

NASA & THE NEXT GENERATION AIR TRANSPORTATION SYSTEM (NEXTGEN)

The Current National Airspace System

Although today's National Airspace System (NAS) is one of the safest means of transportation, it has evolved into a large, complex, distributed, and loosely integrated network of systems, procedures, and infrastructure without the benefit of seamless information exchange. The process of control is primarily through the use of surveillance radars, voice radio systems, limited computer support systems, and numerous complex procedures. Couple this non-integrated, distributed control paradigm with the cognitive human limitations that restrict the number of aircraft an individual air traffic controller can handle, and it becomes evident how today's system has severe limitations on operational flexibility and overall capacity.

Uncertainties in the total flight environment (such as winds, convective weather, unpredictable aircraft performance, and operator procedural changes) are manifest in many areas in today's system, taking a toll on system throughput. In today's system, uncertainty is managed by queuing traffic waiting to be serviced, and demand is managed by restricting access to the airspace to avoid straining capacity. The primary function of the current Traffic Flow Management is to identify and resolve imbalances in the demand and supply of NAS resources such as airspace and runways. However, the current airspace structure is rather rigid, increases restrictions, leads to ground delays during convective weather, and is largely unable to accommodate user preferences.

Noise and emissions are becoming a bigger problem at airports and are already constraining the growth of the air transportation system. It is anticipated that emissions will also become a problem en route. Development of civil aviation must be compatible with environmental compliance.

Finally, safety assurance is currently based on prescriptive rule compliance, with the regulatory authority focused on extensive testing, inspecting, and certifying individual systems and operational elements. Risk analyses are lacking continuity, are often time consuming, and are not always shared. Even though today's system is extremely safe, there are concerns that problems are handled reactively rather than proactively.

The Need For Change

Forecasts indicate a significant increase in demand, ranging from a factor of two to three by 2025.¹ However, the current system is already strained and cannot scale to meet this demand. The ensuing shortfall could cost the U.S. billions of dollars annually in lost productivity, increased operational costs, higher fares, and lost value from flights that airlines must eliminate to keep delays to an acceptable minimum.² As noted in the recently released National

¹ JPDO Progress Report, December 2006

² Estimated at \$9.2 billion to \$23 billion annually. *Socio-Economic Demand Forecast (SEDF) Study*, January 2004, page 5.

Aeronautics R&D Policy, “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.” In short, U.S. competitiveness depends upon an air transportation system that can significantly expand capacity and flexibility, in the presence of weather and other uncertainties, while maintaining safety and protecting the environment.

The problem and the path forward were highlighted in a statement by then-Department of Transportation Secretary, Norman Y. Mineta in a January 27, 2004 speech when he stated, “The changes that are coming are too big, too fundamental for incremental adaptations of the infrastructure...we need to modernize and transform our air transportation system – starting right now.” Evolutionary extrapolation of the current system simply cannot get us where we need to go.

The Solution: The Next Generation Air Transportation System (NextGen)

The United States Congress recognized the magnitude of the challenge and addressed it in the Vision 100 Century of Aviation Reauthorization Act (Public Law 108-176). Vision 100 established the Joint Planning and Development Office (JPDO) to engage multiple agencies that would collaborate to plan, develop and implement the Next Generation Air Transportation System or NextGen. The JPDO is comprised of members from the Departments of Transportation (DOT), Defense (DOD), Commerce (DOC) and Homeland Security (DHS) together with the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA). *Each* agency has a critical role to play in NextGen. The recently released NextGen Concept of Operations (ConOps) describes the capabilities the system requires. Achieving these capabilities will require a mixture of research, technology development, policy and procedure development, system development, and other actions. Agencies will contribute to the achievement of NextGen based on the relationship of their missions to the required capabilities. Table 1 below highlights the key characteristics and capabilities of NextGen, and they are synopsised in Appendix A.

<u>NextGen Key Characteristics</u>	<u>NextGen Key Capabilities</u>
<ul style="list-style-type: none"> □ User focus □ Distributed Decision-making □ Takes advantage of human and automation capabilities □ Scalable □ Robustness and resiliency □ Integrated safety management □ An Environmental management framework 	<ul style="list-style-type: none"> □ Network-Enabled Information Access □ Performance-Based Operations and Services □ Weather Assimilated into Decision-making □ Layered, Adaptive Security □ Position, Navigation and Timing (PNT) Services □ Aircraft Trajectory-Based Operations □ Equivalent Visual Operations (EVO) □ Super Density Arrival/Departure Operations

Table 1. Key Characteristics and Capabilities of the NextGen ConOps

NASA research will contribute to many, but not all, of these key characteristics and capabilities. For example, network enabled information access will be critical to NextGen's success, but NASA does not have a significant role to play in achieving that capability. Listed below are some of the research areas to which NASA (and other partners) will contribute that will have a direct effect on achieving the NextGen characteristics and capabilities.

- Trajectory-based operations using 4D trajectories (NASA, FAA)
- Highly automated systems enabling controllers to manage considerably more aircraft (the human role will transition to strategic decision-making, with tactical separation becoming fully automated) (NASA, FAA)
- Reduced separation in dense traffic (NASA, FAA)
- Dynamic resource allocation to meet demand (NASA, FAA)
- Integrated weather prediction information in the design of 4D trajectories and traffic flow management (NASA, FAA, DOC, DOD)
- Collaborative air traffic management among all participants (NASA, FAA, DOD)
- TFM that can handle a mixed and changing fleet that includes transport aircraft, general aviation, rotorcraft, uncrewed air systems, supersonic aircraft, and ultimately, commercial space vehicles, as well as a fleet with mixed equipment (e.g., those that can, and cannot, design 4D trajectories of their choice in real time while separating themselves from others.) (NASA, FAA)
- A new generation of lower noise- and emission-generating aircraft that also are more fuel efficient (NASA, DOD, FAA)
- Performance-based services (shifting from technology to performance certification) (NASA, FAA)
- Prognostic approach to safety that includes comprehensive monitoring, sharing, and analysis of data (NASA, FAA)

So how do we get there from here?

The answer to this question has three parts.

