Federal Aviation Administration and National Aeronautics and Space Administration

Next Generation Air Transportation System

Human Factors Research Status Report

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Next Generation Air Transportation System
Joint Planning and Development Office

Table of Contents

Executive Summary

This report discusses progress made by the Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) toward human factors research needed to implement the Next Generation Air Transportation System (NextGen). Progress to date and remaining challenges are assessed in the context of recognized national goals. This assessment relies upon coordination of best practices that both agencies have enhanced since releasing the Joint Planning and Development Office (JPDO) FAA/NASA *NextGen Human Factors Research Coordination Plan* (HFRCP) in 2011. After an overview of progress made and challenges remaining in the mobility and aviation safety topic areas, the report provides short synopses of recent human factors research results and plans. Many of the research activities were undertaken as joint efforts between the two agencies and have resulted in technology transfer that advances the aviation community toward NextGen.

High-level goals from the *National Aeronautics Research and Development Plan*, produced by the National Science and Technology Council, provide a common foundation for assessing FAA and NASA progress toward NextGen human factors needs. Other guiding documents include the *NASA Strategic Plan* and the *FAA National Aviation Research Plan*. Effective coordination between the agencies led to notable progress toward key national goals, including the completion of a formal NextGen technology transition initiative under the Research Transition Teams and shared participation in regular program reviews and international technical aviation conferences.

Research accomplishments notwithstanding, there remain key technical challenges in fully realizing the benefits of NextGen, including:

- Development and refinement of verification and validation methods to demonstrate safety for the human component in complex systems
- Modeling of functional allocation to systematically examine the envelope of human performance under different operational conditions
- Integrating human factors into safety risk management processes
- Acquiring tools and processes to support standardized assessment of human factors readiness of NextGen capabilities.

Detailed research results and plans have been organized according to the ten Initial Focus Areas (IFAs) identified in the HFRCP published in 2011. Human factors research is conducted at NASA and FAA as part of NextGen-related programs and projects to examine advanced concepts, new technologies, and requirements for implementation and certification.

FAA and NASA will continue working together, making progress on key challenges for NextGen, and ensuring the right mechanisms are in place for continued coordination and collaboration. As a commitment to continual improvement and to ensure sustained progress towards national goals, FAA and NASA will regularly refine their strategies for human factors research coordination.

Introduction

Our Nation's air transportation system serves as a critical engine of economic growth and facilitates safe and efficient movement of people and goods across the globe. The vision for the Next Generation Air Transportation System (NextGen) is "a transformed aviation system that allows all communities to participate in the global marketplace, provides services tailored to individual customer needs, and accommodates seamless civil and military operations." Transforming the system to meet the needs of the 21st century will ensure U.S. leadership in the global economy.

Achieving NextGen will require advanced concepts and technologies, along with higher levels of automation – all of which will result in changes to roles and responsibilities for pilots and air traffic controllers. These transitions, in combination with increased interaction with automation, can lead to unwanted side effects, such as increased errors, loss of situational awareness, or mode confusion. This necessitates an understanding of human factors, which studies how humans' abilities, characteristics, and limitations interact with the design of the equipment they use, the environment in which they function, and the jobs they perform.

The Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) undertake human factors research as part of their NextGen-related programs and projects to assess the envelope of human performance capabilities and limitations with new concepts and automation. The focus of FAA NextGen human factors research is primarily on near- and mid-term research, while NASA focuses mainly on mid- and far-term research.

In February 2011, the Joint Planning and Development Office (JPDO) – the interagency office charged with creating an integrated plan for NextGen – published a joint FAA and NASA *NextGen Human Factors Research Coordination Plan* (HFRCP) to further coordinate the human factors research efforts of both agencies. As part of the coordination process, the two agencies identified complementary goals for providing a framework to move forward with continued human factors coordination. In addition, the agencies compared results and plans under the ten Initial Focus Areas (IFAs) originally identified in the HFRCP. This comparison found good coverage between the two agencies and provided an initial indication of progress.

This report provides an overall assessment of FAA and NASA human factors research activities that support NextGen implementation, including progress toward high-level national goals, remaining key challenges, and synopses of research results and plans for major activities (Appendix A). The progress section discusses accomplishments in human factors research toward goals from national plans including the *National Aeronautics Research and Development Plan* (National R&D Plan), the *NASA Strategic Plan,* and the *FAA National Aviation Research Plan* (NARP). It also highlights collaborations and best practices for coordinating research activities and identifying opportunities for joint work. The key challenges section identifies important, complex issues that pose significant technical risk in realizing the full benefits of NextGen. The Appendix provides select research results and plans, highlighting recent accomplishments and future plans for both agencies arranged by the ten IFAs originally identified in the HFRCP published in 2011.

