, a model of the D8 "double bubble" ultra-efficient subsonic design, and a model of a quiet supersonic technology design.

Summary

NASA's New Aviation Horizons Initiative and complementary investments are based on 10 years of successful planning, research, and public-private partnerships. NAH is a natural next step for opening a new era of aviation and ensuring continued U.S. technological leadership.

NASA, industry and academia are well prepared and ready to move forward and begin flight demonstrations and related research for the benefit of the U.S. economy and the air transportation system.

Highlights of Possible X-Plane Configurations

STARC

Hybrid Electric Demonstrator

- Size: Large-scale (50 percent)
- Piloted for safe flight in public airspace
- Electric motors attached to turbofan engines distribute power through aircraft and reduce drag
- Electric motor-driven tail cone reduces drag from wake, improving efficiency and making it possible to reduce size of wing engines
- T-tail accommodates tail-mounted fan

HWB

Hybrid Wing Body (HWB) Demonstrator

- Size: Large-scale (50 percent)
- Piloted for safe flight in public airspace
- Non-circular pressurized fuselage
- Top-mounted engines to shield noise from ground
- Multiple technologies tested for use on multiple platforms (structures, materials, aerodynamics, flight controls, propulsion/airframe integration)
- Designed for initial application as a cargo transport

QUESST

Quiet Supersonic Test Demonstrator

- Size: Large scale (90-foot length); simulates supersonic sound of a future 100-passenger supersonic airplane
- Piloted for safe flight in public airspace
- Sonic "thump" instead of sonic boom
- Uses existing engines for low cost but burns alternative fuel to study effects on emissions

SCEPTOR (X-57)

Hybrid Electric Demonstrator

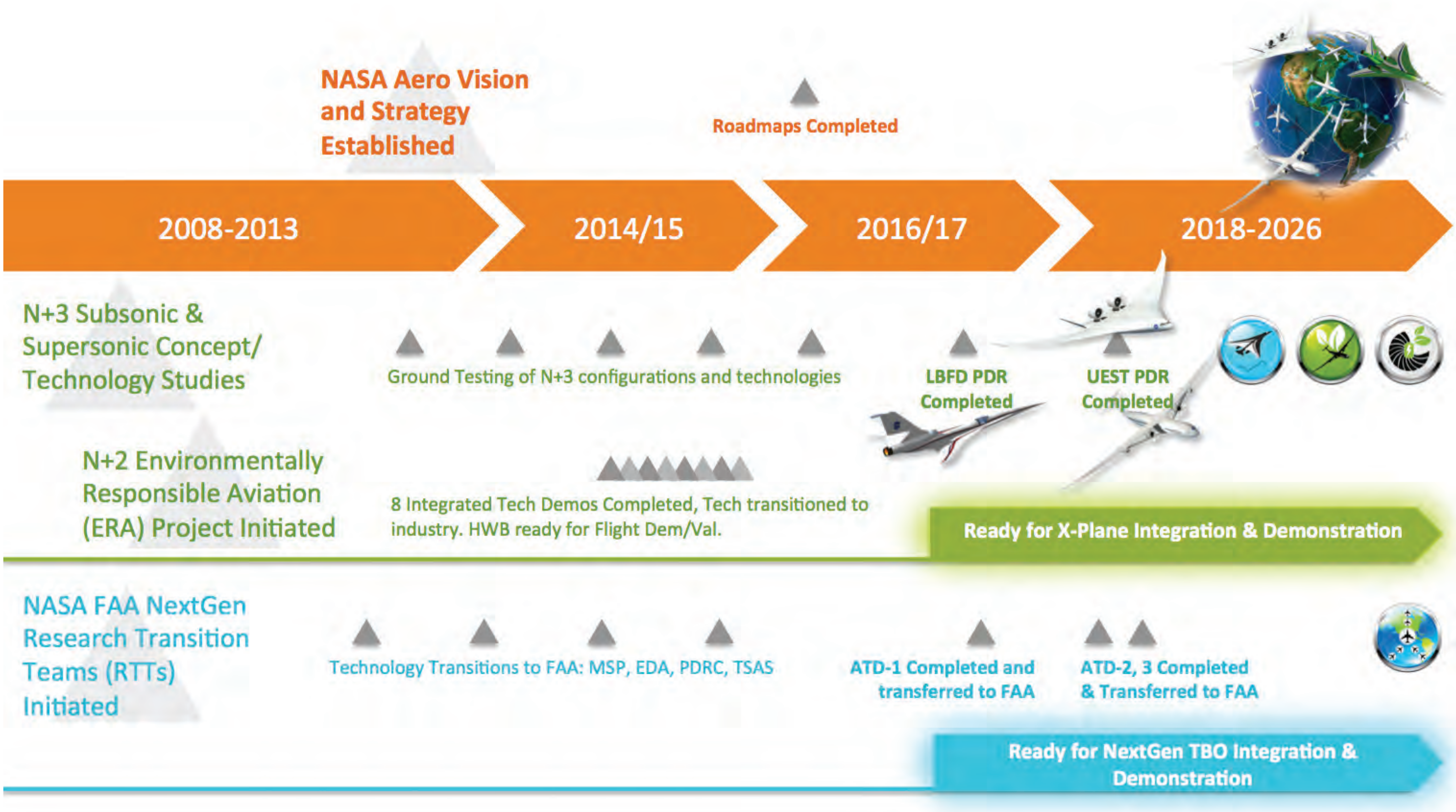
- Size: Small-scale (general aviation size)
- Piloted for safe flight in public airspace
- Multiple small electric engines installed along entire wing
- Wing placed higher on fuselage
- Based on Tecnam P2006T light aircraft
- Designed to be learning tool for technologies that could be on larger airplanes, or could be spun off to the general aviation market

WE'RE AT THE RIGHT PLACE, AT THE RIGHT TIME, WITH THE RIGHT TECHNOLOGIES

For nearly 10 years NASA's aeronautics researchers have been, piece by piece, working to "line up the stars" to make something like New Aviation Horizons possible.

Starting with a set of concept studies whose results proved that NASA's ambitious goals for greener aviation were realistic, and leading to a perfect storm of ground testing of those concepts and simultaneous creation of a strategic vision and plan, the past 10 years have brought us to a threshold where we can, for the benefit of the United States:

- Inject excitement and opportunity into the aerospace industry
- Inspire and motivate a new generation of scientists and engineers
- Contribute to new opportunities for manufacturing and high-paying jobs
- Accelerate the adoption by industry of technologies that make aviation more Earth-friendly



NASA AERONAUTICS STRATEGIC PLAN

The NASA Aeronautics Strategic Implementation Plan guides NASA's aeronautics research investments. The plan and its accompanying research thrust area roadmaps are intended to be living documents that evolve with knowledge gained from research and partnership activities.

View and download the documents from *http://www.aeronautics.nasa.gov/strategic-plan.htm*. Comments are welcome and can be submitted to NASA by using the "Comment Here" link available on the web page.

Investments in NASA's cutting-edge aeronautics research today are investments in a cleaner, safer, quieter and faster tomorrow for American aviation:

- A future where Americans are working in stable, well-paying jobs.
- A future where we fly on aircraft that consume half as much fuel and generate only one quarter of current emissions.
- A future where flight is fueled by greener energy sources.
- A future where our air transportation system is able to absorb nearly four billion more passengers over the next 20 years without compromising the safety of our skies.
- A future where our airports are better neighbors because aircraft noise is contained well within the airport boundary.
- A future where people can travel to most cities in the world in six hours or less in an airplane that can fly faster than the speed of sound on bio-fuels.

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