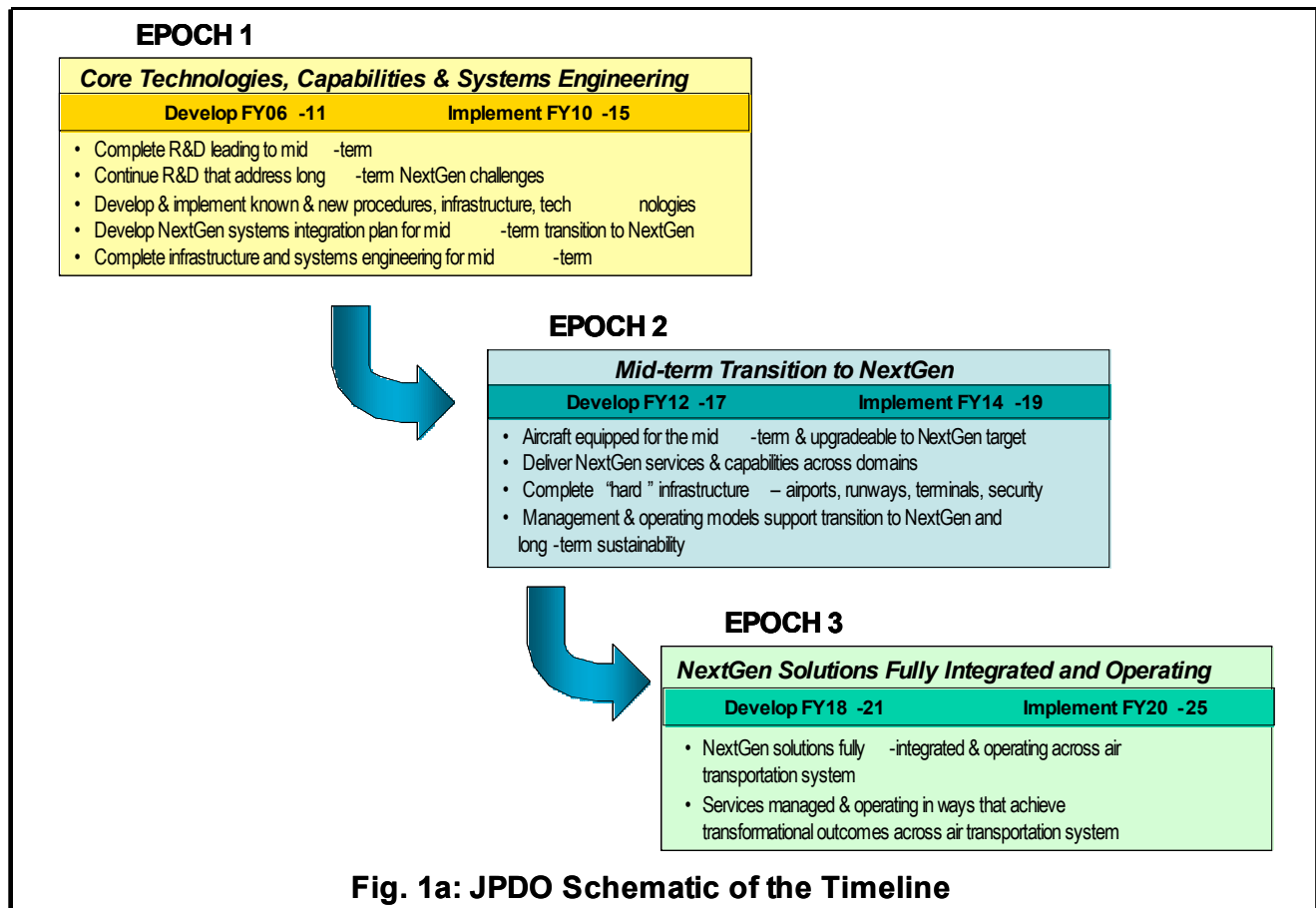
1) We must recognize the magnitude of the challenge.

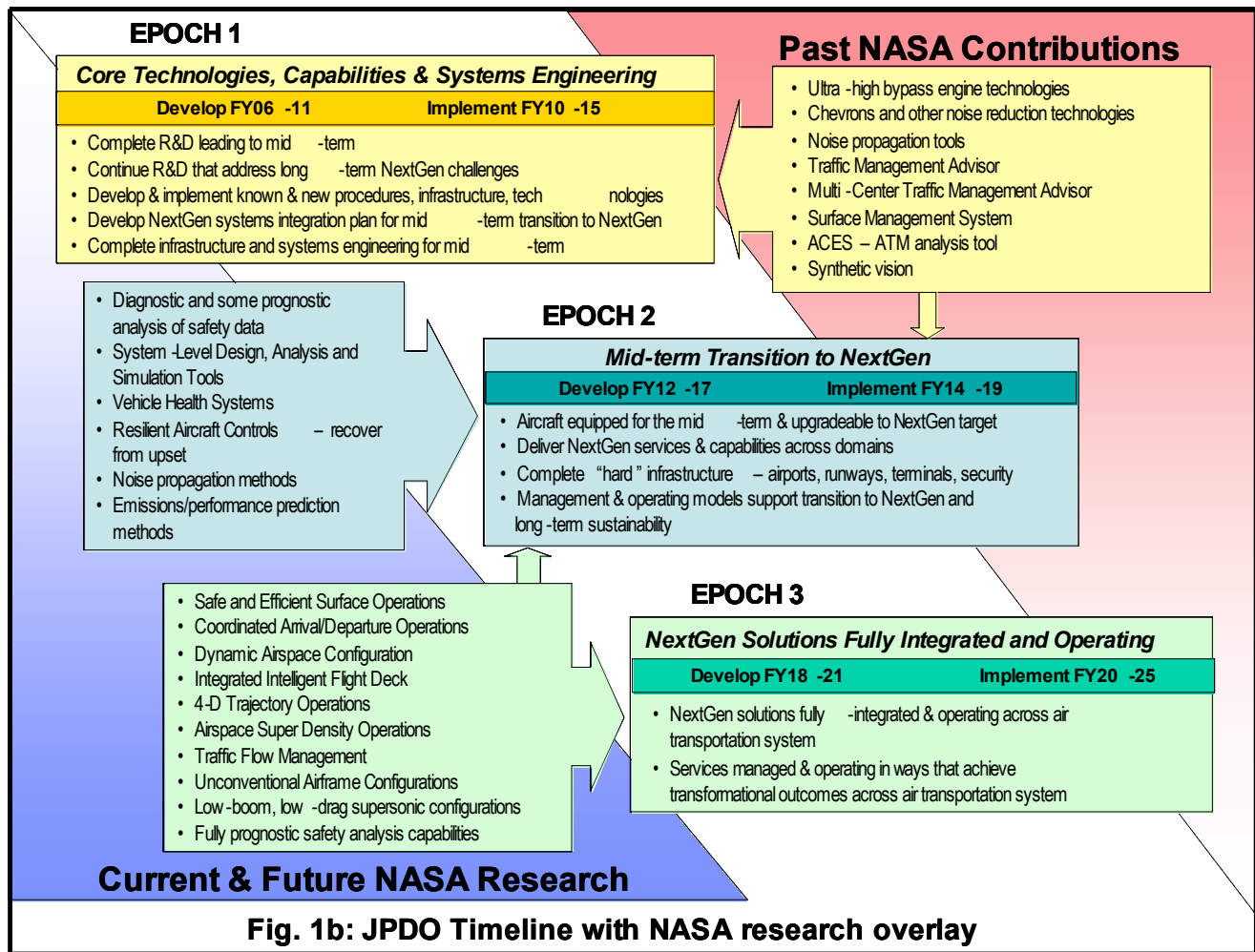
Each of the capabilities listed above represents a major jump from where we are today, and a system that possesses all of these capabilities clearly signifies a true paradigm shift from today's system. As noted in the recent JPDO Progress Report (2006), "The FAA previously tried to modernize the existing system. **NextGen does not modernize the existing system – it completely transforms it.**"

