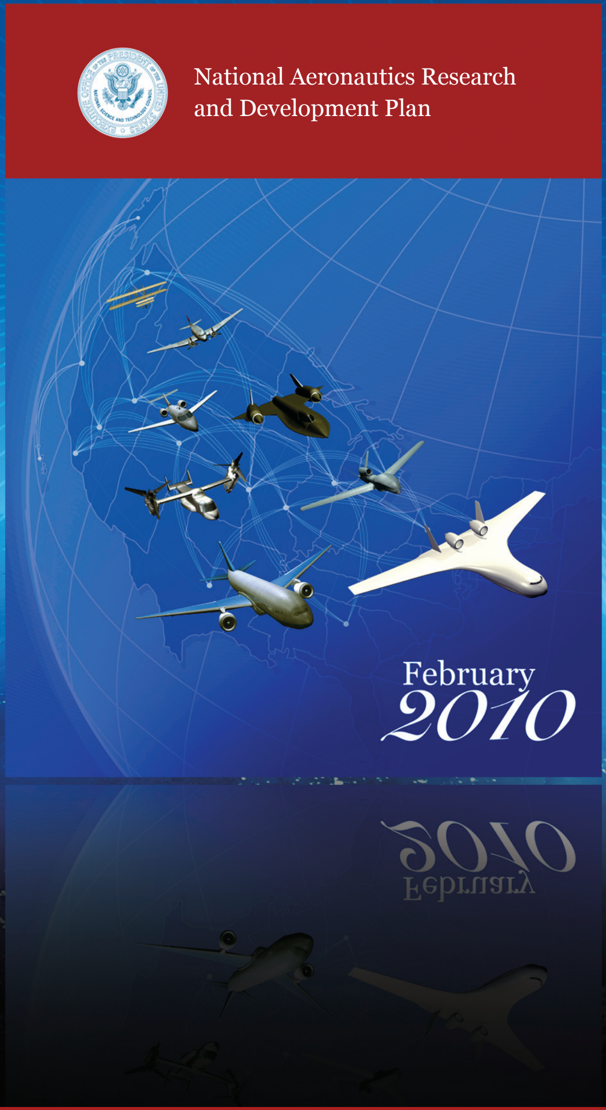
December
2011


National Aeronautics Research
and Development Plan

February
2010

Executive Office of the President of the United States
National Science and Technology Council

2011 Progress Assessment

of the 2010 National Aeronautics Research and Development Plan

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES

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EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

December 21, 2011

Dear Colleague:

I am pleased to share with you the *2011 Progress Assessment for the National Aeronautics Research and Development Plan*, the fifth in a series of National Science and Technology Council reports intended to provide a national policy and planning foundation for Federal aeronautics research and development.

The series responds to Executive Order (EO) 13419, "National Aeronautics Research and Development," which implemented the National Aeronautics Research and Development Policy (Policy) to help guide the conduct of U.S. aeronautics research and development (R&D) through 2020. To further implement the Policy, EO 13419 called for a series of follow-on plans. The 2010 National Aeronautics Research and Development Plan is the current approved plan and it represents the Federal consensus regarding national aeronautics research challenges, goals, and time-phased objectives.

EO 13419 also called for periodic assessments of the progress of the executive departments and agencies towards achieving the R&D goals and objectives in the approved plan. This 2011 Progress Assessment fulfills that requirement and will also help inform the next update to the 2010 National Aeronautics R&D Plan.

The 2011 Progress Assessment is part of this Administration's sustained emphasis on interagency planning to define and achieve high-priority national aeronautics R&D goals and objectives that can contribute to the economic growth and security of the Nation and help retain America's position as the world's technological leader in aeronautics.

Sincerely,

John P. Holdren

John P. Holdren
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy

2011 PROGRESS ASSESSMENT

National Aeronautics Research and Development Plan

December 2011

Aeronautics Science and Technology Subcommittee
Committee on Technology
National Science and Technology Council

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EXECUTIVE SUMMARY

On December 20, 2006, Executive Order (EO) 13419, "National Aeronautics Research and Development," established the National Aeronautics Research and Development Policy (Policy) to help guide the conduct of U.S. aeronautics research and development (R&D) programs through 2020. As part of the implementation of the Policy, EO 13419 called for a series of follow-on plans to implement the Policy as well as periodic assessments of progress.[1]

"The National Plan for Aeronautics R&D and Related Infrastructure" was approved in December 2007 (2007 R&D Plan)[2] and was organized according to the Principles contained in the National Aeronautics R&D Policy.[3] It established aeronautics R&D challenges, prioritized goals, and time-phased objectives. In accordance with EO 13419, the initial 2007 R&D Plan was updated with approval of the "National Aeronautics Research and Development Plan" (2010 R&D Plan)[4] and the "National Aeronautics Research, Development, Test and Evaluation (RDT&E) Infrastructure Plan" (2011 Infrastructure Plan).[5]

As part of the implementation actions, EO 13419 also called for periodic assessments of R&D progress. This assessment fulfills that requirement by reporting on progress implementing the objectives in 2010 R&D Plan. The time frame covers the progress anticipated through December 2012—a period of 5 years from the publication of the initial December 2007 R&D Plan. This coincides with the 5-year near-, mid-, and far-term time frames in the R&D Plans.

The assessment consists of an overall green, yellow, or red progress assessment for the objectives laid out in the 2010 R&D Plan and is based on anticipated levels of effort in the near, mid, and far terms:

- A green assessment denotes that current R&D activities are sufficient to achieve the objectives in the time frame indicated.

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1 Executive Order no. 13419, Federal Register 71, no. 247 (26 December 2006), http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-eo-2006.pdf.

2 Executive Office of the President, National Science and Technology Council, "National Plan for Aeronautics Research and Development and Related Infrastructure," December 2007, http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-natplan-2007.pdf.

3 Executive Office of the President, National Science and Technology Council, "National Aeronautics Research and Development Policy," December 2006, http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-natrdpolicy-2006.pdf.

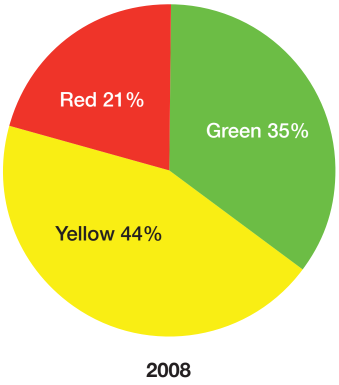
4 Executive Office of the President, National Science and Technology Council, "National Aeronautics Research and Development Plan," February 2010, http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-rdplan-2010.pdf.

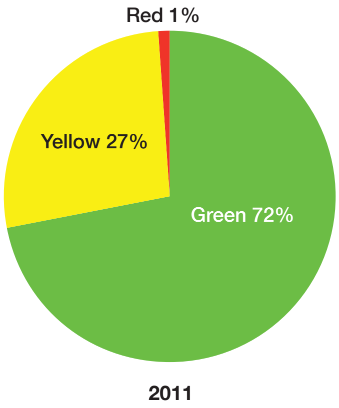
5 Executive Office of the President, National Science and Technology Council, "National Aeronautics Research, Development, Test and Evaluation (RDT&E) Infrastructure Plan," January 2011, http://www.whitehouse.gov/sites/default/files/microsites/ostp/nat-aero-rdte-plan-jan11.pdf.

- A yellow assessment indicates that ongoing or planned R&D activities have achieved progress toward the objectives but there is some risk due to programmatic, technical, and other constraints that merits continued attention.
- A red assessment indicates there is serious risk due to programmatic, technical, or other constraints that will significantly delay or prevent completion.

The results from this 2011 assessment indicate that the combined focus on aeronautics R&D by the departments and agencies of the Federal Government has been adequate to advance the goals and objectives contained in the National Aeronautics Research and Development Plan. Seventy-two percent of the activities were assessed as green (i.e., sufficient to achieve the objectives), with near-term objectives being more heavily represented by green assessments than the mid- and far-term objectives. Twenty-seven percent were assessed as yellow (i.e., sufficient to achieve the objectives with some risk), with the majority of yellow assessments being listed in the mid- and far-term periods. Only 1% were assessed as red (a far-term objective) and considered subject to serious risk due to programmatic, technical, or other constraints that will significantly delay or prevent completion.

A similar assessment was conducted in 2008 and published as the "Technical Appendix: National Plan for Aeronautics Research and Development and Related Infrastructure."[6] The 2011 assessment rankings indicate that there has been progress toward achieving the aeronautics R&D goals and objectives since the 2008 assessment. Objectives with green assessments effectively doubled, going from 35% to 72%, and the totals of both the yellow and red assessments were significantly reduced, compared with totals from the 2008 assessment. The findings of the 2008 and 2011 assessments are depicted in the two pie charts below:





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[6] Executive Office of the President, National Science and Technology Council, "Technical Appendix: National Plan for Aeronautics Research and Development and Related Infrastructure," December 2008, http://www.whitehouse.gov/files/documents/ostp/default-file/technical_appendix_high.pdf.

It is intended that this assessment will be used to inform future biennial updates to the 2010 R&D Plan and 2011 Infrastructure Plan. It is anticipated that the vast majority of objectives with yellow assessments will be advanced to completion, but in some cases not precisely as described in the 2010 R&D Plan. This can occur because some of the desired outcomes and associated objectives assessed as yellow may evolve as a result of lessons learned in the course of R&D. The objective being reported as red will probably not be completed given current prioritization for this far-term objective.

INTRODUCTION

On December 20, 2006, Executive Order (EO) 13419, "National Aeronautics Research and Development," established the Nation's first policy to guide Federal aeronautics research and development (R&D) through 2020. The Executive Order stated, "Continued progress in aeronautics, the science of flight, is essential to America's economic success and the protection of America's security interests at home and around the globe," and called for a plan for national aeronautics R&D and for related infrastructure that would be updated biennially.[7]

The National Aeronautics R&D Policy (Policy) established by EO 13419 laid out seven key Principles[8] to guide the conduct of the Nation's aeronautics R&D activities through 2020:[9]

- Mobility through the air is vital to economic stability, growth, and security as a Nation.
- Aviation is vital to national security and homeland defense.
- Aviation safety is paramount.
- Security of and within the aeronautics enterprise must be maintained.
- The United States should continue to possess, rely on, and develop its world-class aeronautics workforce.
- Assuring energy availability and efficiency is central to the growth of the aeronautics enterprise.
- The environment must be protected while sustaining growth in air transportation.[10]

These Principles, with the two exceptions noted, serve as the framework for national aeronautics R&D planning process and were included in the initial 2007 R&D Plan and the updated 2010 R&D Plan.[11] For each Principle addressed, the 2010 R&D Plan includes a description of the state of the art of related technologies and systems and a set of fundamental challenges and associated high-priority R&D goals that seek to address these challenges. (See the 2010 R&D Plan for the expanded text.) To give additional clarity and definition, the 2010 R&D Plan provides supporting objectives for each goal. These objectives were phased over three time periods: near term (<5 years), mid term (5–10 years), and far term (>10 years).

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[7] Executive Order no. 13419, Federal Register 71, no. 247 (26 December 2006), http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-eo-2006.pdf.

[8] Two Principles were not addressed in the Plan: (1) Aviation Security R&D efforts are coordinated through the National Strategy for Aviation Security and its supporting plans, and (2) aerospace workforce issues are being explored by the Aerospace Revitalization Task Force led by the Department of Labor pursuant to Public Law 109-420.

[9] Executive Office of the President, National Science and Technology Council, "National Aeronautics Research and Development Policy," December 2006, http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-natrdpolicy-2006.pdf.

[10] Energy and Environment were separate Principles in the Policy; however, they are sufficiently coupled that they were considered together in the 2007 and 2010 R&D Plans.

[11] Executive Office of the President, National Science and Technology Council, "National Aeronautics Research and Development Plan," February 2010, http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-rdplan-2010.pdf.

As part of the implementation actions, EO 13419 also called for periodic assessments of R&D progress. This assessment fulfills that requirement by reporting on progress implementing the objectives in the 2007 and 2010 R&D Plans. The time frame covers the progress anticipated through December 2012—a period of 5 years from the publication of the initial December 2007 R&D Plan. This coincides with the 5-year near-, mid-, and far-term time frames in the R&D Plans.

To conduct the assessment, the methodology developed to ascertain assessment rankings—green, yellow, or red—for the objectives laid out in the 2010 R&D Plan is based on anticipated levels of effort in the near, mid, and far terms:

- A green assessment denotes that current R&D activities are sufficient to achieve the objectives in the time frame indicated.
- A yellow assessment indicates that ongoing or planned R&D activities have achieved progress toward the objectives, but there is some risk due to programmatic, technical, and other constraints that merits continued attention.
- A red assessment indicates there is serious risk due to programmatic, technical, or other constraints that will significantly delay or prevent completion.

Assessments of the goals and objectives represent the level of achievement in demonstrating the necessary knowledge or capabilities to further advance the R&D objectives according to their respective time frames but do not represent the operational implementation of the objectives.

This assessment is the result of an interagency effort coordinated by the Aeronautics Science and Technology Subcommittee (ASTS) of the Committee on Technology of the National Science and Technology Council. ASTS representation includes membership from the Departments of Agriculture, Commerce, Defense, Energy, Homeland Security, State, and Transportation, as well as from several Federal agencies and offices, including the Environmental Protection Agency (EPA), the Federal Aviation Administration (FAA), the Joint Planning and Development Office (JPDO), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the National Institute of Standards and Technology (NIST), and the National Science Foundation (NSF).