This report serves to enhance other existing means for NASA and the FAA to monitor research investments, enable leveraging between NASA and FAA research, avoid duplication of effort, identify and resolve gaps, and facilitate best use of expertise and resources. The FAA will also refer to this report when developing operational concepts, information requirements, standards, guidance, advisory circulars and other regulatory matters.

Progress

The FAA and NASA are working together to support the aviation community's transition toward NextGen. Many major activities are conducted jointly by the two agencies. Research results from these activities contribute insight and understanding on operational concepts, systems design, and workforce allocation, among other areas. Significant results are organized topically by IFA and provided in the Appendix. While the IFAs provide a means to organize accomplishments along areas of common interest, overall progress can also be assessed with respect to national goals.

The *National R&D Plan* lays out high-priority national aeronautics R&D challenges, goals, and supporting objectives to guide the conduct of U.S. aeronautics R&D activities through 2020 as called for by Executive Order 13419, which established the National Aeronautics R&D Policy. The *National R&D Plan* enables robust interagency planning to define and achieve high-priority national aeronautics R&D goals and objectives.

Both the FAA and NASA conduct research to support the principals, challenges, and goals in the *National R&D Plan*. Biennially, an assessment is made of the progress towards achieving these goals, many of which require human factors contributions. This assessment is a result of input from all the agencies conducting research in aeronautics. The progress assessment of the *National R&D Plan* in 2011 noted that "NextGen human factors research has increased since the last progress assessment (reported in the 2008 Appendix to the *National R&D Plan*) and the objective related to human machine interaction in a highly automated air transportation system is assessed as green." The assessment also noted that "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."

Guided by the *National R&D Plan* and the *NASA Strategic Plan*, the NASA Aviation Safety Program (AvSP) and Airspace System Program (ASP) incorporate human factors research as part of their activities. Many of these activities support NextGen. Both programs align research with technical challenges chosen to address national needs. Although the technical challenges do not involve advancing human factors research as a discipline, many of them include important human factors elements that must be accomplished to achieve the technical challenge's desired outcome.

The FAA's *NextGen Implementation Plan* (NGIP) and the NARP provide the framework for aligning FAA human factors research to help the FAA achieve NextGen objectives by identifying challenges, understanding barriers, and developing solutions associated with capacity, safety, controller efficiency, and pilot workload. While the NGIP identifies the supporting role and activities for human factors research, the NARP is the FAA's performance-based plan to ensure that its R&D investments are well managed, deliver results, and are sufficient to address national priorities. The FAA uses the NARP to identify program roles and responsibilities, measure and track program and portfolio performance, and report results.

The FAA and NASA considered complementary goals from across these documents when assessing their progress in human factors research. That being said, the following sections discuss human factors research progress (both within and across agencies) with respect to the mobility and aviation safety goals of the *National R&D Plan*. This R&D plan provides a unifying common reference framework for noting progress toward national goals. Whereas the JPDO website and the FAA NAS Enterprise Architecture Portal listed in the references provide detailed perspectives, this report offers a broad view of the many relationships between the progress of human factors research and the achievement of NextGen operational improvements (OIs).

Mobility

The National R&D Plan includes five goals under mobility. Goal 1 is to develop reduced aircraft separation in trajectory- and performance-based operations. In this area, human factors work often addresses performance and acceptability of new decision support tools, controller and pilot workload, user interface issues, and safety of newly developed procedures. NASA's work in separation assurance research strives to improve capacity by reducing human workload. Air/ground concepts and technologies emphasize mature NextGen environments in transition and cruise airspace. Key areas of research include development of automated separation assurance technologies, addressing human/automation operating concepts and functional allocation issues, and conducting system safety and failure recovery analyses. As part of this effort, NASA completed the first in a series of human-in-the-loop simulation experiments exploring air-ground functional allocation under advanced trajectory-based operations. Results revealed that both ground-based and airborne-based separation concepts yield comparable performance related to maintaining separation, adhering to schedule constraints, and avoiding airspace hazards. FAA separation assurance work focuses on near and mid-term solutions, concentrating on oceanic airspace and en route corridors. Human factors work supports procedures, equipage, training, and design to enable reduced and delegated separation. Like NASA, FAA human factors research also defines the changes in the roles and responsibilities between pilots and controllers and between humans and automation required to implement NextGen. Through regular technical dialogue, FAA and NASA researchers exchange ideas and promote compatible solutions to these functional allocation challenges. In 2011, FAA completed initial research to evaluate and recommend procedures, equipage, and training to safely conduct oceanic and en route pair-wise delegated separation. NASA worked closely with the FAA and other partners to implement an oceanic in-trail procedure in the South Pacific. Through these and other efforts, NASA and FAA will work collaboratively to assess human factors performance during early operations.