2) We must establish a plan with a clear timeline and deliverables for all partner agencies.

In June 2007, the JPDO released its Concept of Operations (ConOps) and Enterprise Architecture (EA). These two documents provide details regarding "what" NextGen is. In addition, the JPDO is currently developing its Integrated Work Plan (IWP) that provides a detailed schedule and essentially answers the question of "when" and "how" capabilities will be researched, developed and implemented. The IWP includes R&D, implementation, and policy milestones, and is scheduled for completion in July/August 2007.

While the IWP does not yet exist, the JPDO has broken the problem down into three “epochs”, which can be considered near-, mid-, and long-term timeframes. Each epoch represents a key period in NextGen’s development. A schematic depicting these epochs is shown in Fig. 1a. In Fig. 1b, we have overlaid boxes to indicate examples of where NASA research, both past and present, will impact these epochs. For a given “NASA research box”, a large arrow indicates where the majority of the research results will be implemented, while a small arrow indicates where a smaller portion of the research results will be implemented.





Clearly, many of the technologies and capabilities that will be implemented during Epoch 1 are borne from past NASA research efforts. “Epoch 1 aircraft” will benefit from noise-reduction technologies such as chevrons, ultra high bypass engine designs, a host of computational tools, and safety advances in the cockpit, just to name a few examples. Furthermore, the NASA-developed Airspace Concept Evaluation System (ACES) is currently being used to analyze the initial NextGen concepts, many of which were the result of airspace-related research at NASA over the past several years.

The second Epoch builds upon the first to begin critical implementation of NextGen capabilities. Some of NASA’s past and current research will also contribute to the mid-term epoch. Examples include airspace system design and analysis tools, noise and emissions prediction tools and noise and emissions reduction technologies applicable to “Epoch 2-aircraft”, and diagnostic capabilities in data mining of multiple sources of aviation data.

The greatest impact of NASA’s current research investment will manifest itself in Epoch 3, which represents the fully operational implementation of NextGen in 2025. The current NASA research plan has been developed with a goal of enabling the transformational capabilities that

define NextGen in this period. Details regarding what research NASA is conducting in support of NextGen, and especially Epoch 3, are found below and in Appendix B. A successful transition from Epoch 1 to Epoch 3 requires a long-term, focused commitment to cutting-edge research across a breadth of aeronautics core competencies, and such a commitment is exactly what NASA's Aeronautics Programs offer.

It is worth noting that, in the development of a major system like NextGen, there are tremendous pressures on the performing organizations to show quick results in order to "sustain advocacy". This pressure often drives the research and development to focus on the near- and mid-term (Epochs 1 and 2) at the expense of the long term (Epoch 3). This pressure must be resisted, because there are critical trades and research areas that must be investigated to refine and focus the ConOps that require sufficient time to explore and resolve. The IWP must provide enough time to properly tackle these key issues; otherwise Epoch 3 will end up looking very similar to Epoch 2. NASA will be addressing many of these issues, in partnership with other JPDO agencies and the broader aeronautics community. Examples include:

- Identification of actions best-suited to be moved from the ground-based air navigation service provider to the aircraft, particularly for separation assurance
- Humans versus automation management and control responsibilities
- Uncertainty impacts on traffic flow management (weather being a prime example)
- Stability of aircraft gate-to-gate 4D trajectories
- The development of prognostic analysis capabilities to identify potential inadvertent safety impacts of NextGen concepts, approaches, and technologies
- Improving aircraft efficiency and performance within the constraints of environmental compliance

3) Cooperation and collaboration among all member agencies will be critical to the successful transition of R&D to implementation.

The U.S. Congress, through Vision 100, recognized the importance of transition, and stated that it is the responsibility of the JPDO to facilitate "the transfer of technology from research programs such as the National Aeronautics and Space Administration program and the Department of Defense Advanced Research Projects Agency program to Federal agencies with operational responsibilities and to the private sector".

Successful transition relies upon a close working relationship among those who conduct the research and those who use its results, and the JPDO has been established precisely to address this challenge. NASA intends to work closely with all of the member agencies of the JPDO throughout the entire technology development process to ensure that, to the greatest extent practicable, researchers and system operations personnel collaborate to make the technology development and transition as effective as possible. Figure 2 below illustrates our approach in the case of the transition of our airspace systems research to the FAA. This approach enables both NASA and the FAA to do what each does best according to its charter and mission in the best interest of the Nation. Without committed participation by both the research organizations

and the implementing organizations throughout the development process, implementation of NextGen will not be realized.