It is intended that this assessment will serve to support informed discussion of aeronautics R&D across the aviation enterprise, enhance interagency coordination, and be used to inform future biennial updates to the 2010 R&D Plan and 2011 Infrastructure Plan, as well as individual department and agency planning efforts.[12]

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[12] Executive Office of the President, National Science and Technology Council, "National Aeronautics Research, Development, Test and Evaluation (RDT&E) Infrastructure Plan," January 2011, http://www.whitehouse.gov/sites/default/files/microsites/ostp/nat-aero-rdte-plan-jan11.pdf.

MOBILITY THROUGH THE AIR IS VITAL TO ECONOMIC STABILITY, GROWTH, AND SECURITY AS A NATION

Providing for mobility requires an aeronautics enterprise with sufficient capacity to meet increasing demand for air travel and transport and with sufficient flexibility and affordability to accommodate the full range of aircraft requirements and attributes. Possessing the capability to move goods and people point to point, anywhere in the Nation and around the world, is essential to advance the local, state, and national economies of the United States. Furthermore, the United States, in cooperation with international partners, should play a leading role in ensuring global interoperability.

—"National Aeronautics Research and Development Plan," February 2010, p. 12

SUMMARY OF R&D ACTIVITIES SUPPORTING THE MOBILITY PRINCIPLE

Aeronautics R&D for the Mobility Principle is divided into five goal areas. These five goals include R&D objectives intended to help reduce the separation requirements between aircraft, better manage flows of aircraft, reduce the impacts of weather on operations, improve arrival and departure capacity at major airports, and expand the future performance capabilities of aircraft to help maximize the benefits of enhanced air traffic control capabilities. (For complete text, see the 2010 R&D Plan.) Interagency cooperation supporting the advancement of Mobility R&D includes participation from NASA, FAA, and the Department of Defense (DoD).

ASSESSMENT OF R&D PROGRESS FOR THE MOBILITY GOALS

Overview

Planned and ongoing efforts are sufficient for meeting all near-term, mid-term, and long-term objectives for Mobility Goals and were assessed as green, with the exception of a near-term Goal 3 objective that was assessed as yellow. This objective concerned the development of requirements for weather observation and forecasting information and probabilistic forecasts and methods for communicating forecast uncertainty. A detailed assessment of progress and areas where improvements are possible are discussed for each of the goals in the following sections. A summary of the assessment is shown in Table 1.

Goal 1—Develop reduced aircraft separation in trajectory- and performance-based operations

R&D progress for all near-, mid-, and far-term objectives for Goal 1 is consistent with expectations and thus assessed as green. The FAA has started the implementation of capabilities that met some of the near-term research objectives. There is some risk associated with achieving the mid- and far-term objectives due to competing priorities, but FAA slips in deployment schedules will provide some relief. The Next Generation Air Transportation System (NextGen) human factors research has increased since the last progress assessment (reported in the 2008 Appendix to the National Plan), and the objective related to human-machine interaction in a highly automated air transportation system is assessed as green and discussed below.

Recent accomplishments leading to reduced aircraft separation include developing recommendations for an alternative set of wake separation standards and determining an optimal set of aircraft flight characteristics and weather parameters for use in setting wake separation minimums. Progress has been made in developing wake-mitigation application solutions that safely enable reduced aircraft separations in congested air corridors and during arrival and departure operations at our Nation's busiest airports.

Automatic Dependent Surveillance-Broadcast (ADS-B) was successfully integrated into all four air traffic control automation platforms at key sites across the country. Air traffic control computers were updated to enable use of ADS-B in non-radar airspace, and the resulting improved surveillance enabled the use of reduced (radar-like) separation standards and flight following services. The FAA also began deployment of capabilities that will lead to 3- and 5-mile separation standards using ADS-B surveillance.

Optimized profile descent (OPD) permits aircraft to remain at higher altitudes on arrival to the airport and use lower power settings during descent. A number of newly published Area Navigation (RNAV) procedures accommodate an OPD for appropriately equipped aircraft. Traditional arrival procedures have multiple segments of level flight during the descent, and each step down requires a change in power settings. OPD procedures enable arrival aircraft to descend from cruise altitudes to final approach with significantly fewer level-offs. Since aircraft can use lower and steady power settings, OPD procedures result in reduced fuel burn, lower emissions, and reduced noise. This accomplishment also supports Goal 4.

The role of controllers, pilots, and the automation they use will change in the future. A major unknown that must be addressed is the proper allocation of the aircraft separation functions between airborne and ground-based systems and human operators and automation. Significant progress is being made in concept development and in research to explore the evolution of human roles. Advanced NextGen concept simulations were conducted to investigate ground-based automation for conflict detection and resolution, airborne self-separation, and advanced trajectory-based operations at approximately twice the current maximum capacity, with integrated metering, weather, and conflict avoidance. The simulated increased capacity was managed with no substantial differences in operator performance or acceptability between the future concepts and current operations. In comparing the ground-based and airborne approaches, no significant differences in schedule conformance and flight path deviations were found. These simulations are the first in a series to investigate separation functions.

Goal 2—Develop increased NAS capacity by managing NAS resources and air traffic flow contingencies

R&D progress for all near-, mid-, and far-term objectives for Goal 2 is consistent with expectations and rated green. For the near-term objectives, the development of airspace design concepts and trajectory-based operations concepts for introduction into the National Airspace System (NAS) in the mid term has been a significant step forward. The mid- and far-term objectives, both yellow in the 2008 assessment, are now green, thanks in part to the development of a 2025 Trajectory-Based Operations (TBO) concept of operations, the integration of weather information into the mid-term decision support tools, and research emphasis on dynamic airspace reconfiguration.

A near-term concept for TBO with air/ground data link communication that promises to dramatically improve the efficiency of operations in en route and transition airspace was developed. As part of this effort, laboratory simulation involving Fort Worth Center's entire traffic load during busy periods was completed. Subsequent analysis of the simulation findings showed that the proposed concept and automation reduced the number of flight plan amendments by a factor of 8.

A four-dimensional Flight Management System TBO concept was developed. Initial validation and analysis of performance capabilities and standards as well as a Required Time of Arrival proof-of-concept demonstration were completed. Also, a mid-term Trajectory-Based Flow Management concept of operations was completed. These are critical components of mid-term (2018) trajectory-based operations.

Algorithms for dynamically combining sectors in response to changing traffic and staffing conditions were developed. Analysis using Cleveland Air Route Traffic Control Center data indicates that the sector combinations suggested by the algorithm can lead to 15% fewer congested control positions with only 5% more frequent reconfigurations. This work will lead to future airspace design improvements.

Simulations showed that when weather conditions require rerouting of flights, dynamic airspace configuration can reduce imbalances between traffic demand and air traffic control capacity. These reduced imbalances are expected to benefit both user and service provider by reducing the number of flights that need to be rerouted or delayed to maintain balance between traffic demand and capacity.

Goal 3—Reduce the adverse impacts of weather on air traffic management decisions

R&D progress for one near-term objective was assessed as yellow. Progress on other objectives was assessed to be consistent with expectations and thus assessed as green. The yellow assessment was given to the near-term objective relating to probabilistic weather prediction. Foundational R&D work on this objective is adequate, and realization of the necessary models is within the state of the science, but requirements may exceed the rate at which needed computing capabilities may be advanced. This merits continued attention. While all Goal 3 objectives were rated green in the 2008 assessment, opportunities for improvement were identified in the areas of interagency coordination and better portfolio definition across agencies. Both have improved, but they merit continued attention. An interagency effort to develop a Science and Technology Roadmap for NextGen Weather that has been initiated at the request of the National Weather Service and the Office of the Federal Coordinator for Meteorology is a step in that direction.

The primary weather phenomenon impacting aviation safety and efficiency is convective activity. Accordingly, significant work has been done by FAA and NOAA to produce more accurate forecasts with probabilistic components that will be needed for integrating weather into air traffic management decision aids. Timely and precise forecasts of these aviation-specific weather hazards require forecast models that are not only accurate and updated frequently, but also can be easily enhanced as research advancements become available. A number of models and forecast enhancements have been developed or enhanced over the past three years:

- The Weather Research and Forecasting (WRF) Model, completed in fiscal year (FY) 2010, is an operational next-generation numerical weather prediction system designed to serve both operational aviation forecasting and atmospheric research needs.
- Two weather forecasting tools are in use at the FAA Air Traffic Control System Command Center to support strategic planning and control for daily air traffic flow. The Localized Aviation Model Output Statistics Program (LAMP) is a statistical system that provides forecast guidance for weather elements that can be sensed, especially convection. This tool has been combined into a hybrid product with the Collaborative Convective Forecast Product (CCFP), which provides a national thunderstorm forecast based on input from NOAA forecasters, air traffic decision-makers, and airlines.
- An experimental Extended Convective Forecast Product (ECFP) tool was developed to help plan for weather hazards, specifically convection, one and two days in advance. It provides a graphical representation of the forecast probability of thunderstorms for days two and three based only on the model output probability of thunderstorms.
- Two convective weather forecast tools, The Corridor Integrated Weather System (CIWS) and the Consolidated Storm Prediction for Aviation (CoSPA), have been developed under FAA sponsorship. The former provides information on thunderstorms from near term through two hours and assists FAA in terminal area flow planning when thunderstorms are present or imminent. CoSPA extends the CIWS

functionality out to eight hours through incorporation of NOAA's experimental High-Resolution Rapid Refresh (HRRR) model. CoSPA is now in its second season of field testing and has been well received by its users.

- The FAA completed development of a National Ceiling and Visibility Analysis product in 2011 and is continuing to sponsor work on development of the National Ceiling and Visibility Forecast, a probabilistic 1–10 hour ceiling, visibility, and flight category forecast that is updated hourly.

Evaluating the possibility of implementing new capabilities and services to enable net-centric weather data access was a key challenge that was met. Specific accomplishments include proof-of-concept activities for a net-centric four-dimensional weather information system (the NextGen 4-D Weather Data Cube) and demonstrations of additions to the sensor network from non-ground-based sensors (e.g., satellites and aircraft). This will provide aircraft operators and the Air Navigation Service Provider with enhanced weather information to improve flight and clearance planning, trajectory-based operations, and flow management.

Goal 4—Maximize arrivals and departures at airports and in metroplex areas

R&D progress for all near-, mid-, and far-term objectives for Goal 4 is consistent with expectations and thus assessed as green. Time-based metering research and demonstration of methods for higher throughput and reduced emissions in congested terminal areas represent significant progress toward the achievement of near-term objectives for Goal 4. The assessment of progress toward the mid- and far-term objectives has changed from yellow (in the 2008 assessment) to green because of progress in wake vortex research and increased emphasis on surface, arrival, and departure management research for NextGen, including progress in refining time-based metering and merging concepts.

A laboratory prototype of a tool that helps controllers select an airport configuration to optimize traffic efficiency, taking into account forecast weather, expected traffic, and other factors, has been developed. Simulation showed that the sequence of airport configurations recommended by the underlying algorithm will result in significantly less delay than the airport configurations that were actually used by controllers under the same conditions. A modeling and simulation tool to collect data and conduct analysis of alternate proposals for further reductions of separation standards in runway spacing was completed. This will support the development of high-throughput arrival and departure operations that minimize environmental impact. The tool was used to reevaluate the blunder model for closely spaced parallel runways. The results indicate that it will be possible to reduce the lateral separation of runways without giving up the capability of independent operations. Several alternatives for showing wake turbulence information on situational aircraft-separation displays were developed, and a concept feasibility simulation of wake turbulence mitigation for arrivals was completed. This research will lead to operations with equal or increased levels of wake encounter safety and increased capacity. Improved extraction of wake vortex circulation and position estimates data from light detection and ranging (LIDAR) measurements will support NASA's fast time wake vortex prediction model development and also serve as the foundation of wake-informed, advanced automated separation assurance systems.

There were several accomplishments that will lead to improved arrival and departure flows. An arrival scheduling capability, which incorporates conflict-free metering points in en route airspace, was developed, tested, and deployed. This will enable the development of more extended arrival metering capabilities. A more advanced concept for an air traffic control tool for computing efficient, low-power arrival solutions during busy traffic conditions, called the Efficient Descent Advisor, has been developed and tested in human-in-the-loop simulations. When implemented, this tool will reduce fuel burn and environmental emissions, increase arrival throughput, and reduce controller workload.

NASA, in collaboration with the FAA, a domestic airline, and Dallas Fort Worth airport, has completed a multi-week field evaluation of the Precision Departure Release Capability. It uses trajectory-based takeoff time estimates from a surface automation system to improve en route tactical departure scheduling into constrained overhead flows. This will improve the merger of traffic into existing overhead openings and increase throughput.

There were a number of accomplishments aimed at improving surface movement. Several enhanced low visibility operational improvements were completed, including the use of lower runway visual range minima. Ground infrastructure aimed at improved surface operations was installed and certificated at several airports.

Goal 5—Develop expanded manned and unmanned aircraft system capabilities to take advantage of increased air transportation system performance

Measurable progress in research and technology development for all near-, mid-, and far-term objectives for Goal 5 is being made, with an attendant progress assessment of green. The foundational work being conducted is generating the knowledge base that is enabling technology innovations, capabilities, and design concepts for the achievements in N+2 and N+3 vehicle technology goals. In the area of design and control of lightweight flexible structures, these achievements could have a more near-term impact for the N+2 technologies. With steady investment of resources, technical skills, and time, along with the timely mitigation of potential risks for the N+2 and N+3 aircraft, it is anticipated that these objectives, which include significantly improved performance and lower environmental impact, will be achieved.