Goal 2 is to develop increased NAS capacity by managing NAS resources and air traffic flow contingencies. In close cooperation with FAA, NASA has been conducting Dynamic Airspace Configuration (DAC) research to better serve users' needs by tailoring the availability and capacity of the airspace and promptly communicating its status to users. The fundamental objective of this research is to provide flexibility where possible and structure where necessary through strategic airspace organization and dynamic airspace adjustments in response to changing demand. NASA partnered with the FAA to develop and test a tool that helps air traffic supervisors re-structure adjacent sectors to better balance workload. NASA and the FAA tested this tool on the Cleveland Center airspace, validating several airspace changes made recently by the FAA and also proposing new configurations. FAA human factors research is focused on demonstrating improvement in Air Navigation Service Provider (ANSP) efficiency (e.g., greater number of aircraft) and effectiveness (e.g., improvement of safety metrics) through automation and standardization of operations, procedures, and information, including new procedures that allow ANSP personnel to manage and introduce routing, airspace, and equipage mix changes in the dynamic air traffic environment. In 2011, the FAA conducted a strategic job analysis of planned NextGen OIs during the mid-term and determined that the skills, knowledge, and abilities of controllers will not require a change in the selection tools for hiring controllers. This will result in cost savings to the time and resources needed to modify selection tools. FAA operational concepts research continues to develop methods, metrics, and models to demonstrate that the modernized system can handle the anticipated growth in forecasted traffic demand, comparing the modernized system with the current system using capacity and efficiency metrics.

Goal 3 is to reduce the adverse impacts of weather on air traffic management decisions. NASA is doing research in Traffic Flow Management (TFM) to identify and resolve imbalances in the demand and supply of NAS resources, such as airspace and runways. The TFM function in NextGen must accommodate future traffic growth, while accounting for system uncertainties and accommodating user preferences. During the summer of

2011, NASA worked with the FAA to complete a shadow-mode evaluation of a decision support system that promotes more optimal ground delay programs at San Francisco airport. In a follow-on study, the FAA plans to evaluate this system during actual operations at the Air Traffic Control System Command Center. This activity represents a notable technology transfer from NASA to FAA that will reduce delays at a major airport. FAA research contributes to creating a common situational awareness that includes weather information and will lead to Shared Situational Awareness (SSA) that will allow controllers, dispatchers, Flight Service Station (FSS) specialists, and others to have a common picture and conduct more efficient operations. In 2011, the FAA developed NextGen mid-term Concepts of Operation (ConOps) and user requirements for the provision, integration, and use of weather information in the cockpit. In 2015, researchers plan to demonstrate the integration of navigation, flight, and weather information into cockpit decision-making and shared situational awareness among pilots, dispatchers, and air traffic controllers supported by NextGen air and ground capabilities.

Goal 4 is to maximize arrivals and departures at airports and in metroplex areas. NASA is conducting Super Density Operations (SDO) research focused on managing airport environment and surface traffic safely and efficiently to enable maximum throughput and minimal environmental impact. Activities within this research include developing ConOps, sequencing and de-confliction technologies, precision merging and spacing, concepts for regional SDO resource optimization, and technologies for arrival/departure runway balancing and assignment. NASA worked with the FAA and American Airlines to conduct a field evaluation of its Precision Departure Release Capability, a system designed to improve en route departure scheduling. FAA human factors research also promotes safe and efficient surface operations. It supports procedures, equipage, training, and design to enable enhanced aircraft spacing for surface movements. In 2011, the FAA identified strategies for integrating Cockpit Display of Traffic Information (CDTI) with synthetic and enhanced vision displays to facilitate flight crew recognition and response to ground obstacles and other aircraft posing collision threats. This work directly complements a FAA/NASA/industry partnership to apply these technologies toward reducing weather minimum requirements for instrument approaches (see discussion below). FAA research will also evaluate and recommend minimum display standards and operational procedures for use of CDTI to support pilot awareness of potential ground conflicts and to support transition between taxi, takeoff, departure, and arrival phases of flight.

Goal 5 is to develop expanded manned and unmanned aircraft system (UAS) capabilities to take advantage of increased air transportation system performance. Increased use of UAS in the NAS poses a number of human factors research challenges related to system development and integrated operations. NASA and the FAA are working together with other government agencies to support integrated UAS operations in the NAS. As part of this effort, NASA and the FAA are exploring human-system integration issues related to requirements for ground control stations, separation assurance, and certification.

Aviation Safety

The National R&D Plan has three goals under Aviation Safety:

- Goal 1: Develop technologies to reduce accidents and incidents through enhanced vehicle design, structure, and subsystems
- Goal 2: Develop technologies to reduce accidents and incidents through enhanced aerospace vehicle operations on the ground and in the air
- Goal 3: Demonstrate enhanced passenger and crew survivability in the event of an accident.

The FAA and NASA conduct human factors research to support Goals 1 and 2. FAA also addresses Goal 3 in its core aviation safety research program.