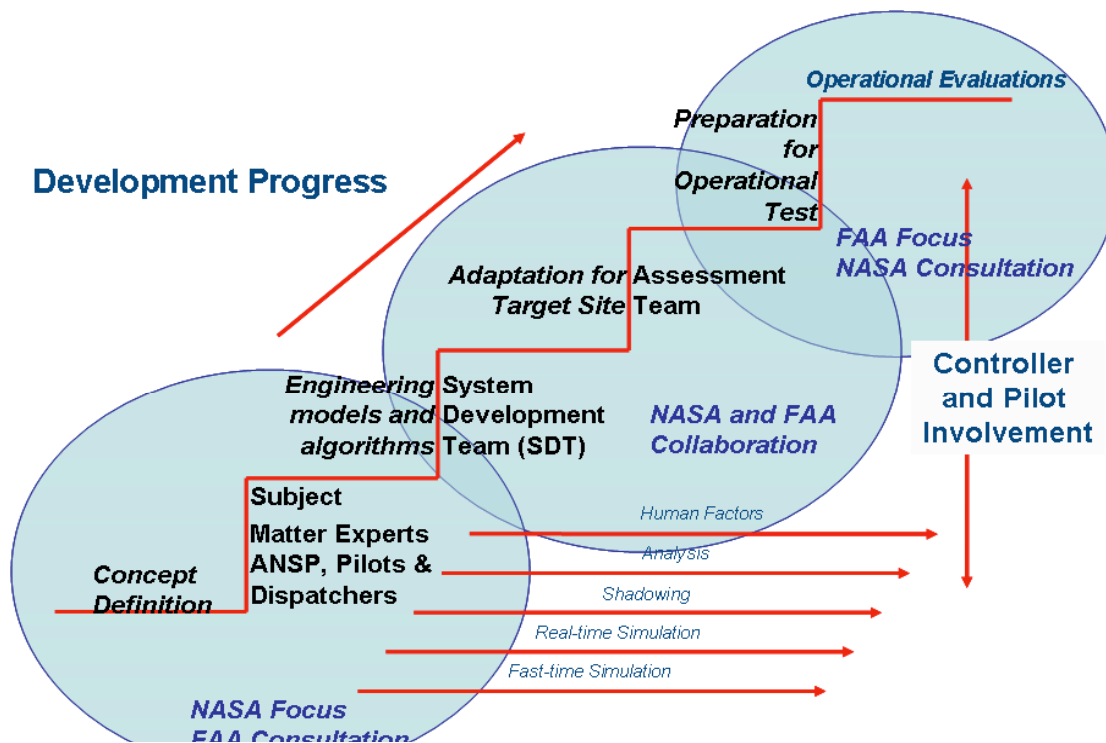


Figure 2: Illustration of Transition of NASA research to the FAA/user community

So, how does NASA’s research investment in Aeronautics contribute to NextGen?

All three of the Aeronautics Research Mission Directorate (ARMD) research programs (Fundamental Aeronautics, Aviation Safety, and Airspace Systems) contribute directly and substantively to the NextGen. Together, these programs address critical air traffic management, environmental, efficiency, and safety-related research challenges, all of which must be worked in order for the NextGen vision to be realized. The outputs of this focused commitment and investment will include advanced concepts, algorithms, tools, methods, and technologies, and all of these products will be critical to the success of NextGen. We provide here a brief summary of how each Program within NASA’s ARMD supports NextGen. Further technical details are provided in Appendix B.

The Airspace Systems Program

The Airspace Systems Program addresses the air traffic management research needs of the NextGen and is comprised of two projects: *NGATS ATM-Airspace* and *NGATS ATM-Airportal*. The two projects are designed to make major contributions to future air traffic needs by developing en route, transitional, terminal and surface capabilities. Both projects are, much like

the airspace system itself, highly integrated, and pay close attention to information management at critical transition interfaces in the NAS.

Specific technical goals of the *NGATS ATM-Airspace* project include:

- Increasing capacity through dynamic allocation of airspace structure and controller resources;
- Effectively allocating demand through departure time management, route modification, adaptive speed control, etc., in the presence of uncertainties such as wind prediction, dynamic convective weather, aircraft performance, and crew/airline procedures and preferences;
- Reducing the capacity-limiting impact of human controlled separation assurance by developing methods to improve sequential processing and merging of aircraft in transition and cruise airspace. This includes analysis of human cognitive workload, situational awareness, performance, human/machine operating concepts, human/automation allocation, and controller/pilot roles and responsibilities during nominal and off-nominal operations;
- Developing accurate trajectory predictions that are interoperable with aircraft flight management systems and account for prediction uncertainty growth and propagation;
- Quantifying the performance-enhancing effects of emerging airborne technologies; and
- Developing an approach and computer-modeling tools that can evaluate the systematic impact of new technologies and capabilities for the NextGen.

Specific technical goals of the *NGATS ATM-Airportal* project include:

- Developing trajectory-based automation technologies to increase the safety and efficiency of surface operations and minimize runway incursions in all weather conditions;
- Enabling reductions in arrival and departure separation standards while balancing arrival, departure, and surface capacity resources at a single airport; and
- Enabling the use of dynamic NextGen resources by addressing the following challenges in the airportal environment: (1) creation of seamless traffic flow by integration of dynamic operator roles, decision aids, sensor information, airportal and terminal area constraints, real-time weather information, and regional/metroplex operations; and (2) identification and understanding of new roles, responsibilities and authority required between humans and automation.