An important component of the research activities supporting Goal 5 is the development of higher fidelity analysis and design tools and capabilities for more accurate prediction of air vehicle performance characteristics. These improved tools will allow earlier understanding of how advanced aircraft integrate into the air transportation system most advantageously. First-generation multidisciplinary analysis and optimization (MDAO) tools have been completed and validated. The second-generation MDAO suite of tools has been used successfully in validating the aerodynamic performance of the (unconventional) blended wing body (BWB) aircraft, with the predictions showing good agreement with the estimates provided. Open MDAO, an open-source computational framework that facilitates the solution of complex problems by allowing users to link analysis codes from multiple disciplines at different levels of fidelity, has been released.[13] Finally, mixed-fidelity model prediction and propagation have been successfully implemented and demonstrated within the system framework of the Aircraft Noise Prediction Program (ANOPP) II tool.

Another important component of the research activities supporting Goal 5, underway under JPDO auspices, is modeling and simulation to support analysis of the interactions between TBO services, a net-centric communications structure, Performance Based Navigation in all four dimensions (lateral, longitudinal, vertical, and time), and ADS-B in services for properly equipped aircraft. Precision Navigation and Timing is currently being modeled in the subsonic domain to support the use of TBO services.

An avionics roadmap was developed by government and industry partners to provide an estimate of the avionics capabilities that will be required for aircraft to take advantage of NextGen in the far term. This roadmap directly addresses the challenge, from the aircraft perspective, of ensuring that the avionics characteristics match up with the capabilities of the Air Navigation Service Provider's services. The roadmap provides the basis for the typically 15– to 20-year process of identifying future characteristics; developing design standards; and building, certifying, and installing the equipment on the aircraft. The roadmap allows the FAA to anticipate future systems that will require certification, thus allowing them to formulate that system's certification process and design standards prior to the system being actually submitted for certification.

NASA, in partnership with industry and academia, completed advanced concepts and technology studies to better define advanced airframe and propulsion concepts and enabling technologies. A study to assess the technology needs and sonic boom mitigation concepts for future supersonic transports revealed slender, highly integrated configurations

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[13] http://openmdao.org/.

with unique shapes that practically eliminate sonic boom. The configurations and related advanced technologies will facilitate the ushering in of overland supersonic flight.

The Air Force Research Laboratory completed a flight test of a 30-degree sweep laminar flow wing designed for a high altitude, long endurance (HALE) aircraft. The test demonstrated that significant laminar flow (~50% chord) is achievable, leading to drag and fuel burn reductions. This flight test was done with a test article that represented a wing incorporating not only a laminar flow design, but lift, pitching moment, and overall drag characteristics necessary for a practical wing design. This research has matured swept wing laminar flow control for HALE and validated the design approach and tools necessary for developing fuel-efficient mobility platforms.

The Air Force Research Laboratory has completed a parametric study of technology impacts for reduced energy use and outlined the development approach for these technologies. Teams led by five major U.S. aerospace companies finished studies of new mobility transport aircraft for the 2035+ time frame and defined technologies needed to improve overall mission energy efficiency. Areas for aircraft efficiency improvement included optimizing wing aerodynamic and structural efficiencies, reducing parasite drag, and integration of higher bypass ratio engines.

NASA, in partnership with industry and university teams, completed an 18-month study to develop advanced N+3 technology concepts for commercial subsonic transport that could enter service in the 2030–35 time frame. The study defined a range of promising technologies and vehicle architectures capable of meeting the N+3 performance requirements in fuel burn, noise, and emissions reductions. In addition, system studies were completed that show promise for commercially viable large (100 passenger) civil rotary wing transport or civil tiltrotor with vertical take-off and landing capability (i.e., without runways). This has the potential of providing more efficient point-to-point air travel in NextGen.

The JPDO partner agencies collaborated and are in the joint-agency approval process with development of a strategic NextGen unmanned aircraft system (UAS) research, development, and demonstration (RD&D) roadmap. This RD&D roadmap will help create the foundation for an overall national roadmap for UAS access into the NAS and NextGen. NASA initiated a UAS integration in the NAS project to advance technology development and demonstrations in specific technology elements (separation assurance, human systems integration, communication, and certification) that will address operational/safety issues related to this integration. DoD has completed significant R&D regarding UAS integration; this is noted in the National Security and Homeland Defense section below.

SUMMARY

As illustrated in Table 1, R&D progress has been achieved across the Mobility goals and objectives over the past several years. Further, the green assessments convey that the R&D efforts, as understood today, are considered adequate to advance the goals and objectives necessary to achieve the near-, mid-, and far-term objectives for: reduced aircraft separation; more capable use of the national airspace; reduced impacts from weather; improved capacity in metroplex areas; and aircraft systems necessary to safely benefit from future national airspace enhancements. As Mobility R&D proceeds, learning will inevitably take place that will impact the course of technology and future Mobility R&D planning. An example is the desire to advance multidisciplinary research (e.g., validation and verification of complex systems) to address enterprise-level issues and better forecast the complex events, interdependencies, and cascading effects associated with the deployment of future air transportation enhancements. This challenge cuts across numerous goals and is not directly addressed in the current mobility R&D objectives. Continued vigilance and integrated planning will be needed to help ensure the coordinated and efficient R&D progress that is essential across the departments and agencies to create a successful R&D foundation for the national aeronautics systems of the future.

Table 1. Assessment of Mobility R&D Progress

Goal	Near Term (<5 years)	Mid Term (5-10 years)	Far Term (>10 years)	Near Term Objectives	Mid-Term Objectives	Far-Term Objectives
Goal 1 Develop reduced aircraft separation in trajectory- and performance-based operations	Develop separation standards that vary according to aircraft performance and crew training Develop nonradar 30-mile separation procedures for pair-wise maneuvers in oceanic airspace	Develop 5-mile nonradar separation procedures for current nonradar airspace Develop positioning, navigation and timing precision requirements for fixed- and variable-separation procedures	Demonstrate self-separation in at least one airspace domain Validate performance-based variable separation standards for multiple domains	G	G	G
	Develop Automatic Dependent Surveillance-Broadcast 3- to 5-mile spacing Develop positioning, navigation and timing (including backup) capabilities to support NextGen	Develop merging and spacing tools for continuous descent approaches that balance capacity and environmental considerations Establish the basis for separation standards to increase airspace density	Implement human-machine and air-ground interaction methods in a highly automated air transportation system	G	G	G
Goal 2 Develop increased NAS capacity by managing NAS resources and air traffic flow contingencies	Develop advanced airspace design concepts to support scalability to 3× operations Develop Special Use Airspace and general aviation access procedures to maximize capacity to match demand	Develop dynamically adjustable advanced airspace structures—including flow corridors—scalable to accommodate an interim target of an environment supporting 2× operations Develop methodologies for the dynamic allocation of NAS resources	Demonstrate dynamic allocation of NAS resources Develop automated flight and flow evaluation and resolution capabilities to support Air Navigation Service Provider negotiations	G	G	G
	Develop trajectory management methods for collaborative preflight routing including prediction, synthesis, and negotiation Develop comprehensive strategies to translate weather information into operational impacts and integrate those impacts into decision support tools	Integrate weather information into flow management decision support tools	Demonstrate gate-to-gate trajectory-based flight planning and flow management to increase NAS efficiency, capacity, and reduce weather delays and environmental impact	G	G	G
Goal 3 Reduce the adverse impacts of weather on air traffic management decisions	Develop resolution and accuracy requirements for weather observation and forecasting information Develop requirements for probabilistic weather prediction systems and methods for communicating forecast uncertainty	Develop technologies for sharing weather hazard information measured by on-board sensors with nearby aircraft and ground systems and vice-versa Develop probabilistic weather forecast products that communicate uncertainty information	Integrate weather observation and forecast information in real time into a single authoritative source of current weather information Develop air traffic management decision strategies to reference a single authoritative weather source, including understanding impacts of disparate interpretations of the data	Y	G	G
	Develop initial capability for net-centric four-dimensional weather information system, including enabling fusion of multiple weather forecast and ground and airborne observation products and researching the roles of humans in applying operational expertise to augment automated, four-dimensional weather grids	Develop severity indices for aviation weather hazards using observations and forecasted weather data for short-to-long range decision making Develop capabilities to translate weather severity information into adverse weather information for operational use	Demonstrate NextGen Network-Enabled Weather capabilities to reduce adverse impacts	G	G	G

Goal	Near Term (<5 years)	Mid Term (5-10 years)	Far Term (>10 years)	Near Term Objectives	Mid-Term Objectives	Far-Term Objectives
Goal 4 Maximize arrivals and departures at airports and in metroplex areas	Develop traffic spacing/ management technologies to support high-throughput arrival and departure operations while minimizing environmental impact	Develop technologies and procedures for operations of closely spaced parallel runways Integrate weather information into terminal area decision support tools	For a system that is scalable to 3× operations: Reduce lateral and longitudinal separations for arrival and departure operations Demonstrate technologies and procedures to support surface operations Develop time-based metering for flows transitioning into and out of high-density terminals and metroplex areas to enable significant airspace design flexibility and reduced environmental impact	G	G	G
	Develop time-based metering of flows into high density metroplex areas	Develop performance-based trajectory management procedures for transitional airspace		G	G	G
	Develop technology to display aircraft and ground vehicles in the cockpit to guide surface movement	Develop operations and procedures to integrate surface and terminal operations, especially in low-visibility conditions		G	G	G
Goal 5 Develop expanded manned and unmanned aircraft system capabilities to take advantage of increased air transportation system performance	Develop validated multidisciplinary analysis and design capabilities with known uncertainty bounds for N+1 aircraft, and develop procedures for the interaction of a variety of vehicle classes with the airspace system (including N+1, very light jets, UAS, and other vehicle classes that may appear in the system)	Develop validated system analysis and design capabilities with known uncertainty bounds for N+2 and N+3 advanced aircraft, including their interaction with the airspace system	Develop suitable metrics to understand realizable trades between noise, emissions, and performance within the design space for N+2 and N+3 advanced aircraft	G	G	G
	Develop dynamic, need-based "fast-track" Federal approval process for airframe and avionics changes Develop aircraft capability priorities for NextGen through 2015 to support standards development and certification	Develop N+2 aircraft fleet and associated capabilities to support the development of procedures, policies, and methodologies for reduced cycle times to introduce aircraft and aircraft subsystem innovations	Continue development and refinement of procedures, policies, and methodologies supporting reduced cycle times for introduction of advanced (N+3 and beyond) aircraft and associated subsystem innovations	G	G	G
	Enable commercial supersonic aircraft cruise efficiency 15% greater than that of the final NASA High Speed Research (HSR) program baseline	Enable advanced technologies for N+2 aircraft with significantly improved performance and environmental impact Enable commercial supersonic aircraft cruise efficiency 25% greater than that of the final NASA HSR program baseline Enable the development of N+2 cruise-efficient short takeoff and landing aircraft, including advanced rotorcraft, with between 33% and 50% field length reduction compared with a B737 with CFM56 engines*	Enable advanced technologies for N+2 and N+3 aircraft with significantly improved performance and environmental impact Enable N+2 and N+3 commercial supersonic aircraft cruise efficiency 35% greater than that of the final NASA HSR program baseline (through reductions in structural and propulsion system weight, improved fuel efficiency, and improved aerodynamics and airframe/ propulsion integration)	G	G	G

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* The reference aircraft is a B737-800 with CFM56/7B engines, representative of 1998 entry into service technology.

AVIATION IS VITAL TO NATIONAL SECURITY AND HOMELAND DEFENSE

Aviation is a central part of America's National Security Strategy, providing needed capabilities to project military power around the globe in defense of U.S. interests and overcome a wide range of national security challenges. At the same time, the military must possess the ability, at a moment's notice, to seamlessly use the NAS for defense anywhere within and approaching U.S. borders.

—"National Aeronautics Research and Development Plan," February 2010, p. 23

SUMMARY OF R&D ACTIVITIES SUPPORTING THE NATIONAL SECURITY AND HOMELAND DEFENSE PRINCIPLE

Aeronautics R&D for the National Security and Homeland Defense (NS&HD) Principle is divided into six goal areas. These six goals include R&D objectives to improve lift-to-drag and other performance parameters; reduce fuel consumption; increase power generation and thermal management capacity for aircraft; demonstrate sustained, controlled hypersonic flight; and develop capabilities for the integration of UAS into the National Airspace System. (For complete text, see the 2010 R&D Plan.) Interagency cooperation supporting the advancement of NS&HD R&D includes participation primarily from DoD and NASA.

ASSESSMENT OF R&D PROGRESS FOR THE NATIONAL SECURITY AND HOMELAND DEFENSE GOALS

Overview

Each of the six NS&HD Goals areas was given a broad assessment of green or yellow based on this review. A green assessment denotes that R&D activities planned or ongoing are sufficient to achieve the objectives in the time frame indicated. A yellow assessment indicates that R&D activities should provide significant progress toward the objectives but there is some risk that merits continued attention. The overall results of this analysis are shown in Table 2 at the end of this section.

Goal 1—Demonstrate increased cruise lift to drag and innovative airframe structural concepts for highly efficient high-altitude flight and for mobility aircraft

The ability to cruise efficiently at a range of altitudes, enabled by a substantial increase in cruise lift-to-drag ratios over today's high-altitude reconnaissance aircraft, is a critical goal and key element in support of national security, providing sustained presence, long range, and advanced sensing capabilities. Work has continued on novel configurations and lighter weight structures to meet this goal. The Aerodynamic Efficiency Improvement program has performed wind tunnel testing to address increased lift-to-drag ratios. The configurations tested have included hybrid wing body and joined-wing aircraft with active loads control, gust load alleviation systems, and demonstration of extended laminar flow.