FAA and NASA human factors research promotes system design and flight crew and controller operations that complement human performance capabilities and accommodate their limitations. As with other areas of the human factors portfolio, the FAA emphasizes near- and mid-term applications, while NASA generally focuses on the mid- to far-term timeframe. These tendencies are not absolute, however, and the FAA and NASA typically work together on areas of common interest. In one example (discussed below), NASA worked with the FAA and industry partners on mature flight deck technology to promote safe, lower visibility operations.

FAA research defines human and system performance requirements for design and operation of aircraft and air traffic control (ATC) systems. The FAA completed research to analyze likely human factors implications and recommend mitigation strategies for improving flight-crew-automation performance. This research included activities to reduce the potential adverse effects of adaptive, non-deterministic flight deck automation. In 2012, the FAA will complete initial research to evaluate and recommend procedures for negotiations and shared decision making between pilots and controllers.

The FAA also performs research supporting procedures, training, display, and alerting requirements that facilitate planned and unplanned transitions between NextGen and legacy procedures. FAA human factors research develops and applies error management strategies, mitigates risk factors, and reduces automation-related errors with the aim of identifying and managing the risks posed by new and altered human error modes in the use of NextGen procedures and equipment. In 2010, the FAA identified equipment categories for legacy flight deck avionics to support human factors evaluations of use of these systems in NextGen flight procedures. FAA research is working to increase pilot weather situational awareness through common, accurate, and real-time weather information. In 2011, the FAA identified, validated, and documented data communications system attributes that may affect use of weather in the cockpit. Researchers will simulate, test, and evaluate cockpit use of weather decision support tools, including probabilistic forecasts.

NASA human factors research has completed several simulator studies to address new flight deck systems that support safe flight planning under advanced NextGen Trajectory-Based Operations (TBO). Within this environment, NASA designs and evaluates flight deck displays and other human interfaces under anticipated conditions, including uncertain trajectory prediction, nearby hazardous weather, and highly congested airspace.

Supporting today's flight operations, NASA collaborated with the FAA, Gulfstream, and Honeywell to evaluate the use of synthetic and enhanced vision systems during instrument approaches under low-visibility conditions. Synthetic vision, originally studied by NASA as foundational research over a decade ago, has the potential to greatly improve pilot situational awareness and aircraft control under high workload conditions. Complementing these efforts, the FAA completed research on issues experienced by pilots and controllers in use of the Navigation Reference System (NRS), which is an enabler for TBO, and developed recommendations to mitigate these issues. The FAA will continue human factors research to enable enhanced aircraft spacing for surface movements in low-visibility conditions guided by enhanced and synthetic vision systems, as well as cockpit displays of aircraft and ground vehicles and associated procedures.

NASA has also developed several toolsets to model expected pilot response during flight operations, allowing designers to explore human-system interactions. Other tools enable pilots to become aware of their own degraded states (such as fatigue) during flight. Early versions of an operator state tool suite have been tested in simulation and flight. NASA is also providing airlines with human factors design guidance to support checklist development. The FAA developed a Human Automation Relationship Taxonomy as part of a tool for FAA field office analysis of human-automation interactions in support of aircraft equipment certification and operational approval for flight procedures in the NextGen operational environment. In 2012, the FAA will initiate research to assess pilot performance in normal and non-normal NextGen procedures, including single-pilot operations.

Addressing a longer-term objective supporting safe operations, NASA has an extensive ongoing effort in the safety assurance of highly complex systems. This work focuses on four major areas: supporting argument-based safety cases, ensuring properly allocated authority and autonomy between humans and automated systems, preventing undesirable dependencies between distributed systems, and developing formal methods to address software errors early in the development lifecycle. The second of these areas (authority and autonomy) directly addresses human/automation functional allocation, an initial focus area within the HFRCP and an area emphasized within the *National R&D Plan*. NASA research in this area is developing tools to validate and verify that complex human/automation systems provide clear decision making authority structures under all conceivable scenarios. NASA will work closely with the FAA on developing these tools to ensure their viability toward safely reducing the time needed to certify new systems and operations.

NASA is making significant contributions to a community-wide effort to promote energy state awareness and stall recognition and recovery. This effort aligns with the *National R&D Plan* objective of developing capabilities that allow recovery from flight upset conditions. Working with Boeing, the Navy, the FAA, and other partners, NASA conducted extensive piloted simulator evaluations of enhanced aerodynamic models that accurately portray flight in extended envelope conditions, including full aerodynamic stall. Developed by NASA and Boeing, these models will fill a critical gap in current simulator capabilities used to train pilots. NASA provided the models and training guidance to a FAA Aviation Rulemaking Committee and the International Committee on Aviation Training in Extended Envelopes.

Best Practices

The progress toward NextGen human factors goals discussed above directly benefitted from FAA and NASA's continued development of cross-agency best practices in coordination. The FAA and NASA together employ best practices to coordinate research activities and identify opportunities for joint work. Joint research efforts are included as part of the research results reported in the Appendix. Potential overlaps are avoided through these key activities including participation in respective program reviews, collaboration in technical conferences, and use of Research Transition Teams (RTTs).