The Fundamental Aeronautics Program

The Fundamental Aeronautics Program addresses research of importance to NextGen through three of its four projects. The research investments in the *Subsonic Fixed Wing*, *Subsonic Rotary Wing*, and *Supersonics* projects are focused on removing environmental and performance barriers that would otherwise prevent the projected growth in capacity. In addition, these projects support the growth of NextGen by enabling new aircraft (including rotorcraft) that can lead to better utilization of our airspace system. More specifically, the some of the key program contributions to the NextGen are as follows:

- Development of noise reduction technologies including those that could be used on conventional (high-lift systems, landing gear, propulsion system) and unconventional aircraft configurations (engine shielding, continuously-deformable mold lines, etc.).
- Development of emissions reduction technologies (low NO_x combustors, for example) for NO_x, CO₂, water vapor, particulates, soot, and other volatiles.
- Studies, concepts, and ideas for development and utilization of alternative fuels.
- Development of noise and emissions predictive capabilities (for conventional and unconventional aircraft) that can be used to guide the development of the architecture of the NextGen.
- Development of technologies, concepts, and ideas for future, high-performance aircraft (blended wing body, short take-off and landing, rotorcraft, supersonic cruise) that can enhance the capacity, flexibility, and efficiency of the NextGen.

The Aviation Safety Program

The Aviation Safety Program develops cutting-edge technologies to improve the intrinsic safety attributes of current and future aircraft that will operate in the NextGen. Four projects comprise the Aviation Safety Program:

- The *Integrated Vehicle Health Management (IVHM)* project conducts research to advance the state of highly integrated and complex flight-critical health management technologies and systems. These technologies will enable nearly continuous onboard situational awareness of the vehicle health state for use by the flight crew, ground crew, and maintenance depot. Improved safety and reliability will be achieved by onboard systems capable of performing self-diagnostics and self-correcting of anomalies that could otherwise go unattended until a critical failure occurs.
 - As part of IVHM, NASA is working closely with the FAA and the Commercial Aviation Safety Team to advance data mining tools and methods (that are critical for future IVHM capabilities) that can be applied to distributed, heterogeneous (continuous digital, discrete digital, analog, and textual) aviation-safety data sources to discover system-level safety vulnerabilities. This will enable a prognostic approach to system safety.
- The *Integrated Intelligent Flight Deck (IIFD)* project pursues technologies related to the flight deck that ensure crew workload and situation awareness are both safely optimized and adapted to the future operational environment as envisioned by NextGen.
- The *Integrated Resilient Aircraft Control (IRAC)* project conducts research to advance the state of aircraft flight control to provide onboard control resilience for ensuring safe flight in the presence of adverse conditions (e.g., faults, damage and/or upsets) that could otherwise lead to a loss-of-control type accident.
- The *Aircraft Aging and Durability (AAD)* project develops advanced diagnostic and prognostic capabilities for detection and mitigation/management of aging-related hazards in order to decrease the susceptibility of current and next generation aircraft and onboard systems to pre-mature deterioration, thus greatly improving vehicle safety.

Appendix A

Synopsis of the Key Characteristics and Capabilities for the NextGen ConOps

NextGen Key Characteristics

- NextGen will emphasize a *user focus*, providing more flexibility and information to users while reducing the need for government intervention and control of resources.
- NextGen will feature *distributed decisionmaking*, with decision being made at the local level whenever possible based on a rich information exchange environment and tools to create shared situational awareness.
- NextGen will *take advantage of human and automation capabilities* – ensuring humans do what they do best – choose alternatives and make decisions – and ensures automation functions do what they do best – acquire, compile, monitor, evaluate and exchange information.
- NextGen will be *scalable* to meet changing traffic load and demand – both on a daily basis as well as time-scales measured in years and decades.
- NextGen will have greater *robustness and resiliency*, with built in contingency measures including “fail-safe” modes for automation that do not fully rely on human cognition as a backup.
- *Integrated safety management* will be employed to proactively manage system, organizational and operational risk.
- An *environmental management framework* will include new technology, procedures and policies to minimize the impact of aviation on community noise and local air quality and mitigate water quality impacts, energy use, and climate effects.

NextGen Key Capabilities

- *Network-Enabled Information Access* will ensure information is available, securable, and usable in real time for different communities of interest and air transportation domains.
- *Performance-Based Operations and Services* ties regulations and procedures to levels of vehicle and crew performance rather than to specific equipment and further, it matches levels of service within the airspace to levels of performance of the vehicle and crew; this provides a framework that encourages innovation and provides users with a predictable environment.
- *Weather Assimilated into Decisionmaking* directly utilizes digital, probabilistic weather information in automation platforms and decision support tools.
- *Layered, Adaptive Security* creates an integrated suite of risk-based security measures.
- *Position, Navigation and Timing (PNT) Services* allow operators to define their desired flight path based on their objectives, rather than on the location of ground-based navigational aides.
- *Aircraft Trajectory-Based Operations* is the basis for allocation of resources (airspace and runway use, etc.) and tactical separation of aircraft.

- ***Equivalent Visual Operations (EVO)*** allows aircraft to conduct operations without regard to visibility conditions.
- ***Super-Density Arrival/Departure Operations*** safely reduces separation in surface and terminal operations to maximize the performance of the busiest airports.

Appendix B

What Is NASA Doing in Support of the NextGen Vision?

NASA's Aeronautics Research Mission Directorate (ARMD) has been constructed according to the following three core principles: 1) we will dedicate ourselves to the mastery and intellectual stewardship of the core competencies of aeronautics for the Nation in all flight regimes; 2) we will focus our research in areas that are appropriate to NASA's unique capabilities; and, 3) we will directly address the fundamental research needs of the NextGen while working closely with our agency partners in the Joint Planning and Development Office (JPDO). In accordance with these principles, ARMD has established a balanced research portfolio that draws upon our NASA-unique capabilities to address air traffic management, environmental, efficiency, and safety-related research challenges, all of which must be worked in order for the NextGen vision to be realized.

Details of how the research in each of our Programs contributes to NextGen are provided below, in addition to a brief explanation of our contribution to the planning and development activities of the JPDO.