These technologies have the potential to increase intelligence, surveillance, and reconnaissance aircraft time on station by up to 50%.

Two projects have been initiated to address integration of antenna arrays into the primary structure with direct improvements to the aircraft structural and aerodynamic efficiency, one focused on X-band frequency arrays and the other on ultrahigh frequency (UHF) band arrays. The X-band project has the goal of developing and demonstrating embedded X-band structural arrays. The arrays have met key radio frequency (RF) gain and primary load-bearing performance parameters and are currently undergoing deformation compensation tests. RF chamber tests will lead to flight demonstrations of an electrically capable array. The UHF band project has developed embedded wing arrays and started preparations for ground demonstrations. Structural durability tests will be completed in 2012, and integration of transmit/receive modules with antenna for electrical characterization has begun.

The Air Force and NASA have conducted a series of system studies that include a number of novel configurations applicable to mobility aircraft that would significantly improve cruise lift-to-drag ratios and improve efficiency. In addition, NASA has invested in foundational research on tools and technologies to enable these configurations, including advanced material concepts and new design tools that can analyze complex configurations. Flight testing of the X-48B hybrid-wing body aircraft has also had a significant impact on understanding control aspects of these configurations. A key technical challenge is scaling of structures such as large, non-circular pressure vessels while avoiding a severe weight penalty. One possible solution to the weight penalty is the Air Force's and NASA's Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) concept. In this concept, a stitched carbon-epoxy material system has been developed with the potential for reducing the weight and cost of mobility aircraft structures. In addition, the X-55 Advanced Composite Cargo Aircraft, a proof-of-concept technology demonstrator for composite manufacturing processes in a full-scale, certified aircraft, demonstrated that large, unitized, high-performance composite structures could be made at reduced costs, using fewer parts and processes that avoid autoclave curing techniques. The X-55 successfully completed a series of demonstration flights that included airspeed, stability, control, and envelope expansion tests.

Goal 2—Develop improved lift, range, and mission capability for rotorcraft

Future national security plans will benefit from rotorcraft systems that have significantly improved lift, range, survivability, and mission capability compared with year 2005 state-of-the-art technology and an overall reduction in logistics and cost of operation. Investment in advanced rotor concepts is essential to adequately mature the capability and realize the true potential of the technology.

Reductions in gearbox noise and decreased weight of rotorcraft drive systems are critical. The recently completed Enhanced Rotorcraft Drive System (ERDS) showed 40% increase in horsepower-to-weight ratio and a 15 dB noise reduction, as well as demonstrating that the technologies enabling this improved performance could cost up to 30% less to fabricate and maintain. ERDS demonstrated the capability to increase aircraft range and payload capability by exploiting breakthrough technologies in the area of materials, design methods, manufacturing, and configurations for rotorcraft main rotor drives. Improvements were demonstrated by using composites for housing covers and drive shafts, using helical face gears, and incorporating automatic detection of critical failures. The Future Advanced Rotorcraft Drive System, which is in the initial stages of development, will build on the success of ERDS and continue to improve drive efficiencies with expected performance levels approaching the mid-term objectives.

Wind tunnel tests have recently been completed on individual blade control and active blade control technologies to reduce vibration and improve hover efficiency. Wind tunnel tests have also been recently completed on current helicopter rotors to gather loads data for validation and verification purposes that will result in improved modeling and simulation capabilities. The rotorcraft R&D community has also been working on improved main rotor design and analysis to address rotorcraft noise, through the use of computational fluid dynamics and computational structural dynamics modeling and simulation tools. These tools will allow improved predictive capability for source noise in hover and maneuvering flight. Their development will be coupled with the other rotor development activities.

The DoD recently initiated the Joint Multi-Role Technology-enabled Capability Demonstration (JMR-TCD) program, which is positioned to potentially redefine future rotorcraft concepts and technologies. The JMR-TCD will develop and demonstrate transformational aircraft technologies for the next generation of rotorcraft, advanced aircraft configurations that provide enhanced operational efficiencies, platform survivability, and integrated vehicle health usage monitoring that will result in reduced procurement and support costs and increase the survivability of the warfighter. The project is currently performing configuration trades and analyses to provide a wide range of attributes for an objective aircraft. The configuration trade studies will continue through 2013, leading to concept demonstrators planned for development and flight testing.

Goal 3—Demonstrate reduced gas turbine specific fuel consumption

Reduction in propulsion system specific fuel consumption (SFC) would provide important improvements in aircraft range, endurance, mission flexibility, and payload capability. The DoD's Versatile Affordable Advanced Turbine Engine (VAATE) program, which serves as an overarching framework for military turbine engine science and technology development, has a number activities focused on providing significant SFC reductions. The Highly

Efficient Embedded Turbine Engine (HEETE) program has two high pressure ratio compressor demonstration programs that have proceeded from development to the testing stage. Design and development of the experimental testing rigs incorporates thermal management systems for demonstration at full temperature conditions. Compressor testing is scheduled for completion in late 2012, with demonstration of high pressure engine core technologies scheduled for 2016. Vision system studies are evaluating advanced engine cycles combining high pressure ratio with variable-cycle features to achieve SFC reduction. This effort builds on the HEETE compressor rig testing under the near-term objective, as well as combustor testing and analysis under an adaptive combustor program. Materials efforts including hybrid disk systems and 2700 °F SiC/SiC (silicon carbide/silicon carbide) are progressing successfully and are anticipated to contribute to the success of the HEETE program. Overall, technologies are on pace to deliver a more than 30% SFC reduction for engine demonstration in 2019.

The Advanced Affordable Turbine Engine (AATE) program will be delivering 65% increased horsepower to weight, decreasing SFC by 25%, and reducing both production and maintenance cost by 35% in turboshaft engines for rotorcraft. Initial high-pressure engine core testing has been completed, with full engine demonstration to follow in early 2012. The Future Affordable Turbine Engine (FATE) program embraces technology improvements beyond that of AATE planned for turboshaft engines.

The Adaptive Versatile Engine Technology (ADVENT) program is developing multi-design point engine technologies that provide optimized fuel efficiency and performance capabilities over a wide range of flight regimes, resulting in a greater than 25% overall improvement in propulsion system fuel efficiency. ADVENT will provide a suite of revolutionary technologies for a range of future and legacy air vehicles, including tactical and long-range strike aircraft, as well as future strategic and tactical mobility and intelligence, surveillance, and reconnaissance platforms. Key component tests have been completed on adaptive fans, compressors, combustors, turbines, bearings, and heat exchangers. These tests have documented the performance and structural characteristics of each component. In some cases the tests have verified predictions, and other tests have resulted in component design modifications. Engine designs incorporating the findings from the component tests have been completed, and hardware fabrication is nearing completion, with engine testing planned in 2013.

Goal 4—Demonstrate increased power generation and thermal management capacity for aircraft

Dramatic improvements in power and thermal management are required to facilitate additional sensor packages and advanced electronics, along with the potential development of airborne directed-energy weapons. In, addition, higher temperature propulsion systems and higher flight speeds will yield much higher heat loads to be managed by future aircraft, with some projections of heat loads reaching 10 times those of today's tactical military aircraft such as the F-15 or F-16.

The Integrated Vehicle Energy Technology (INVENT) program was created to address these growing requirements. The INVENT Spiral 1 program completed early and delivered a family of models to design energy-optimized fifth-generation tactical aircraft systems. The modeling and simulation toolsets developed in conjunction with INVENT Spiral 1 have transitioned to assess energy, power, or thermal management growth or improvement options for legacy platforms, including Global Hawk, B-52, F-15, F-16, and F-22, as well as the emerging F-35 Joint Strike Fighter (JSF). In addition, key technology initiatives were launched for smart, adaptive power systems using SiC high-speed power switches in an advanced JSF-style electrical distribution unit for next-generation aircraft.

The Air Force demonstrated a multi-megawatt, high-speed (15,000 rpm) generator, showing a 10× power improvement for its weight (less than 500 lb) over existing state-of-the-art generators and the ability to produce greater than 1 MW continuous load. The generator is intended to supply power through a compact package for directed-energy applications and for aircraft with increasing load and mission requirements. The generator's rated peak power is 2.5 MW for low-duty cycles. At the same time, several ongoing programs are working to reduce power and thermal management system weight. These are examining a greater use of vapor compression refrigeration cycle systems (VCS) for aircraft thermal management. Past studies have shown that increasing the use of VCS, potentially in hybridization with more traditional air cycle systems, can lead to significant weight and volume reductions for aircraft thermal management systems.

The use and proliferation of UAS, and especially small UAS, where weight and volume are especially stressing, have necessitated the development of power technologies designed especially for them. The SURGE-V (Small Unmanned Renewable enerGy long Endurance Vehicle) program was initiated to transition fully integrated and ruggedized small UAS power system technologies to end users, providing a power and propulsion system for a man-packable UAS that uses renewable energy. In addition to SURGE-V, a successful wind tunnel test was completed of a fuel-cell-powered small UAS that used synthetic JP-8 as its fuel.

An Energy Optimized Aircraft (EOA) Steering Committee is being established to guide the future of EOA development. EOA development will enable future energy optimized air platforms with enhanced operational capabilities by minimizing thermal impact and reducing energy and power consumption in aircraft design. The EOA Steering Committee will oversee new technology development capabilities including:

- Platform-level energy optimization and systems integration;
- Advanced component and subsystem development;
- Fully integrated multi-level modeling and simulation; and
- Comprehensive hardware-in-the-loop testing.

Goal 5—Demonstrate sustained, controlled, hypersonic flight

High-speed and hypersonic flight has the potential to transform flight across the air-space continuum but is extremely challenging, requiring R&D into all areas of high-speed atmospheric flight. In May 2010, the X-51A Scramjet Engine Demonstration program demonstrated powered hypersonic flight at a speed of nearly Mach 5. The program was largely successful through its first flight and demonstrated most of is critical objectives, including launch from a B-52 with a fixed-geometry inlet, use of JP-7 fuel, and demonstration of endothermic fuel-cooled structures. A successful launch and flight were tempered by an anomaly at Mach 5 that ended the initial flight early. Even with the anomaly, the scramjet burn time was the longest ever recorded. Data from the X-51A project will support the development of analytical tools for validation of design and analysis capability. A second flight test in June 2011 was less successful, though lessons learned will improve future efforts. There are up to two more flight tests remaining in the X-51A program.

Ground testing and component development of key scramjet technologies have also progressed. Both the X-51A and the HyFly programs successfully completed ground tests of scramjet propulsion systems. NASA is investing in ceramic matrix composite panels and heat exchangers for scramjet combustors. NASA turbine-based combined cycle engine development and testing in the Glenn Research Center 10×10 supersonic wind tunnel is advancing controls technology for turbine-based combined cycle turbojet-to-scramjet propulsion mode transition. The Hypersonic International Flight Research Experiment (HIFiRE), a collaborative program between the Air Force and Australian Department of Defense with NASA involvement, has developed a hydrocarbon fueled scramjet experiment payload to be flight tested in 2012, which will provide valuable data on a hydrocarbon-fueled scramjet at Mach 8 flight conditions as well as ramjet-to-scramjet mode transition in atmospheric flight.

The technologies required for hypersonic flight are equally challenging for the airframe. The Fully-reusable Access to Space Technologies (FAST) program is a ground-test program to evaluate component technologies and prepare them for eventual flight test. The FAST program is integrating work in structures, thermal protection systems, adaptive guidance and control, health management, and other subsystems into a set of coordinated ground experiments, with the ultimate goal to mature technology for reusable space access vehicles with spin-off to high-speed aircraft. The program demonstrated adaptive guidance and control hardware-in-the-loop simulation in June 2011. Operational control and health management technologies with test cycles of thermal and flight loads are scheduled to be completed in 2013.

The Hypersonic Technology Vehicle 2 (HTV-2) and Advanced Hypersonic Weapon (AHW) programs are being leveraged for technologies in aerodynamic shaping, thermal protection systems, and adaptive guidance and control. HTV-2 and AHW are boost-glide vehicle concepts that are exploring different aerodynamic approaches to achieve hypersonic flight and cross-range maneuverability. HTV-2 is using a waverider aeroshell; AHW is using a conic shape. A DoD initiative on high-temperature materials and structures is focused on providing adequate thermal management performance to control internal vehicle structural temperatures. NASA is also investing in R&D for structurally integrated thermal protection system technology.

The X-37B Orbital Transfer Vehicle, flown in 2010, is demonstrating efficient aerodynamics for high lift-to-drag and a highly durable, high-temperature thermal protection system and thermal management techniques for high-speed reentry from orbit on a reusable vehicle. The Responsive Reusable Booster System for Space Access (RBS) program builds upon previous airframe advancements to develop a reusable winged rocket plane. RBS would launch vertically; fly to a staging point; separate an expendable upper stage; and then return to base, landing like an aircraft. If successful, the RBS program will validate reusable hypersonic technologies for thermal management, high-temperature/low-weight structures, lightweight warm structures, integrated vehicle health management, and hypersonic maneuver adaptive guidance and control.