During 2011, the FAA and NASA improved their coordination by increasing participation in each other's program reviews of results and plans. Personnel from the FAA Human Factors Division participated in the Technical Interchange Meetings (TIM) for the NASA Airspace Systems Program (ASP) and Aviation Safety Program (AvSP). The TIMs provided a venue to actively discuss key research issues needed to safely implement NextGen. An FAA human factors expert participated as a member of the NASA Independent Review Panel (IRP) to evaluate the fiscal year 2011 Aviation Safety Program. NASA senior leadership is a member of the FAA Research, Engineering and Development Advisory Committee (REDAC), other senior executives are members of the REDAC Subcommittees for Aviation Safety (SAS) and NAS Operations, and a human factors expert participated as a member of the REDAC Human Factors Subcommittee. These subcommittees reviewed the FAA NextGen flight deck and ATC human factors programs, the operations concept validation program, and the weather technology in the cockpit program. The exchange resulted in a better understanding of the complementary goals and the human factors portfolio of the two agencies and promoted sharing of research best practices, expertise, and facilities.

FAA and NASA collaborated on research in 2011 by participating in international technical conferences. During 2011, this included the premier 2011 Air Traffic Management Seminar held jointly with the European aviation research community. In addition, the agencies coordinated with the International Symposium on Aviation Psychology (ISAP) on special joint sessions to share research with the broader human factors community. NASA also participated in FAA NextGen Human Factors Reviews in January and September 2011, during which R&D program and project plans were presented along with a special session on human factors associated with UAS.

Both agencies commemorated the success of a NextGen technology transfer initiative between the FAA and NASA. The RTT is an interagency structure that enables the two agencies to collaborate on technology transition. The RTT completed in 2011 focused on NextGen work toward flow-based trajectory management (FBTM) and yielded multiple refinements of the FBTM concept, developed prototype multi-sector planning (MSP) tools, and led to a major change in MSP thinking. The RTT found that instead of establishing a new, stand-alone strategic air traffic controller position to manage aircraft trajectories across multiple sectors, the FAA can achieve the same benefits by allocating the MSP functions to the current structure of traffic management and en route controllers. NASA simulations identified FBTM capabilities for the FAA to develop and integrate. Research found that the FBTM concept is not only feasible, but is also useful and beneficial. Most importantly, it can support NextGen initiatives toward prospective “best-equipped, best-served” operations that would create incentives for operators to equip their aircraft to take advantage of NextGen capabilities. Research conducted over the past three years at NASA was jointly funded by the FAA and NASA, and drew input from operations personnel in FAA’s en route and systems operations organizations. The FBTM researchers conducted two major human-in-the-loop simulations, each of them simulating operations at FAA en route centers with participation by controllers, traffic managers, and supervisors. In January 2012, the agencies commemorated another success with the official transfer of Efficient Descent Advisor (EDA) from NASA to the FAA as the 3D Path Arrival Management (PAM). In a June 2011 report, the Government Accountability Office (GAO) cited RTTs as an effective cross-agency collaboration practice.

FAA and NASA continue to maintain and promote their respective technical libraries and research databases that serve to help researchers and others develop concepts, establish requirements, identify R&D gaps, determine additional research and engineering considerations, and identify the results of research portfolios. The FAA continues to maintain the on-line *Human Factors Portfolio* (updated monthly) that lists relevant past, active, and proposed human factors R&D projects conducted by government agencies, contractors, and academia, and an *FAA-NASA Research Facilities Database* (also online), which lists FAA and NASA facilities that are available to conduct human factors research.

Key Challenges

The FAA and NASA are making good progress toward addressing important human factors research issues needed to achieve national mobility and safety goals. This progress notwithstanding, both agencies are also keenly aware that several difficult challenges must be overcome in order to achieve the full benefits of NextGen. As part of the collaboration effort, both agencies identified several areas with high technical risk that require special attention. These key challenges represent some of the most difficult, complex, and important human factors problems confronting NextGen implementation.

To achieve the capacity and efficiency goals of NextGen, the modernized system will become increasingly more automated on the ground and in the air. Human factors research is working towards automation systems that adapt to, compensate for, and augment the performance of the human, enabling both pilots and air traffic controllers to operate safely with increased efficiency. The increased use of automation to enable NextGen creates a significant technical risk in system complexity. Ultimate success of NextGen will depend on development of new verification and validation methods to demonstrate safety of complex interdependent systems. Achieving NextGen involves a quantum leap from the complex flight decks of today to dependent, multi-aircraft operations that rely on extensive interactions between advanced automation systems and humans in aircraft and on the ground. These interactions will involve both piloted aircraft and UAS. FAA and NASA will continue efforts to develop capabilities to demonstrate safety of distributed air/ground systems and assure proper human/automation interaction. The agencies have taken early steps to apply these capabilities to complex experimental air/ground systems and airspace operations.