NASA Contributions to the Planning & Development Activities of JPDO

In direct support of the JPDO NextGen planning process, NASA contributes annually approximately \$18 million in labor and procurement dollars towards JPDO activities. This contribution is over and above the research contributions described below, and includes the current staffing of the JPDO Deputy Director, along with the Directors of the Systems Engineering and Analysis Division (SEAD), Enterprise Architecture and Engineering Division (EAED), and the Agile Air Traffic System Integrated Product Team. In addition, the three ARMD programs of Airspace Systems, Aviation Safety, and Fundamental Aeronautics have provided representatives on both the executive council and the Agile Airspace, Weather, Safety, Airports, and Environment Independent Product Teams (IPTs) along with SEAD and EAED. As the JPDO restructures itself in the coming months, NASA has made it clear that we will continue to provide personnel for key positions.

Airspace Systems Program Research

The Airspace Systems Program consists of two separate projects, NGATS ATM-Airspace and NGATS ATM-Airportal. These two projects form the foundation for conducting the long-term research needed to enable the NextGen vision. The NGATS ATM-Airspace Project develops and explores fundamental concepts and integrated

solutions that address the optimal allocation of ground and air automation technologies necessary for NextGen. The Project will focus NASA's technical expertise and world-class facilities to address the question of where, when, how and the extent to which automation can be applied to moving aircraft safely and efficiently through the NAS. The NGATS-ATM Airportal Project develops and validates algorithms, concepts, and technologies to increase throughput of the runway complex and achieve high efficiency in the use of airportal resources such as gates, taxiways, runways, and final approach airspace. NASA research in this project will lead to development of solutions that safely integrate surface and terminal area air traffic optimization tools and systems with 4D trajectory operations. Ultimately, the roles and responsibilities of humans and automation influence in the ATM will be addressed by both projects.

Trajectory Based Operations

In determining required research challenges, important factors to be considered are that the future Air Traffic Management (ATM) systems will consider user needs and performance capabilities, utilize trajectory-based operations, and optimally utilize human capabilities, automating management of the NAS in ways that may subsume the functions currently performed by pilots and controllers. The NextGen vision calls for the human role within the system to move towards strategic decision-making, and the tactical separation role moves towards full automation. Trajectory based operations will take the guess work out of the system, and introduce predictability as the precise trajectory and scheduled crossing times along points on the trajectory will be known and hence managed for conflict mitigation.

A major challenge of using trajectory-based tools for ATM is the requirement to accommodate both airspace-based and trajectory-based operations, which rely on 4D trajectory accuracy and the ability to transmit trajectory adjustments via data link to the flight deck. Another key element is the ability to dynamically predict uncertainty in development areas such as winds prediction, aircraft performance models, convective weather, and procedural assumptions for use by stochastic-based automation in mitigating its impact. Due to higher levels of automation, an overarching research challenge is to identify trajectory-based technologies and human/machine operating concepts that could support a two to three times increase in capacity under nominal and failure recovery modes, with due consideration of safety, airspace user preferences, and favorable cost/benefit ratios. Another critical factor is the assurance of graceful failure detection and recovery, so human managers can safely resolve off-nominal problems and conflicts.

To address these challenges, NASA research in Trajectory Prediction, Synthesis, and Uncertainty will develop accurate trajectory predictions that are interoperable with aircraft flight management systems trajectory generation using prediction uncertainty growth and propagation. Furthermore, NASA research in Separation Assurance seeks to develop failure-tolerant automated technology for sequential processing of merging and sequencing with separation in transition and cruise airspace. This includes analysis of human cognitive workload, situational awareness, performance, human/machine

operating concepts, human/automation allocation, and controller/pilot roles and responsibilities during nominal and off-nominal operations.

Traffic Flow Management

The future Traffic Flow Management (TFM) function for NextGen has to be designed to deal with as much as three times today's traffic, be less structured, and be able to handle a traffic mix consisting of airline operations, air taxi operations, general aviation, and unmanned air vehicles. It will be enabled by 4D trajectory-based operations, as described above, resulting in optimal utilization of the prevailing airspace and airportal configuration (but flexible and dynamic enough to support the future operational paradigms of NextGen). In the NextGen, many aircraft will have gate-to-gate 4D commitments, which may include gate identification, pushback time, take-off time, a complete 4D trajectory through the airspace, touchdown time, and gate arrival time. However, there may also be some aircraft in the NextGen that are equipped to design, in real time, a 4D trajectory of their choice while separating themselves from other traffic. TFM must accommodate both. All of this must be done with full use of integrated weather information. In addition, airspace adjustments restructuring should be fast and allow for airspace management from any facility by any controller on a routine basis to assist in balancing workload, and capacity and demand. NASA research in TFM will directly address these challenges as it develops concepts to effectively allocate demand through management of departure times, route modification, and adaptive speed control, among others, in the presence of uncertainties such as wind prediction, dynamic convective weather, aircraft performance, and crew/airline procedures and preferences.

Dynamic Airspace Configuration

A major function of Air Traffic Management is the operational practice of predicting and mitigating the mismatch between air traffic demand and capacity. Over-capacity situations degrade system efficiency and system safety, and are typical of the problems that have to be addressed by air traffic managers and service providers. Under-capacity situations also reflect a degradation of system efficiency when the available resources are not adequately utilized. Capacity management is achieved by manipulating the airspace configuration. The purpose of airspace configuration is to make as much airspace capacity available as possible, where and when it is required, which is fundamentally different from today's system where the airspace is a rigidly structured network of navigation aids, sectors, and special use airspace. The goal of the dynamic airspace configuration research is to better serve users' needs by tailoring the availability and capacity of the airspace by creating a dynamic airspace configuration function that will provide the service provider a new degree of freedom to accommodate the airspace requests of users.

Performance Based Services

In the NextGen environment, ATM will use performance based services to deliver instructions (i.e., advisories) to aircraft with specific regard for their unique equipage and

commensurate performance capabilities to safely and efficiently perform said instructions. In order to achieve maximal gains from a Performance Based Services approach, NASA will conduct research and simulation activities to address the unrealized performance gains by investment in emerging airborne ATM technologies, and a paradigm shift from technology certification to performance certification. In addition, NASA will conduct research on the performance-enhancing effects of emerging airborne technologies on solutions to the fundamental ATM problem, i.e. to deliver advisories of the type and manner appropriate for the equipage of the aircraft and airspace.