Goal 6—Develop capabilities for UAS NAS integration

The development of UAS NAS integration capabilities requires the close interaction of the policy, technology, and acquisition communities. The critical technical capability is the ability for UAS to sense and avoid (SAA) other aircraft to meet the regulatory requirement to "see and avoid." The policy that defines the acceptability of such a capability and the acquisition process that determines how such acceptability is proven must be developed in concert with the technology.

The DoD, NASA, FAA, and other UAS stakeholders work through various venues such as an Executive Committee and the JPDO to coordinate technology and policy efforts within and across those agencies. These agencies initiated a set of workshops in late 2010 to continue to address critical definitions and to establish the target level of safety criteria to which an SAA system might be certified. The final report from these workshops is expected in late 2012. The DoD also performed an analysis of alternatives in 2010 for methods to develop and document a safety case for an SAA system. The agencies also collaborate through the Radio Technical Commission for Aeronautics (RTCA) Special Committee-203, helping shape the civil requirements for UAS NAS Integration. These and other such joint efforts (e.g., development of the NextGen UAS RD&D roadmap noted in the Mobility section above) provide valuable policy recommendations and are further informed by lessons learned from technology development efforts.

The Army developed a ground-based SAA system, worked with the FAA to gain acceptance of the safety case prepared for that system, and flew the first ever UAS flight in the NAS using that system in April 2011. This ground-breaking event provided a much needed capability to the DoD as well as valuable feedback for the whole community on the processes required to achieve such a milestone.

The UAS R&D community is also developing airborne SAA systems that are currently being tested. The Navy is investigating cooperative SAA techniques under the All Weather Sense and Avoid System, which has produced 20 units and is beginning flight testing. The Navy is also pursuing the development and demonstration of a dedicated C-Band radar for detecting and tracking non-cooperative air targets. The cooperative and non-cooperative subsystems will be tested together on a manned helicopter in 2014, with transition to the Fire Scout UAS beginning in 2015. The Air Force has been successfully flight testing its Multiple Sensor Integrated Collision Avoidance (MuSICA) system since 2006, increasing the system capabilities along the way. These flight tests have been conducted jointly with the FAA, and the final integrated system tests will occur in 2012, after which the primary development responsibility will shift to the Air Force Global Hawk and Navy Broad Area Maritime Surveillance program offices. A miniaturized version of the electro-optical portion of the Air Force SAA system was integrated into an Army Shadow and flown in January 2011. While challenges remain, this flight demonstrated the flexibility and scalability of these SAA technologies in support of the mid-term objectives. Future algorithm developments will include elements such as formation flight and operations in the terminal area. Sensor technologies are also being developed with the intent to integrate and fly them on a medium altitude UAS, such as the MQ-9 Reaper, in 2013. The key enabling technologies for the far-term integration of UAS into the airspace are lightweight, low-cost sensor suites and autonomy algorithms that enable detection and avoidance of all classes of aircraft or UAS in the NAS.

SUMMARY

Overall, significant advances in NS&HD aviation technology and capability have been made toward accomplishing the objectives as shown in Table 2. Planned and ongoing efforts are sufficient for meeting two-thirds of all near-term NS&HD objectives, and green assessments were assigned. Certainty of success decreases somewhat for the mid-term and long-term objectives, where yellow assessments were assigned to over one-half of all objectives. Many of these objectives are areas where new knowledge gained will result in some adjustment of research priorities and objectives; others are areas where technical advancement simply has not progressed as planned. For these objectives in particular, continued emphasis must be maintained to ensure that R&D activities remain focused and coordinated to improve overall outcomes.

Table 2. Assessment of National Security and Homeland Defense R&D Progress

Goal	Near Term (<5 years)	Mid Term (5-10 years)	Far Term (>10 years)	Near Term Objectives	Mid-Term Objectives	Far-Term Objectives
Goal 1 Demonstrate increased cruise lift to drag and innovative airframe structural concepts for highly efficient high-altitude flight and for mobility aircraft	Develop design methods for efficient, flexible, adaptive, and lightweight aerostructures Demonstrate conformal load-bearing antenna elements and shape sensing subsystems	Demonstrate 20% delay in laminar to turbulent transition over a 30° swept laminar flow airfoil Demonstrate key component technologies for novel configurations with a substantial improvement in lift-to-drag ratios for unmanned intelligence, surveillance, and reconnaissance applications	Flight demonstrate novel aerodynamic configurations with a substantial improvement in lift-to-drag ratios for unmanned intelligence, surveillance, and reconnaissance applications	G	G	Y
	Develop novel configurations for mobility aircraft through advanced aerodynamics and structural concepts	Demonstrate key component technologies for novel configurations with >25% improvement in lift-to-drag ratios for mobility aircraft	Demonstrate novel configurations with >25% improvement in lift-to-drag ratios for mobility aircraft	G	Y	Y
Goal 2 Develop improved lift, range, and mission capability for rotorcraft	Increase power to weight (+40%) and reduce noise of main rotor gearbox (–15 dB)	Increase power to weight (+70%) and reduce noise of main rotor gearbox (–20 dB)		G	G	
	Reduce vibratory loads 20%; improve forward flight efficiency 2%	Reduce vibratory loads 25%; improve forward flight efficiency 5%	Reduce vibratory loads by 30% and improve forward flight efficiency by 10%	G	G	G
	Increase hover efficiency by 4%	Increase hover efficiency by 7%	Increase hover efficiency by 10%	Y	Y	Y
	Develop analytical tools and component technologies for advanced low-noise concepts	Flight test tactically significant acoustic signature reduction	Demonstrate 50% reduction in acoustic perception range	G	G	Y
Goal 3 Demonstrate reduced gas turbine specific fuel consumption	Design and demonstrate high pressure compressor technologies for high overall pressure ratio propulsion systems through key component tests	Demonstrate a high-overall pressure ratio propulsion system enabling a 25% or greater specific fuel consumption reduction	Develop and demonstrate advanced propulsion concepts with variable cycle features and high overall pressure ratio enabling a greater than 30% specific fuel consumption reduction	G	G	Y
	Design and demonstrate variable cycle propulsion component technologies through key component tests	Demonstrate a variable cycle propulsion system enabling a 25% or greater specific fuel consumption reduction		G	Y	
Goal 4 Demonstrate increased power generation and thermal management capacity for aircraft	Demonstrate 2× operating temperatures for power electronics	Demonstrate 5× increase in thermal transport and heat flux for power electronics	Demonstrate 10× increase in thermal transport and heat flux for directed-energy weapons	Y	Y	Y
	Demonstrate 4× increase in generator power density for directed-energy weapons		Demonstrate 50% weight and volume reduction for aircraft power and thermal management systems	G		G
	Demonstrate >60 W/kg power density for UAS rechargeable energy storage	Demonstrate 2× power density for UAS hybrid energy storage		Y	Y	

Goal	Near Term (<5 years)	Mid Term (5-10 years)	Far Term (>10 years)	Near Term Objectives	Mid-Term Objectives	Far-Term Objectives
Goal 5 Demonstrate sustained, controlled, hypersonic flight	Demonstrate sustained, controlled flight at Mach 5–7 for a duration greater than 5 minutes using an expendable airframe and hydrocarbon fuel	Ground test scramjet propulsion systems to 10× airflow of today's scramjet technology Increase effective heat capacity of endothermically cracked hydrocarbon fuel to extend vehicle thermal balance point beyond Mach 8	Demonstrate scramjets operable to Mach 10 on hydrocarbon fuel and to Mach 14 on hydrogen fuel	G	Y	Y
	Ground test hypersonic vehicle component technologies, including high-temperature structures, thermal protection systems, adaptive guidance and control, and health management technologies	Flight test air-breathing vehicle technologies beyond Mach 7 and durations greater than 10 minutes for application to space launch systems and possible reconnaissance/ strike systems Demonstrate a lightweight, durable airframe capable of global reach	Validate an optimum air vehicle solution that demonstrates an efficient thermal management approach to accommodate the combined thermal loads of the aero-thermal environment, integrated engines and internal vehicle subsystems	Y	Y	Y
Goal 6 Develop capabilities for UAS NAS integration	Develop a flight safety case modeling capability including data collection methods Define the appropriate target level of safety and the process for evaluation	Validate and verify flight safety assessment capability	Demonstrate rapid, routine flight safety assessments	Y	Y	Y
	Demonstrate sense and avoid capability for large UAS in low traffic environments	Demonstrate sense and avoid for full range of UAS sizes and multiple UAS in low density airspace and mixed fleet interactions	Demonstrate sense and avoid for full range of UAS in all classes of airspace including high density terminals and metroplex areas	G	G	G

AVIATION SAFETY IS PARAMOUNT

Every individual who enters an airport or boards an aircraft expects to be safe. To that end, continual improvement of safety of flight must remain at the forefront of the U.S. aeronautics agenda.

—"National Aeronautics Research and Development Plan," February 2010, p. 29

SUMMARY OF R&D ACTIVITIES SUPPORTING THE AVIATION SAFETY PRINCIPLE

Aeronautics R&D for the Aviation Safety Principle is divided into three goal areas. These three goals include R&D objectives intended to help develop technologies to reduce accidents and incidents through enhanced vehicle design, structure, and subsystems; to do the same for aerospace vehicle operations; and to enhance passenger and crew survivability in the event of an accident. (For complete text, see the 2010 R&D Plan.) Interagency cooperation supporting the advancement of Aviation Safety R&D includes participation primarily from FAA and NASA, with support from DoD, NIST, and NOAA.

ASSESSMENT OF R&D PROGRESS FOR THE AVIATION SAFETY GOALS

Overview

Each of the three Aviation Safety goal areas was given a broad assessment of green, yellow, or red based on this review. The overall results of this analysis are shown in Table 3 at the end of this section. As shown in Table 3, significant progress is expected toward all Aviation Safety aeronautics R&D objectives in the near term, and adequate coverage is planned for the mid- and far-terms with one exception—the ability to validate future design and analysis tools for integrated vehicle structure and occupant restraints—because of insufficient foundational research. Each of these areas is addressed in more detail under the associated goal below.

Goal 1—Develop technologies to reduce accidents and incidents through enhanced vehicle design, structure, and subsystems

Near-term research in maintaining airworthiness and health of vehicle structures and propulsion systems is being conducted by NASA, the FAA, and the DoD and has been assessed to be adequate. FAA research is directed toward providing technical bases for the use of health monitoring systems in civil aircraft. NASA is conducting research toward this goal's far-term objectives and examining the health monitoring of a wide-range of aircraft systems, including software. Far-term research in this field is based on projections of likely future vehicle characteristics; the rapid emergence of new technologies may require new research to examine vehicle health.

NASA is developing an integrated system concept for vehicle health assurance that fully integrates ground-based inspection and repair information with in-flight measurement. Recent accomplishments include development and validation of vehicle health management sensor fusion, fault detection, and isolation methods. In 2010, NASA demonstrated, on a representative current generation electromechanical system test bed, improved vehicle health management for varying operating conditions and demonstrated fault detection and diagnosis and examined tradeoffs between accuracy and diagnosis time. Additionally, in 2010, the FAA developed technical data for certification processes for rotorcraft Health and Usage Monitoring Systems (HUMS).

NASA and the DoD are conducting research into adaptive-control mechanisms. R&D includes near-term demonstrations of the effectiveness of adaptive-control mechanisms and far-term research into validation through flight research and formal methods. In addition, far-term research will ensure that adaptive control does not conflict with similar functions in guidance and trajectory planning occurring at different time scales.

NASA has developed and evaluated concepts for on-line integrity monitoring for adaptive control systems through simulation tests. In 2010, NASA developed a tool suite that provides an order-of-magnitude reduction in analysis time over current Monte Carlo simulation methods that would be used to locate failure points in the flight envelope for a chosen adaptive control system and a set of adverse events. In 2011, NASA conducted flight validation tests of adaptive control algorithms on a full-scale aircraft test bed. As adaptive-control techniques are developed, FAA research will assess factors driving pilot performance and will consider transfer of training from various classroom methodologies on the ground to operations in static and dynamic simulators emulating physiologically stressful flight conditions (e.g., acceleration, altitude, aerobatic maneuvers) and ultimately in flight. In 2011, a study in usage, design, and training issues for rudder control systems in transport aircraft was completed.

Research into material degradation, and corresponding far-term research into methods to design structures and materials with extended life, is conducted by several entities within the DoD, the FAA, and NASA. Near-term research in this area is generally focused on the materials and structures in current-day aircraft. Far-term research in this field is based on projections of likely future vehicle characteristics; the rapid emergence of new technologies may require new research to examine their aging and durability.

NASA has developed a process to increase the capability for superalloy turbine engine disks to run at higher temperatures than with the previous state-of-the-art while maintaining required high stress and cycle life. This process will allow safe, durable operations under the conditions required for future engine designs. In 2010, NASA researchers developed an atomistic model capable of predicting the degradation caused by environmental effects on resins in selected polymer matrix composite materials.

FAA continues to work with industry to develop consensus for a damage tolerance and fatigue certification protocol for advanced materials. In 2010, the FAA generated composite material dynamic properties important to crashworthiness and assessed new material forms (such as discontinuous fiber composites) that have found application in primary aircraft structures. In 2011, FAA R&D supported development of a cost-efficient process to make compression molded parts from carbon fiber composites; Boeing subsequently used that process for about 600 parts in each Boeing 787.