To support the increased use of automation in NextGen, FAA and NASA must understand the allocation of functions, or roles and responsibilities, between the air traffic controller, pilot or flight crew, and automation systems in the air and on the ground. FAA and NASA are working together on functional allocation research to identify the roles of human and machine in the air and on the ground to provide integrated solutions for traffic conflicts, metering, and weather avoidance and to provide recommendations for procedures on negotiations and shared decision making between pilots and controllers. Research will include a series of human-in-the-loop simulations (HITLs) of increasing complexity with higher traffic densities and mixed equipage operations in nominal and off-nominal conditions. Research in human-automation operating concepts will analyze cognitive workload, situational awareness, performance under different concepts of operations, and roles and responsibilities of controllers and pilots. Initial research is in the laboratory, but ultimately it will progress to a partnership with industry using actual systems in a relevant environment. NextGen is a complex safety system including humans and machines, and it has significant interest across many industries, in addition to aviation.

Human error contributes to accidents and incidents; however, assessing the human component of risk and estimating the associated impact on the NAS is complex and inconsistently implemented across safety management system processes. Improving the integration of human factors in safety assessments requires research to support enhancements to current processes such as in the classification of human factors related causal factors; standardization of data collection efforts, sources and results; creation of tools and techniques for quantitative and qualitative human reliability assessments; and development of shared human factors methodologies for integration with operational data or larger system models to create NAS-wide views of risk.

FAA and NASA will continue to work together on human factors research to facilitate technology transfer. FAA is working to standardize human factors readiness to determine when user interfaces are mature enough for transition to implementation and to track and report lessons learned from practitioners from each evaluation to improve future research products.

Conclusion

This report demonstrates how the FAA and NASA are using human factors research to achieve NextGen. The FAA and NASA reviewed human factors research results and plans, evaluated progress within a framework of complementary goals, and identified key challenges. The FAA and NASA will continue working together, making progress on key challenges for NextGen, and ensuring the right mechanisms are in place for continued effective coordination. As a commitment to continual improvement and to ensure sustained progress toward national goals, the FAA and NASA will regularly refine their strategies toward human factors research coordination.

The nation's air transportation system depends on people – from pilots and air traffic controllers to technicians and ground maintenance personnel. Every aspect of NextGen must be developed with humans in mind, and address how humans' abilities, characteristics, and limitations interact with the design of the equipment they use, the environments in which they function, and the work they perform. The overall goal of the FAA and NASA human factors research is to enhance human-machine performance to make the system safer and more efficient.

Appendix A: Research Results and Plans

In February 2011, the JPDO published the joint FAA and NASA HFRCP to further coordinate human factors research efforts. In response to that plan, the agencies have produced this status report to discuss progress toward major human factors research goals needed to support NextGen. This Appendix highlights selected research results and plans for developing and transitioning to NextGen by focusing initially on the following human factors research areas identified in the HFRCP. These areas are referred to as Initial Focus Areas (IFAs):

- Workforce Development
- Workstation Requirements
- Safety Assessment and Management of Risks
- Ground Operations Optimization
- Traffic Flow Management and Collaboration
- Human Interaction with Technology and Automation
- Human Automation Functional Allocation
- Procedure Design and Training
- Trajectory-based Operations
- Air/Ground Integration

The IFAs are a synthesis of the human factors issues that FAA and NASA research currently address, and they highlight the range of challenges posed by new NextGen technologies, automation, procedures and NAS actor roles. The following highlights include more than 90 results and plans produced by FAA and NASA human factors related research. Over 30 of these activities were conducted by NASA working jointly with FAA operational and research offices, and appear exclusively in the joint columns. Table 1 provides a detailed summary of the number of results and plans under each IFA. The highlights included in this Appendix and summarized in the table reflect several considerations including differences in roles and responsibilities between the FAA and NASA and their areas of research emphasis.

	Initial Focus Area (IFA)	Results				Plans				Total
		NASA	Joint	FAA	Subtotal	NASA	Joint	FAA	Subtotal	
1	Workforce development		1	1	2			3	3	5
2	Workstation requirements		1	9	10		2	2	4	14
3	Safety assessment and management of risks	1		2	3	3	2	3	8	11
4	Ground operations optimization		1		1	3	2		5	6
5	Traffic flow management and collaboration		6	1	7		4	1	5	12
6	Human interaction with technology and automation	5	4	2	11	4	2		6	17
7	Human automation functional allocation	4	2	1	7	1		1	2	9
8	Procedure design and training	2	2	1	5			2	2	7
9	Trajectory-based operations	3	1		4	2		1	3	7
10	Air/ground integration	1	1		2		1	2	3	5
		16	19	17	52	13	13	15	41	93

Table 1: Highlights of Human Factors Research Results and Plans

1. Workforce Development

Workforce selection and training research helps to identify new skills, knowledge, and abilities that will be needed by NextGen controllers, maintainers, and pilots. The primary focus is on the changing role of NAS operators in the NextGen environment. For example, the strategic job analysis helps to predict how the job of the controller will change in the NextGen environment. Results enable modifying the controller selection criteria and process to match the needs of the new job, if necessary, and identification of impacts to required training. The strategic training needs analysis investigates NextGen controller and maintainer training needs in order to ensure that training needs for those individuals are identified well in advance of the introduction of new technologies, policies, and procedures.