Super Density Operations

Another important factor is that required airspace super density operations capability near today's congested hub airports will only provide increased operations by addressing the fundamental hurdles associated with capacity and uncertainty. Increasing theoretical capacity of an airport can be achieved in a number of ways: reducing separation minima, relaxing runway occupancy requirements, or adding runways, taxiways and gates. The practical value of capacity improvements in any one area, however, is often limited by capacity in another area (e.g., additional runways may result in congested taxiways or unmanageable airspace). Reducing the level of uncertainty inherent in the air traffic system will enable airports to operate more efficiently near their theoretical capacity by shortening or eliminating queues in the system.

Airportal Operations

NASA research efforts in Safe and Efficient Surface Operations will address the challenges of developing surface operations concepts by developing and validating automated, safe, and efficient all weather surface operations concepts through fast- and real-time simulations. In addition, NASA research in Airspace Super Density Operations will develop concepts for simultaneous sequencing, spacing, merging, and de-confliction in terminal airspace. Furthermore, NASA research in Coordinated Arrival/Departure Operations Management will develop a suite of tools that may be mixed or matched at the overall Airportal system level to meet capacity goals. These tools may include technologies to reduce runway occupancy time, to reduce lateral or longitudinal approach and departure spacing, to mitigate weather impacts, to mitigate the interference between intersecting or parallel runways, and others. Limitations in the current projections for airport/runway expansion indicate the importance of investigation of novel approaches for dramatically increasing airportal throughput during peak congestion. One targeted research approach will explore optimization concepts for metroplex (regional inter-airport) operations.

System Analysis Tools

Finally, in order to ensure that the final integrated NextGen ATM system will function as required, systems analysis tools must be developed and used to evaluate the future state. NASA research in System-Level Design, Analysis and Simulation Tools will develop

system design and analysis tools to sort out the functional/temporal distribution of authority and responsibility among/between automation and humans, and overall system performance. In addition, NASA Airportal Transition and Integration Management research will perform a set of culminating experiments to understand and validate key Airportal contributions to super density operations. Key aspects include optimization for arrival, departure, and taxi scheduling, and balanced allocation of airportal resources to maximize airportal productivity in response to arrival, departure, surface traffic demands, and uncertainty in intent and weather information, nominal and off-nominal traffic and weather, and operational paradigms (e.g., service provider and aircraft operator).

Aviation Safety Program Research

A key challenge to enable the NextGen Vision will be to ensure its safety. Today's accident rates, although extremely low, will not be acceptable with the anticipated increased volume of travel and numbers of operations projected for NextGen. Moreover, increased density of air traffic, a wider diversity of users, and the introduction of NextGen concepts, systems, technologies, and procedures will all pose additional challenges to maintaining aviation safety. "We cannot think in terms of 'safety versus growth.' We must continue to innovate, continue to collaborate and continue to improve the way we do business so that we achieve both."¹ NextGen will require the introduction of new safety concepts, systems, technologies, and procedures that must be implemented and monitored to achieve acceptable levels of safety in a more complex and more demanding environment resulting from increased throughput and wider diversity of users.

The Aviation Safety Program will develop tools and methods for aircraft designers to incorporate revolutionary safety technologies and capabilities into their vehicles. This will be accomplished by conducting long-term, cutting-edge research to produce the tools, methods, and technologies that will improve the intrinsic safety attributes of current and future aircraft, as well as overcome the safety technology barriers that would otherwise constrain full realization of the NextGen. The Aviation Safety Program has four projects that contribute to the NextGen Vision.

The Aircraft Aging and Durability Project develops advanced diagnostic and prognostic capabilities for detection and mitigation of aging-related hazards. The research and technologies to be pursued will decrease the susceptibility of current and next generation aircraft and onboard systems to premature deterioration, thus greatly improving vehicle safety. The project will emphasize new material systems and fabrication techniques, as well as the potential hazards associated with aging-related degradation. The intent is to take a proactive approach to identifying aging-related hazards before they become

¹ Department of Transportation Secretary Norman Y. Mineta FAA-sponsored International Safety Form, 2004

critical, and to develop technologies and processes to incorporate aging mitigation into the design and maintenance of future aircraft operating in the NextGen.

The Integrated Resilient Aircraft Control Project conducts research to advance the state of aircraft flight control automation and autonomy in order to prevent loss-of-control in flight. Taking into account the advanced automation and autonomy capabilities as envisioned by the NextGen, the research will pursue methodologies to enable an aircraft to automatically detect, mitigate, and safely recover from an off-nominal condition that could lead to a loss-of-control. A key component of the research will be to develop technologies that will enable an aircraft control system to automatically adapt or reconfigure itself in the event of a failed or damaged component.

The Integrated Vehicle Health Management Project will conduct research to advance the state of highly integrated and complex flight-critical health management technologies and systems. These technologies will enable nearly continuous onboard situational awareness of the vehicle health state for use by the flight crew, ground crew, and maintenance depot. Improved safety and reliability will be achieved by onboard systems capable of performing self-diagnostics and self-correcting of anomalies that could otherwise go unattended until a critical failure occurs. A key component of this project that will enable the success of the NextGen is Data Mining and Information Analysis. This research will develop tools and technologies to enable the integration and automated analysis of large sources of disparate data, to detect systemic anomalies or degradations before an unsafe situation occurs.

The Integrated Intelligent Flight Deck Project will pursue flight deck related technologies that will ensure crew workload and situation awareness are both safely optimized and adapted to the future operational environment as envisioned by the NextGen. A key component of this research will be investigating methods to automatically monitor, measure, and assess the state of the crew awareness, and to model human performance in order to safely optimize the human interface with new automation capabilities of the NextGen.

As a result, the NextGen will be a transformed air transportation system employing new safety-enhancing technologies and comprehensive, more proactive safety practices. Aviation system technologies will be aimed at managing hazards, eliminating recurring accidents, and mitigating accident and incident consequences.