Goal 2—Develop technologies to reduce accidents and incidents through enhanced aerospace vehicle operations on the ground and in the air

With continued vigilant focus, R&D planned for this goal is adequate. Significant progress has been made in the first objective to increase operator awareness and error prevention and recovery. FAA and NASA are coordinating human factors R&D by developing a top-level roadmap and a plan for periodic integration meetings. Consistent with progress noted previously in the Mobility section, near-term research into human-systems integration is being conducted by the FAA and NASA, largely concentrating on the most immediate aspects of NextGen operation. The FAA is also conducting mid-term research into human-machine interfaces in support of mid-term NextGen developments. Likewise, NASA is conducting mid- and far-term research into flight-deck systems that support far-term NextGen operations, with a particular focus on robust automation-human systems and on information display and decision-making. NASA validated through tests the influence of vision-aiding technology on pilot performance, assessed active operator assistance in key tasks, assessed multi-modal presentation formats and interaction methods for uncertainty display concepts, and thus provided flight deck guidelines, information, and display requirements that meet NextGen operational needs without a measurable increase to safety risk. FAA researchers completed initial investigations and introduced a DataComm package into the terminal radar approach control facility (TRACON) domain workstations to represent the 2018 environment. Results show that DataComm can enhance controller performance (e.g., number of aircraft handled in the arrival sector) and reduce workload; however, the major improvement resulted from integration with RNAV routes. A human-in-the-loop demonstration of the new surface trajectory-based operations (STBO) concept showed an increase in the number of deviation detections as well as a decrease in detection times in some cases.

A wide array of R&D has occurred to enhance human performance through the advancement of weather information and automation to improve safety. The FAA is concentrating on the near-term aspects of the objective, primarily examining ground-based methods of observing weather phenomena and integrating diverse sources of information. NASA continues to primarily address mid- and far-term aspects, developing flight-deck alerting concepts and airborne sensors for atmospheric hazards, including icing conditions, turbulence, and convective weather activity. Consistent with the Mobility section above, research is planned within NextGen programs to enable availability and enhance the quality and quantity of meteorological information available to the aircraft; the purpose is to enhance safety and efficiency in commercial, business, and general aviation operations and to provide common weather information to both the ATC and flight deck. R&D was conducted to understand human factors issues related to use of cockpit display of traffic information (CDTI) based on ADS-B and other aircraft surveillance applications systems. Also, other human factors research led to recommended air traffic and flight deck procedures and operating limitations for CDTI applications such as closely spaced parallel operations, in-trail procedures, enhanced visual approach, interval management, and surface alerting.

Observation and sensing systems to provide specific weather-related hazard information are being developed. The NASA Icing Remote Sensing Station (NIRSS), a test bed for remote and in-situ sensing technologies, has been upgraded to include the NASA Narrow-Beam Multi-Frequency Scanning Radiometer. NASA and FAA are partnering to develop plans, data, and methods to solve flight concerns in high ice water content (HIWC) environments. Data and methods were developed to support the evaluation of aircraft engines for operation in HIWC environments. In particular, enhanced icing instruments were developed for in-flight measurements of high ice-crystal content environments, and development of methods to test engines in simulated HIWC environments continued. The initial trial flight campaign gathered in-situ characterization data of a high ice-crystal content environment.

Advanced tools to translate data into meaningful prognostic information were developed. NASA continues to provide tools to Aviation Safety Information Analysis and Sharing (ASIAS) and the general community to better analyze diverse sets of narrative text, digital flight, and other data. A scalable anomaly detection method was developed for heterogeneous data, with an algorithm that identified at least three anomalies in real flight data. FAA demonstrated a working prototype of network-based integration of information extracted from diverse, distributed sources. Also, development continued on an advanced infrastructure and laboratory for sharing analysis tools, aggregated safety information, and automated tools to monitor databases for potential safety issues. Several safety analytical studies and safety assessments were conducted using ASIAS and other safety aviation data. ASIAS was also expanded to include other domains (e.g., general aviation and rotorcraft).

Initial progress was made to understand concepts of degradation and failure, so that the safety of distributed, complex, systems can be validated and verified. FAA's Operational

Safety Oversight of the NAS has been improved by the development of a user interface and trend analysis capability for equipment performance, testing of the equipment module for facility performance, and development of a user guide to facilitate use by air traffic safety inspectors. NASA has begun its research into advanced tools and methods for validation and verification by applying a novel use of machine learning techniques to refine test cases and exercise "margins" (or off-nominal cases) of critical software systems and by developing a static code analyzer that can eliminate run-time errors in complex software with minimal analysis time. Overall, however, NASA's planning of its validation and verification research is in its infancy, and therefore the ability to meet the long-term objective associated with this effort merits continued attention.

Goal 3—Demonstrate enhanced passenger and crew survivability in the event of an accident

The individual department and agency plans partly address the first Goal 3 objective to develop occupant-restraint design tools. Near-term R&D at the FAA is directed at ensuring the occupants will survive a crash by enabling the development of enhanced occupant-restraint systems. In 2011, the FAA developed standardized methods to obtain anthropomorphic test dummy (ATD) data to support analytical modeling. Industry, government, and academic entities worked together to develop a standardized method to obtain ATD sled data and define a set of ATD evaluation parameters. The effort involved manufacturers of ATDs, seats, and aircraft to ensure that all aspects of the requirements were integrated into the resulting protocols. These parameters will be used in the development of numerical ATD models leading to the design and certification of aircraft seats. The DoD also has research focused on enhancing rotorcraft crew and passenger survivability in a crash environment with energy-absorbing structures. The combined agencies' time lines are adequate to achieve the objective in the near term.

However, there is limited foundational research to achieve the mid- and far-term objectives for other classes of aircraft, including large air transport passenger aircraft. Foundational research with respect to passenger and crew safety at DoD and NASA is focused on rotary-wing aircraft. A highly successful MD-500 (light utility helicopter) full-scale crash test was performed. This crash test: provided a wealth of data and video photogrammetry for calibrating and validating finite-element models; helped enable the development of methodologies to certify crashworthy designs by analysis, thus reducing the need for full-scale testing; and also supported Mobility Goal 5 analysis and design objectives. R&D to support the far-term objective to conduct foundational work to validate integrated vehicle and structure occupant restraint tools for advance concept vehicles has not occurred. At present, this work is not sufficiently prioritized to advance and hence is reported as red.

For the second objective under Goal 3, the individual department and agency plans partly address the development of analytical methodologies to model dynamic events needed to achieve this objective. Focus within FAA is near and mid term and on determining material dynamic properties important to crashworthiness, primarily for composite materials, and using those properties to develop standards and methods to support rules and guidance. NASA developed a system-integrated finite-element model with detailed representations of airframe, occupants, seats, and energy-absorbing structures for a rotorcraft application. A full-scale crash test was performed to calibrate the analytical model and demonstrated an energy absorbing concept. As with the first objective, the combined agencies' time lines are adequate to achieve the objective in the near term. The near-term plans require continuous focus because the planned level of foundational research will challenge the timely achievement of the mid- and far-term objectives.

The FAA is currently the only agency planning research for the third objective under Goal 3. The FAA has a robust R&D program to address the issues of flammability and smoke toxicity of aircraft materials, including advanced materials, needed to achieve this objective. Recent accomplishments include the development of a laboratory-scale test method for determination of flame propagation of composite fuselage materials. Near-term plans also include defining composite fuselage fire safety design criteria and extending an FAA burning model to predict flame spread on cabin materials and composite fuselage structures. Planned R&D activities by the FAA are adequate to achieve this near-term objective under Goal 3. Completion of the mid- and far-term objectives for the third objective under Goal 3 will be challenging. FAA research is focused on near-term activities, with limited foundational research focused on the mid- and far-term objectives; consequently, those objectives are at some risk of falling short of completion. There are, however, near-term accomplishments and planned activities that do support the mid- and far-term objectives. In 2010 FAA researchers analyzed the variation in flammability exposure of a fuel tank consisting of a composite material skin versus that of a traditional aluminum skin. Improved aircraft rescue and fire-fighting procedures and equipment standards were developed for double-decked aircraft carrying up to 800 passengers. Far-term FAA fire safety research focuses on development of environmentally friendly and ultra-fire-resistant materials and post-crash fire-fighting equipment and technologies.

SUMMARY

Department and agency plans are adequate to achieve all near-term objectives. A few of the mid- and far-term objectives (Goal 3) that warrant additional attention are denoted by yellow in Table 3. One area in Goal 3, the ability to validate future design and analysis tools for integrated vehicle structure and occupant restraints, will not be achieved unless prioritization is enhanced to complete necessary foundational research, and it is denoted by the red assessment in the table.

Table 3. Assessment of Aviation Safety R&D Progress

Goal	Near Term (<5 years)	Mid Term (5-10 years)	Far Term (>10 years)	Near Term Objectives	Mid-Term Objectives	Far-Term Objectives
Goal 1 Develop technologies to reduce accidents and incidents through enhanced vehicle design, structure, and subsystems	Develop vehicle health-management systems to determine the state of degradation for aircraft subsystems	Develop and demonstrate tools and techniques to predict, detect, and mitigate in-flight damage, degradation, and failures	Develop reconfigurable health-management systems for managing suspect regions in N+2 vehicles	G	G	G
	Develop and test adaptive-control techniques in flight to enable safe flight by stabilizing and establishing maneuverability of an aircraft from an upset condition	Develop, assess, and validate methods to avoid, detect, and recover from upset conditions	Develop formal methods to verify and validate the safety performance margins associated with innovative control strategies, decision- making under uncertainty, and flight path planning and prediction	G	G	G
	Develop improved mitigation techniques that prevent, contain, or manage degradation associated with aging, and show that tools and methods can predict the performance improvement of these techniques	Deliver validated tools and methods that will enable a designer or operator to extend the life of structures made of advanced materials	Develop advanced life-extension concepts (designer materials and structural concepts) by using physics-based computational tools	G	G	G
Goal 2 Develop technologies to reduce accidents and incidents through enhanced aerospace vehicle operations on the ground and in the air	Validate and verify methods that enable improvements in pilot and controller workload, awareness, and error prevention and recovery, including during off-nominal scenarios, given the increased automation assumed in NextGen	Develop human-machine interfaces that enable effective human performance during highly dynamic conditions and allow for flexible intervention to ensure safety	Develop formal methods to verify and validate the safety of complex airspace operations	G	G	G
	Develop flight deck displays and automation to convey up-to-date weather conditions and near-term forecasts Investigate in-situ and remote observing systems, technologies, and architectures that will provide hazardous and other weather information	Develop an integrated flight deck system that alerts flight crews of all on-board and environmental hazards and defines and coordinates an appropriate, safe flight path Develop in-situ and remote observing technologies, systems, and architectures that will provide weather information to flight crews and air traffic controllers	Develop high-confidence, flight deck decision-support tools that use single authoritative information source for shared decision-making between air traffic management and flight crew about weather and other concerns in planning a safe flight path	G	G	G
	Develop advanced tools that translate numeric (continuous and discrete) system performance data into usable, meaningful information for prognostic identification of safety risks for system operators and designers	Develop advanced methods to automatically analyze textual safety reports and extract system performance information for prognostic identification of safety risks for system operators and designers	Develop fundamentally new data-mining algorithms to support automated data analysis tools to integrate information from a diverse array of data resources (numeric and textual) to enable rapid prognostic identification of system-wide safety risks	G	G	G
	Understand the concepts of degradation and failure as well as other potential safety issues associated with critical system functions integrated across highly distributed ground, air, and space systems (including UAS)	Develop techniques to enable a priori safety assurance and real-time monitoring and assessment of critical system functions across distributed air and ground systems (including UAS)	Validate and verify the safety of complex flight-critical systems (including UAS) in a cost- and time-effective manner	G	G	Y

Goal	Near Term (<5 years)	Mid Term (5-10 years)	Far Term (>10 years)	Near Term Objectives	Mid-Term Objectives	Far-Term Objectives
Goal 3 Demonstrate enhanced passenger and crew survivability in the event of an accident	Develop occupant-restraint design tools that support occupant crash protection that is as strong as the fixed- and rotary-wing aircraft structure	Validate integrated vehicle structure and occupant restraint tools	Validate integrated vehicle structure and occupant restraint tools for advanced concept vehicles	Y	G	R
	Develop analytical methodologies to model dynamic events in aircraft crashes to enable the development of lightweight and crash-absorbing airframe technologies for the fixed- and rotary-wing legacy fleet	Establish analytical methodologies to model dynamic events in aircraft crashes to enable the development of lightweight and crash-absorbing airframe technologies for advanced aircraft, including those made with advanced composite and metallic materials	Validate and verify analytical methods that model dynamic events in aircraft crashes for airframe structures	G	Y	Y
	Assess and reduce flammability and smoke toxicity of advanced materials to be used in aircraft platforms	Determine fuel vapor characteristics of alternative aviation fuel spills for post-crash survivability	Validate and verify methodologies to determine impact of alternative fuels on cabin material flammability and propulsion system fire safety and survivability	G	Y	Y

ASSURING ENERGY AVAILABILITY AND EFFICIENCY IS CENTRAL TO THE GROWTH OF THE AERONAUTICS ENTERPRISE, AND THE ENVIRONMENT MUST BE PROTECTED WHILE SUSTAINING GROWTH IN AIR TRANSPORTATION

> *Aviation must have reliable sources of energy and use that energy efficiently to enable aircraft and an air transportation system to meet growing demand in an economic fashion. Appropriate environmental protection measures must be part of strategies for continued growth in air transportation.*
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> *—"National Aeronautics Research and Development Plan," February 2010, p. 37*

SUMMARY OF R&D ACTIVITIES SUPPORTING THE ENERGY AND ENVIRONMENT PRINCIPLES

Aeronautics R&D for the Energy and Environment Principles are divided into three goal areas. These three goals include R&D objectives intended to derive new aviation fuels from diverse and domestic resources, significantly increase the energy efficiency of the aviation system, and decrease significant environmental impacts of the aviation system. (For complete text, see the 2010 R&D Plan.) Interagency cooperation supporting the advancement of energy and environment R&D includes participation from NASA, FAA, DoD, NIST, EPA, Department of Energy (DOE), the U.S. Department of Agriculture (USDA), and NSF.