Results:

- **Multi-Sector Planner [NASA and FAA]:** Controller-in-the-loop studies investigated the feasibility and potential benefits of an Air Route Traffic Control Center (ARTCC) multi-sector planner (MSP) position for applying strategic flow management initiatives at the aircraft level. Results suggest that the benefits of multi-sector planning (efficient, conflict-free solutions that respect sector traffic limits) can be obtained by adding the capabilities to existing positions without requiring a separate MSP position. NASA transferred these results to the FAA as part of the Flow-Based Trajectory Management Research Transition Team (RTT). Findings from this study contributed to the successful completion of the RTT.

- **Impact of NextGen on the Air Traffic Control Specialist (ATCS) Occupation [FAA]:** The FAA investigated the impact of mid-term NextGen technologies and procedures on the profile of abilities and aptitude required to enter the ATCS occupation. The initial focus was on the tower cab working environment. Results showed that new capabilities will supplement human perception, but controllers will remain responsible for the same major job functions they currently perform and are likely to continue relying upon their own perceptions and judgments, perhaps looking to the automation to confirm a course of action. Given that the overall functions to be performed by controllers are unlikely to change by the mid-term, the profile of aptitudes required to perform those functions is unlikely to change. However, not all of these aptitudes are represented in the current ATCS test battery, therefore development, validation, and implementation of measures of these aptitudes are needed to address mid-term NextGen tower cab aptitude requirements.

Plan**:**

- **NextGen Human Factors Technical Operations Research [FAA]:** Investigations will be conducted to support three derived NextGen Human Factors Technical Operations research goals: enhancing personnel development and utilization, improving support services and engineering infrastructure, and developing advanced support services and engineering management infrastructure. This research will be part of a contributive effort to develop and deploy a common, real-time decision support environment that maximizes the effectiveness and efficiency of technical operations personnel resources and extends beyond the technician to support the decision needs of users beyond the maintenance realm.

- **Strategic Job Analysis Database [FAA]:** Research will be conducted to provide the scientific foundation for the continued evolution of the controller selection procedures in accordance with relevant guidelines, standards, principles, policies, and practices. The starting point for the analysis is the job as it is performed today, with existing technologies and procedures.

- **Strategic Training Needs Analysis [FAA]:** Following on the findings of the Strategic Job Analysis, the Strategic Training Needs Analysis project involves identifying the training requirements needed to support these responsibilities. The training needs analysis will begin with identifying the total scope of training that would be required for the controllers in the NextGen Midterm environment.

2. Workstation Requirements

Workstation functional and design requirements research focuses on improving the operations of air traffic controllers and technical operations, as well as pilots, to ensure the envelope of human performance is considered as part of safety, capacity, and performance goals. It does this by developing workstation requirements that improve human system integration in a way that allows air traffic service providers, in concert with pilots and others, to move air traffic cooperatively and efficiently. This is accomplished by focusing on the tasks to be performed, the information required, and the measured enhancement to performance. These objectives encompass the requirements for the mid-term integration of NextGen workstations for en route, TRACON, and tower, as well as the far-term common NextGen workstations. This also includes integration of advanced avionics as part of flight deck systems.

Results:

- **Compression Monitoring and Terminal Conflict Alert [NASA and FAA]:** Researchers conducted simulations to determine the best of three compression monitoring models (dead reckoning, three-segment, and five-segment) for today's automation over many terminal areas, airports, flights, and days. NASA verified that the three-segment deceleration model for compression monitoring consistently has the best probability of detection. NASA successfully transferred the three-segment deceleration model to the FAA for implementation in the Automated Terminal Proximity Alert (APTA) tool. Results indicated controllers felt that Terminal Tactical Separation Assurance Function (T-TSAFE) with altitude entry provided the most adequate time to alerts with the least number of false alerts and felt that the suggested altitude resolutions were useful and acceptable. T-TSAFE has higher acceptability and better user interface than the collision avoidance model. Altitude entry increased awareness without significantly increasing workload, while altitude resolutions received high scores on usefulness and acceptability.