NASA research in risk-reducing systems interfaces, continued airworthiness of aircraft, systems health management, adaptive controls systems to recover from upset conditions, adaptive flight deck systems that accommodate unintended changes in automation, and accident mitigation will enhance the safety of airborne and ground-based systems. Safety will be assured through standards, regulations and procedures including comprehensive monitoring, sharing and analysis of safety information for proactive solutions. NASA Aviation Safety Program research will assure the safety of the NextGen by advancing the

science of vulnerability discovery, methods for verification and validation of complex systems, improving the ability to identify contributing factors to system safety risk, developing prognostic methods to assess risks, increasing the understanding of fault propagation, improving risk assessment capabilities, increasing pre-implementation safety assurance, increasing data accessibility and analysis for safety risk management, increasing confidence in analytical results, and improving the risk management cycle time will provide enhanced monitoring and safety analysis of the air transportation system.

Fundamental Aeronautics Program Research

Starting in FY06, the Fundamental Aeronautics Program has transformed from a demonstration-based program to one focused on fundamental technology, with emphasis on core-capability in discipline and multidiscipline technologies critical to sustaining the advancement of aeronautics. The Program supports the goals of the NextGen and the JPDO by providing foundational research, analysis tools, and advanced technologies that can be used to predict and reduce the noise and emission levels of both current and future aircraft. Together with significant advances in aircraft performance (to reduce overall fuel consumption), these contributions can enable significant growth in the national air transportation system while meeting stringent environmental constraints.

The NextGen environmental challenge is very significant: future aircraft need to be quieter and cleaner to meet the stringent noise and emissions regulations that are expected as the air transportation system increases in capacity (2-3x by 2025). These aircraft must also meet challenging performance requirements to make them economically-viable alternatives to the existing fleet. The Fundamental Aeronautics (FA) Program performs research to address public concerns over noise and emissions, the increasing costs associated with high fuel consumption, and the lack of progress towards faster means of transportation. Three projects, the Subsonic Fixed Wing, Supersonics, and Subsonic Rotary Wing projects, contribute to the NextGen Vision.

The Subsonic Fixed Wing project is developing advanced mitigation strategies for noise and emissions. The program's work on emission reduction includes advanced engine concepts, novel combustor designs, and new operational measures. Engine concepts such as the ultra-high-bypass (UHB) ratio engine reduce CO₂ and specific fuel consumption and create opportunities for noise reduction. By 2012, UHB ratio turbofans will be the new baseline and by 2018, multiple fans driven by high power density cores may enable bypass ratios greater than 20. Innovative combustor designs are required to meet the challenges of the UHB and research within the project will enable low-emission (gaseous and particulate) combustion systems to be developed for subsonic engine applications. New approaches to the operation of air vehicles resulting from advanced aircraft configurations such as the blended wing body and aircraft designed for Cruise-Efficient Short Take-Off and Landing (CE STOL) offer potential increases in capacity while

leading to reductions in congestion and delays at hub airports. These new aircraft can eventually enable operations that keep the noise footprint within the boundary of the airport. The long-term objectives of the research in the Subsonic Fixed Wing project will also make the following possible: (1) noise prediction and reduction technologies for airframe and propulsion systems enabling -52 dB cumulative, below Stage III², (2) emissions reduction technologies, alternative fuels, and particulate measurement methods enabling 80% reduction in landing and take-off NO_x below CAEP/2³, and (3) improved vehicle performance technologies through design and development of lightweight, multifunctional and durable structural components, better integration between the airframe and the propulsion plant, high-lift aerodynamics, and higher bypass ratio engines with efficient power plants enabling 25% fuel burn reduction as compared to the Boeing 737 with the CFM56 engine.

Enabling commercial aircraft to double or triple their speed would open the opportunity for a true revolution in air travel and would have a significant impact on U.S. competitiveness. This is the principal focus of the Supersonics project. Benefits to the general public would include reduced travel time for business and pleasure, rapid delivery of high-value, time-critical cargo, and rapid response to disasters. The country and companies that first achieve these goals will potentially gain an advantage equivalent to the introduction of the jet airliner. NASA's Supersonic Project is addressing some of the key problems that are preventing this vision from becoming a reality. The long-term research objectives of the Supersonics project enable: (1) cruise efficiency improvements, comprising advances in the airframe and propulsion system, of approximately 30% vs. the final NASA High-Speed Research (HSR) program baseline, (2) approximately 20 EPNdB of jet noise reduction relative to an unsuppressed jet, (3) a reduction of loudness on the order of 30 PLdB relative to typical military aircraft sonic booms, and (4) elimination or minimized impact from high altitude emissions; as an example, the emission of oxides of Nitrogen must be reduced from 30 g/kg of fuel to 5. Major research components include variable cycle engine (VCE) inlet and fan performance optimization, high-performance inlet and nozzle concepts, light-weight airframe materials and structures, durable propulsion systems and airframes, and design tools for flexible airframes.

Rotary wing vehicles have the potential to provide point-to-point travel, thereby making routine air transportation more accessible to everyone. This is only true if key limitations can be overcome. The Subsonic Rotary Wing project aims to address these limitations by focusing research on technologies that can increase the range, speed, payload capacity,

² Stage III refers to a limit imposed by ICAO (International Civil Aviation Organization) on the maximum allowable noise levels for current aircraft.

³ CAEP/2 refers to the 2nd stage of regulation recommended by the Committee on Aviation Environmental Protection.

fuel efficiency, precision flight path capabilities, and environmental acceptance (especially noise) of rotorcraft. Rotorcraft noise levels and footprint must be reduced significantly. The current state of the art indicates that 6 dB reductions can be obtained through combinations of rotor design and procedural flight operations. Through research and development, new technologies will reduce the acoustic field for a range of flight conditions and eliminate noise as a barrier to broader commercial utilization. Research within the project will enable design capabilities for low-noise rotorcraft that include the accurate calculation of blade vortex interaction noise, high-speed impulsive noise, and blade/wake interaction noise. Development of acoustic propagation techniques that account for atmospheric effects, terrain, and shadowing such that rotary wing vehicles can be optimized for minimal noise impact while retaining performance and handling quality standards will also be studied. Technologies to enable low-noise, complex, spiraling, descent and ascent approaches through the development of cockpit cueing for the pilot will be addressed. Finally, additional research components of the Subsonic Rotary Wing plan concentrate on external acoustic prediction and validation through testing.