ASSESSMENT OF PROGRESS FOR THE ENERGY AND ENVIRONMENT GOALS

Overview

Each of the three energy and environment goal areas was given a broad assessment of green, yellow, or red based on this review. The overall results of this analysis are shown in Table 4 at the end of this section. As shown in Table 4, planned and ongoing efforts are sufficient for meeting the majority of objectives under each goal. In some areas there are issues that warrant further attention. A more detailed explanation of progress in each goal area is provided below.

Goal 1—Enable new aviation fuels derived from diverse resources to ensure a secure and stable fuel supply

Overall, there has been considerable progress in enabling expanded use of alternative fuels in aviation. An important step in this process has been the certification of new fuels for use in turbine engine aircraft. Significant milestones for certification have been achieved from both a civil and military perspective. ASTM International has approved the use of 50–50 Fischer-Tropsch (F-T) blend of synthetic kerosene with conventional jet fuels and also the commercial aviation use of a 50% blend of hydroprocessed esters and fatty acids (HEFA) biofuels with Jet A. Since biofuel blends are now approved for commercial use, the door is open for fuel producers and investors to successfully deploy the fuel on a commercial scale. The Commercial Aviation Alternative Fuel Initiative (CAAFI) has played a significant goal in achieving these milestones. CAAFI—a coordination forum sponsored by the FAA, Aerospace Industries Association, Air Transport Association, and Airport Council International–North America—seeks to enhance energy security and environmental sustainability for aviation through alternative jet fuels. As a coalition, CAAFI enables its diverse participants—representing the leading stakeholders in the fields of aviation and alternative fuels—to build relationships; share and collect data; identify resources; and direct research, development, and deployment of alternative jet fuels.

For example, the Air Force (a CAAFI stakeholder) developed and implemented a repeatable systems-engineering-based process for alternative jet fuel certification (MIL-HDBK-510). Using this process, the Air Force has nearly completed certification of its entire enterprise for the use of F-T fuels, with approximately 99% of the fleet certified. The Air Force is in the process of certifying HEFA fuels and is conducting introductory testing of other potential alternative fuel candidates. The test results obtained by the Air Force and the certification of these F-T alternative jet fuels have expanded the options available to the commercial and military fleets. Testing conducted by the FAA under the Continuous Lower Energy Emissions and Noise (CLEEN) Program, by satisfactorily addressing a question related to cold flow properties of the fuel, was instrumental in obtaining the recent HEFA approval. These data have been shared with the other CAAFI stakeholders to aid with follow-on testing and future implementation of alternative jet fuels. In addition to qualification and certification efforts by CAAFI and the Air Force, there has been progress toward evaluating the performance and emissions characteristics of alternative fuels and fuel blends by other groups. An example of such work includes the multi-agency Aviation Alternative Fuel EXperiment (AAFEX) I (2009) and AAFEX II (2011), which produced performance and emissions data for conventional jet fuel as well as several synthetic fuels and fuel blends. On a broader scale, multiple agencies and universities are investigating carbon life-cycle analyses to quantify environmental impacts of renewable jet fuels, including air quality and greenhouse gas emissions from direct and indirect sources. Some of these studies and their corresponding results on life-cycle analysis of commercial conventional and alternative fuels were included in a report recently released by the PARTNER (Partnership for AiR Transportation Noise and Emissions Reduction) Center of Excellence.[14]

A critical issue for widespread production of alternative fuels is related to the availability of feedstock, such as camelina, jatropha, algae, and forest and crop residue. To demonstrate developmental progress of feedstocks and their readiness for use in alternative jet fuels on a commercial scale, the FAA and USDA developed the Feedstock Readiness Level (FSRL) Tool. The FSRL—a nine-step scale—is an integrated framework that describes the

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[14] Russell W. Stratton, Hsin Min Wong, James I. Hileman, “Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels” (Version 1.2). A PARTNER Project 28 report. June 2010. Report No. PARTNER-COE-2010-001, http://web.mit.edu/aeroastro/partner/projects/project28.html. PARTNER is a leading aviation cooperative research organization and an FAA Center of Excellence sponsored by the FAA, NASA, DoD, EPA, and Transport Canada.

readiness of feedstocks to be utilized by commercial-scale aviation biofuel refiners and users. There are four components to the FSRL (production, market, policy, and linkage to conversion process), each with one to four "tollgate" descriptions per readiness level. The FSRL tool is structured to complement the Fuel Readiness Level tool in use by the aviation industry as an internationally recognized communication best practice. The FSRL can be used to identify gaps in aviation biofuel supply chains due to differences in the development and readiness of a feedstock for a particular conversion process, a fuel conversion process as a market for feedstocks, and many other uses. This integrated feedstock and conversion technology approach can facilitate a coordinated allocation of resources to effectively develop and implement a viable aviation biofuels industry.

The USDA established five regional Biomass Research Centers, that with public and private partners, will develop sustainable regionalized strategies for producing feedstocks for supplying renewable aviation jet fuels. In addition, a partnership between industry, the USDA, DOE, and Department of the Navy to produce advanced drop-in aviation and marine biofuels to power military and commercial transportation has been initiated. The three government departments will invest a total of up to $510 million over 3 years to jointly construct or retrofit several drop-in biofuel plants and refineries. Additionally, there are efforts to enable the production of fuel from various alternative feedstocks, such as algae and sugar sources. For example, the Air Force is pursuing Alcohol-to-Jet (ATJ) certification, which uses cellulosic materials, starches, or sugars as feedstocks. An ATJ program feasibility demonstration is planned for FY 2012. The FAA is planning testing of additional alternative fuel candidates to build on and complement the Air Force tests. This testing program includes coordination with Air Force, DOE, and NASA. These results will also be shared with CAAFI stakeholders and contribute to future implementation of additional classes of alternative jet fuel.

Two areas have progressed more slowly than originally anticipated: (1) the development of broadly accepted environmental best practices for alternative fuel production and environmental certification and (2) the development of the necessary alternative jet fuel production infrastructure by private industry with support from private-sector financing. Progress has been limited since both concepts are dependent on economically sustainable quantities of fuel being produced. To date, there is no single alternative jet fuel that has shown significant commercial production and operational implementation, in part because alternative jet fuel production is heavily dictated by commercial factors that are outside government control. However, as the available quantity of alternative jet fuel becomes more robust, it will be possible to begin to reap benefits for the environment. These objectives are assessed as yellow in Table 4.

Goal 2—Advance development of technologies and operations to enable significant increases in the energy efficiency of the aviation system

Significant progress has also been made in developing technologies, tools, and operational concepts to improve the efficiency of the air transportation system that is consistent with the Mobility section above. From an operations perspective, there has been work on a number of gate-to-gate procedures, some of which have already been developed and implemented. For example, the OPD procedure (formerly the Continuous Descent Approach procedure) was designed to reduce noise, emissions, and fuel consumption in the terminal area and is currently operational at a number of airports, providing environmental and economic benefits. New surface-optimization techniques are being developed. These techniques have demonstrated potential for improvements in efficiency of ground operations with reduction in fuel burn and emissions. The NASA study "Advanced Vehicle Concepts and Implications for NextGen"[15] investigated the efficiency gains from procedures for the NextGen that also include new aircraft configurations and types. An assessment of potential efficiency improvements was conducted in parallel with development of new operational procedures. The FAA has initiated a similar study with an objective to analyze aircraft mission specifications to achieve optimal environmental performance.

Several new initiatives with a focus on improving aircraft efficiency have recently been started. The FAA CLEEN (Continuous Lower Energy, Emissions and Noise) program was implemented to accelerate maturation of N+1 aircraft technologies with specified reduction goals for efficiency improvement. NASA began the Environmentally Responsible Aviation (ERA) Project, which is making significant advances on N+2 goals with a range of technologies. The NASA Subsonic Fixed Wing Project continues to develop tools, technologies, and knowledge that will enable advanced efficient aircraft.

Advances from the DoD VAATE Program have already influenced CLEEN and ERA technologies, and further advances from related R&D (see National Security and Homeland Defense Goal 3) will continue to help reach these commercial goals by advancing turbine engine propulsion technologies. Examples of specific advances include the development of ultra-high-bypass engine concepts (geared turbo fan and open rotor) and high pressure compressor and combustor technologies that will provide more efficient propulsion opportunities. These programs target technologies to improve turbine engine affordability, power-to-weight ratios, turbine engine fuel burn, and overall engine performance. Additionally, advanced composite manufacturing concepts have been developed that enable lighter weight and damage-tolerant wing and fuselage designs that may result in much

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[15] "Advanced Vehicle Concepts and Implications for NextGen" (NASA/CR—2010–216397), http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110011147_2011009580.pdf.

lower life-cycle costs. Research in drag-reduction concepts also provides a contribution to the fuel-burn goals. NASA has also initiated a number of studies that are exploring novel engine and aircraft configurations. System analyses show that combinations of technologies and engine design configurations may meet or exceed the stated efficiency goals, but additional validation and technology maturation are required before the goals can be fully realized.

In addition to the work on advanced technologies, there has been significant progress on tools needed to analyze vehicle and system performance. For example, a suite of aviation environmental analysis tools has been developed by the FAA, including Aviation Environmental Design Tool (AEDT), Environmental Design Space (EDS), and Aviation Portfolio Management Tool (APMT). Though still under development, these tools are being employed for aviation environmental assessment as well as trade-off and interdependency analyses to support domestic and international activities. NASA has made significant advances in MDAO and other analysis tools that will continue to feed into and augment system-wide analysis capabilities and also support the development of new aircraft.

Goal 3—Advance development of technologies and operations to decrease the environmental impact of the aviation system

An important consideration in successfully decreasing the environmental impact of the aviation system is determining the trade-offs between improvements in fuel efficiency, emissions, and noise and advancing solutions that maximize performance. Many of the same initiatives that have an impact on improving fuel efficiency (Goal 2) are also working to decrease the environmental impact of the overall aviation system. Since many of these have been covered previously, they will only be briefly mentioned here.

Work is progressing on improvements to operational procedures that minimize environmental impact. For example, the OPD procedure noted earlier has resulted in a reduction of noise and emissions. In addition, gate-to-gate procedures under AIRE (Atlantic Interoperability Initiative to Reduce Emissions) and ASPIRE (Asia and South Pacific Initiative to Reduce Emissions) programs have been implemented to achieve reductions in fuel burn and emissions that contribute to climate change and local area air quality. Additional work is needed to develop mid- and long-term procedures that will significantly improve aircraft environmental performance. Since much of this work depends on making decisions regarding certain aspects of NextGen, as well as the development of more extensive assessment tools, these areas are assessed as yellow in Table 4. It is expected that these objectives will remain as mid- and long-term goals for the time being.

The FAA CLEEN and NASA ERA initiatives will also complement other ongoing efforts to develop new capabilities to improve environmental performance. In partnership with industry, FAA CLEEN is accelerating development of aircraft technologies and advancing toward future commercial products beginning in 2015. As an example, full combustor rig tests demonstrated that landing and takeoff NO_x emissions can be reduced by 60% from existing emission standards, meeting a CLEEN goal. This advanced combustor will be used in CFM International's LEAP-X turbofan engine, which will enter service in 2015. The LEAP-X engine will power Boeing's 737MAX aircraft. In addition, CLEEN completed wind tunnel tests of advanced wings to improve aerodynamic efficiency, leading to an estimated 2% reduction in aircraft fuel burn and emissions. Application of systems analysis to R&D work in areas such as advanced combustors and propulsion concepts, new configurations, and new materials suggests that emissions and efficiency goals may be met. Conversely, there is growing concern that some of the long-term noise goals may be too challenging, although this notion is still being evaluated. As described in the previous section, additional research is needed for validation and future technology development to realize these advances.

As mentioned before, there are a number of new or enhanced analytical capabilities for analyzing the environmental performance at a vehicle or system level, including AEDT, EDS, and APMT. Advances in other aircraft environmental analysis tools will further enhance current capabilities. For example, NASA has further modified the ANOPP for aircraft noise prediction, which is utilized by EDS and AEDT. Another aspect of analysis includes better understanding of what environmental metrics are appropriate. For example, NASA carried out multiple AAFEX campaigns involving the FAA and EPA. Results from engine emissions measurements and other AAFEX analyses are being used, along with other supplementary data, to help the Society of Automotive Engineers E-31 Committee to develop a procedure for nonvolatile particulate matter (PM) emissions sampling and measurement techniques for turbine engines, which will help meet certification requirements and establish PM emissions standards and reduction goals.

The FAA has initiated the first phase of the Aviation Climate Change Research Initiative (ACCRI) with support from NASA, EPA, NOAA, and DOE to better understand the impact of aviation on the environment. ACCRI is exclusively funded by the FAA, and currently there are resource limitations for continuing this program into its second phase that will severely limit the ability to better characterize non-CO_2 (carbon dioxide) climate impacts of aviation emissions and constrain underlying uncertainties, as well as informed decision-making. Due to these shortfalls and the limitations in the previously mentioned programs, the objective related to better understanding the impact of aviation on the environment is assessed as yellow.

There has been considerable progress in achieving the environmental objectives for supersonic aircraft and rotorcraft. System-level validation of N+2 low boom/low drag design tools and technologies is underway, but analytical studies indicate that the 30 PLdB (perceived loudness in decibels) goal can be achieved and that the long-term objectives are feasible. Progress is also being made to ensure that airport noise and emissions goals can be met for supersonic aircraft. For example, two nozzle (engine) concepts appropriate for these cycles have been tested at moderate scale, and the basic acoustic performance has been validated. Combustor concepts for achieving nitrogen oxide (NO_x) emission reduction objectives have been designed and successfully tested in small scale test rigs. Several new capabilities for rotorcraft are under development, including advances in noise and performance predictive capabilities; advanced and more efficient turbomachinery; new materials for lightweight drive systems; low drag, efficient fuselage configurations; and high-performance, low-noise rotor systems that combine several technological attributes. Additionally, improvements in the ability to predict low-noise rotor systems have focused on prediction of rotors with advanced systems.

While the jet engine community has been able to move forward with jet fuel alternatives and identifying future technologies for emission reductions, the piston-engine aircraft arena has been actively investigating potential alternatives to the lead additive in aviation gasoline. Progress has been slower than planned regarding the certification of feasible alternatives to lead as an octane-enhancing additive in aviation gasoline. Work continues on an initial assessment for piston-engine aircraft alternative fuels; this work includes activities ranging from fuel investigations, testing, safety, and environmental and economic analyses to securing proper approval for engine use and national implementation. In addition, an Aviation Rulemaking Committee has been established by FAA, in partnership with other government agencies, to collaborate with industry to develop a plan for reducing and potentially transitioning away from leaded aviation gasoline. As a result of progress and anticipated resources, identification of alternatives to lead as an octane-enhancing additive in aviation gasoline is assessed as yellow in Table 4. It should also be noted that the DoD has been investing in R&D for a variety of piston and other internal combustion engines that can run on jet fuel or diesel fuel, in place of aviation gasoline.

Progress has been slower than planned in understanding and mitigating the water quality impacts of increased aircraft operations. The FAA is assessing progress on water quality impacts of aviation operations through the Airport Cooperative Research Program, which focuses on water quality monitoring and treatment of water systems. The EPA is also working on developing guidelines for water recycling and treatment. An initial work scope for general aviation alternative fuels that includes activities ranging from fuels investigations, testing, safety, and environmental and economic analyses to securing its proper approval has been developed for engine use and national implementation. As a result of progress and anticipated resources, this area is assessed as yellow in Table 4.

SUMMARY

Overall, there has been considerable progress toward enhancing the efficiency and minimizing the environmental impact across aviation. As shown in Table 4, most objectives related to each goal are assessed as green, although a few are assessed as yellow. As noted, the primary reasons for yellow assessments are a lack of prioritization compared with other areas. Some of the advances described in the table, such as the approval of fuel specifications for some alternative fuels or more efficient operational procedures, have already been implemented. Advanced tools and design capabilities have been created to facilitate an assessment of both fleet and vehicle performance and to help enable the design of new concepts. Various research efforts are focused across the N+1, N+2, and N+3 generational periods to develop technologies, new configurations, and knowledge that show potential for significant improvement across a wide variety of air vehicles.

Table 4. Assessment of Energy and Environment R&D Progress

Goal	Near Term (<5 years)	Mid Term (5-10 years)	Far Term (>10 years)	Near Term Objectives	Mid-Term Objectives	Far-Term Objectives
Goal 1 Enable new aviation fuels derived from diverse resources to ensure a secure and stable fuel supply	Evaluate performance of alternative versus conventional fuels in associated systems, including consideration of certification processes	Enable affordable “drop in”[a] fuels that have large production potential, meet safety requirements, and are certifiable Explore renewable aviation fuels that reduce carbon footprints	Enable renewable aviation fuels that meet safety requirements, are certifiable, have a large production potential, and are sustainable for aircraft and support systems	G	G	G
	Evaluate alternative fuel-production impacts on the environment	Enable environmental best practices in alternative and conventional fuel production	Enable technologies to ensure that new aircraft, fuel supply systems, and airport infrastructure are built to standards that allow the most environmentally beneficial alternative fuels	G	Y	Y
Goal 2 Advance development of technologies and operations to enable significant increases in the energy efficiency of the aviation system	Define achievable energy efficiency gains via operational procedure improvements Research operational procedures to enhance fuel efficiency Enable fuel efficient N+1 aircraft and engines (33% reduction in fuel burn compared to a B737/CFM56)[g]	Research and enable new energy efficient operational procedures optimized for energy intensity (3%–5% energy intensity improvement[b] for the energy efficient procedures over existing 2006 baseline procedures) Enable fuel efficient N+2 aircraft and engines (at least 40% reduction in fuel burn compared with a B777/GE90)[h]	Enable new energy efficient operational procedures optimized for energy intensity (6%–10% energy intensity improvement for the energy efficient procedures over existing 2006 baseline procedures) Enable fuel efficient N+3 aircraft and engines to reduce fuel burn by up to 70% compared with a B737/CFM56[g] (70% is a 25-year stretch goal and assumes significant advances in novel configurations, engine performance, propulsion/airframe integration, and materials)	G	G	G
	Enable metrics and first-order empirical analytical capabilities to evaluate fuel efficiency enhancement strategies	Develop advanced empirical analytical capability to assess and enhance fuel efficiency enhancement strategies	Enable physics-based simulation analytical capability to optimize fuel efficiency enhancement strategies	G	G	G
Goal 3 Advance development of technologies and operational procedures to decrease the significant environmental impacts of the aviation system	Research and develop ground, terminal, and en route procedures to reduce noise and emissions and determine sources of significant impact	Develop and demonstrate advanced ground, terminal, and en route procedures to reduce significant noise and emissions impacts	Develop new approaches and models for optimizing ground and air operational procedures	G	Y	Y
	Develop improved tools and metrics to quantify and characterize aviation’s environmental impact, uncertainties, and the trade-offs and inter-dependencies among various impacts Enable quieter and cleaner N+1 aircraft and engines (32 dB cumulative below Stage 4);[c] LTO[d] NO_x emissions reduction (70% below CAEP[e] 2 standard)	Reduce uncertainties in understanding aviation climate impacts to levels that enable limiting significant impacts Characterize $PM_{2.5}$[f] and hazardous air pollutant emissions and establish long-term goals for reducing to appropriate levels Research the technical challenges associated with achieving low NO_x and very low CO_2 and soot emissions Enable N+2 aircraft and engines; (42 dB cum below Stage 4); LTO NO_x emissions reduction (80% below CAEP 2) Enable a 70% reduction in high-altitude emissions for supersonic aircraft (reference HSR configuration)	Continue to reduce uncertainties in understanding aviation climate change impacts to levels that enable reducing significant impacts Enable physics-based analytical capabilities to characterize environmental impacts of aviation noise and emissions Enable N+3 aircraft and engines to decrease the environmental impact of aircraft (62 dB cumulative below Stage 4 (a 25-year goal); LTO NO_x emissions reduction better than 80% below CAEP 2) Enable an order-of-magnitude reduction in high-altitude emissions for supersonic aircraft (reference HSR configuration)	G	G	G

Goal	Near Term (<5 years)	Mid Term (5-10 years)	Far Term (>10 years)	Near Term Objectives	Mid-Term Objectives	Far-Term Objectives
Goal 3 continued Advance development of technologies and operational procedures to decrease the significant environmental impacts of the aviation system	Continue research to identify alternatives to lead as an octane-enhancing additive in aviation gasoline			Y		
	Determine significant water quality impacts of increased aircraft operations	Enable anti-icing and deicing fluids and handling procedures to reduce water quality impacts determined to be significant	Enable environmentally improved aircraft materials and handling of fuel and deicing fluids	Y	Y	Y
	Develop predictive capabilities for rotorcraft noise	Enable low-noise acoustic concepts for low-noise rotary-wing vehicles	Enable low-noise operation and high-speed, fuel efficient rotorcraft	G	G	G
		Enable ~15 EPNdB[j] of jet noise reduction relative to unsuppressed jet for supersonic aircraft	Enable ~20 EPNdB of jet noise reduction relative to unsuppressed supersonic aircraft exhaust		G	G
	Enable reducing loudness ~25 PLdB[i] relative to military aircraft sonic booms	Enable reducing loudness ~30 PLdB relative to military aircraft sonic booms	Enable reduction of loudness ~35 PLdB relative to military aircraft sonic booms	G	G	G

Notes:

a A drop in fuel is a fuel that can be used in existing aircraft and supporting infrastructure; drop in fuel properties may vary from average properties of conventional fuels within existing specification limits.

b Energy intensity is the ratio of energy consumption and economic and physical output. Potential metrics for aviation could be fuel consumption per distance, per passenger distance, or per payload.

c Current noise standard for subsonic jet airplanes and subsonic transport category large airplanes, http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgFinalRule.nsf.

d LTO is the landing-and-takeoff cycle.

e CAEP is the International Civil Aviation Organization Committee on Aviation Environmental Protection.

f Particles less than 2.5 µm in diameter.

g The reference aircraft is a B737-800 with CFM56/7B engines, representative of 1998 entry into service technology.

h The reference aircraft is a B777-200 with GE90 engines, representative of 1997.

i PLdB = Perceived loudness in decibels.

j EPNdB = Effective perceived noise (level) in decibels.

ACRONYMS AND DEFINITIONS

4-D	Four-dimensional
AAFEX	Aviation Alternative Fuel EXperiment
AATE	Advanced Affordable Turbine Engine
ACCRI	Aviation Climate Change Research Initiative
ADS-B	Automatic Dependent Surveillance-Broadcast
ADVENT	Adaptive Versatile Engine Technology
AEDT	Aviation Environmental Design Tool
AHW	Advanced Hypersonic Weapon
AIRE	Atlantic Interoperability Initiative to Reduce Emissions
ANOPP	Aircraft Noise Prediction Program
APMT	Aviation Portfolio Management Tool
ASIAS	Aviation Safety Information Analysis and Sharing
ASPIRE	Asia and South Pacific Initiative to Reduce Emissions
ASTS	Aeronautics Science and Technology Subcommittee
ATD	Anthropomorphic test dummy
ATJ	Alcohol-to-Jet
BWB	Blended wing body
CAAFI	Commercial Aviation Alternative Fuel Initiative
CAEP	Committee on Aviation Environmental Protection
CCFP	Collaborative Convective Forecast Product
CDTI	Cockpit display of traffic information
CIWS	Corridor Integrated Weather System
CLEEN	Continuous Lower Energy, Emissions and Noise
CO_2	Carbon dioxide
CoSPA	Consolidated Storm Prediction for Aviation
dB	Decibel
DoD	Department of Defense
DOE	Department of Energy
ECFP	Extended Convective Forecast Product
EDS	Environmental Design Space
EO	Executive Order
EOA	Energy Optimized Aircraft
EPA	Environmental Protection Agency
EPNdB	Effective perceived noise (level) in decibels
ERA	Environmentally Responsible Aviation
ERDS	Enhanced Rotorcraft Drive System
FAA	Federal Aviation Administration
FAST	Fully-reusable Access to Space Technologies
FATE	Future Affordable Turbine Engine

FSRL	Feedstock Readiness Level
F-T	Fischer-Tropsch
FY	Fiscal year
HALE	High altitude, long endurance
HEETE	Highly Efficient Embedded Turbine Engine
HEFA	Hydroprocessed esters and fatty acids
HIFiRE	Hypersonic International Flight Research Experiment
HIWC	High ice water content
HRRR	High-Resolution Rapid Refresh
HSR	High Speed Research program
HTV	Hypersonic Technology Vehicle
HUMS	Health and usage monitoring system
INVENT	Integrated Vehicle Engine Technology
JMR-TCD	Joint Multi-Role Technology-enabled Capability Demonstration
JPDO	Joint Planning and Development Office
JSF	Joint Strike Fighter
LAMP	Localized Aviation Model Output Statistics Program
LIDAR	Light detection and ranging
LTO	Landing and takeoff cycle
MDAO	Multidisciplinary analysis and optimization
MuSICA	Multiple Sensor Integrated Collision Avoidance
MW	Megawatt
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NIRSS	NASA Icing Remote Sensing Station
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NO_x	Nitrogen oxide
NS&HD	National Security and Homeland Defense
NSF	National Science Foundation
OPD	Optimized profile descent
PARTNER	Partnership for AiR Transportation Noise and Emissions Reduction
PLdB	Perceived loudness in decibels
PM	Particulate matter
PRSEUS	Pultruded Rod Stitched Efficient Unitized Structure
R&D	Research and development
RBS	Responsive Reusable Boost for Space Access
RD&D	Research, development and demonstration
RDT&E	Research, development, test, and evaluation
RF	Radio frequency

RNAV	Area Navigation
RTCA	Radio Technical Commission for Aeronautics
SAA	Sense and avoid
SFC	Specific fuel consumption
SiC	Silicon carbide
STBO	Surface trajectory-based operations
SURGE-V	Small Unmanned Renewable enerGy long Endurance Vehicle
TBO	Trajectory-Based Operations
TRACON	Terminal radar approach control facility
UAS	Unmanned aircraft system
UHF	Ultrahigh frequency
USDA	U.S. Department of Agriculture
VAATE	Versatile Affordable Advanced Turbine Engine Technology
VCS	Vapor compression refrigeration cycle systems
WRF	Weather Research and Forecasting

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