- **Future En Route Workstation (FEWS) [FAA]:** The FEWS III simulation provided an initial assessment of the feasibility and benefits of three concepts that are designed to increase airspace capacity to meet NextGen goals. The concepts included the increased use in certain situations of Area Navigation (RNAV) routes, delegation of self-spacing to the flight deck, and an aircraft grouping procedure that enabled two or more aircraft to be controlled as a single unit. The results indicated that participants managed more aircraft, reported lower workload, and held aircraft less when using the FEWS system. They also managed more aircraft when aircraft were adhering to RNAV routes that had both lateral and vertical conformance constraints regardless of which system they used. The participants reacted positively to the self-spacing concept, but did not find the grouping concept useful as it was executed during the simulation.

- **Data Communications (Data Comm) [FAA]:** Data Comm is a key enabler of NextGen, and validating its design is crucial to implementation and usability. The En Route (ER) Data Comm Human Factors Team implemented requirements for three different user interfaces for a Human-In-The-Loop (HITL) experiment. Results showed the most useful input mode was a Human-Machine Interface combining keyboard, template, and graphical capabilities. Increasing levels of Data Comm equipage reduced voice communications and led to a reduction in workload. Equipage level did not affect workload in all controller tasks equally and it did not matter as much to the Data Controller (D)-side as it did to the Radar Controller (R)-side. The lack of FMS integration did not affect the number of voice communications, but it did increase controller workload. The ER Data Comm team used these findings and others to provide recommendations to improve future systems.

- **Common Automation Platform (CAP) [FAA]:** The FAA is planning for development and implementation of a single workstation configuration, the CAP that will provide the information and functional capabilities needed for both en route and Terminal Radar Approach Control (TRACON) air traffic control tasks. The initial step was to develop a set of human factors requirements regarding the design of a CAP. The research team identified and documented requirements for an initial CAP mock-up workstation and initiated the *CAP Mock-up Workstation Requirements* document, which will serve as a framework upon which all further CAP workstation requirements can be documented. Future mock-ups and evaluations are planned and will build on this effort. Also, coordination started for the purpose of aligning this project with the NAS Enterprise Architecture Automation Roadmap.

- **En Route Controller Workstation Requirements [FAA]:** The FAA sought to define the functional requirements and develop the corresponding roadmap of research needs for the Segment Bravo en route controller workstation which is scheduled to be operational in the 2018 time-frame. The functional requirements development will depict new workstation functions, but will not address the corresponding Computer-Human Interface (CHI) design specifications. In 2010, initial decompositions of the Segment Bravo OIs, Future En Route Workstation Study were conducted. The decomposition process identified the purpose, key assumptions, required controller functions, required workstation capabilities for information and decision support tools, system benefits and benefit creating mechanisms, and human factors issues. The decomposition results were combined into a matrix framework for further detailed analysis and for an integrated assessment of impacts of future workstation capabilities drivers.

- **Functional Requirements for Integrated Workstations [FAA]:** The FAA investigated the concept of Integrated Workstation requirements to develop functional design requirements for an integrated workstation and its operation, based on NAS Enterprise Architecture (EA) OIs. Based on detailed cognitive task analyses of controller and traffic management positions, researchers identified the specific impact each OI would have on completing each controller goal. The OI impact statements were then organized into aggregated "capabilities" statements. Operator tasks and integrated workstation function descriptions were identified through capabilities statements. From these descriptions, the research team is writing the first draft of human factors functional requirements for integrated workstations. The next step is to obtain data that is critical for functional requirements validation using low-fidelity human-in-the-loop simulations and fast-time simulations. The ultimate goal of this effort will be to deliver requirements to relevant FAA program leads (e.g., requirements manager, program manager, technical lead, and solution set coordinator).

- **Future Terminal Workstation (FTWS) [FAA]:** The FAA developed the FTWS as a prototype approach control workstation to improve ATC performance and safety and incorporate NextGen changes. Design goals included using human factors best practices, keeping controller workload manageable, and reducing human error. Three design variations were tested with minimal performance differences observed, but large differences in controller behavior. Area navigation routes provided the largest workload savings. Data Comm was useful in arrival and departure sectors, but not for the final approach sector. Automatic Dependent Surveillance-Broadcast (ADS-B) did not affect capacity compared to high levels of radar coverage. Finally, researchers identified problems with the route conformance and relative spacing tools, and found some new tools affect the usability of other tools.

- **Impact of NextGen Segment-Bravo Operational Improvements on ATC [FAA]:** The FAA attempted to determine the human performance impact of NextGen Segment-Bravo OIs and associated enablers. Researchers worked with subject matter experts to evaluate the OIs in isolation, followed by a prioritization of the OIs in terms of their impact on controller performance, and discussions of the overall impacts of the concepts when used in synchrony. In addition, a catalog of nominal to emergency events for three operator positions was compiled. The events are being used as the basis for storyboard generation, which are intended to illustrate the impact of integrating all of the different operational improvements into ATC operations, and can address issues of implementation.

- **Digital-Taxi (D-Taxi) [FAA]:** Researchers looked at air traffic control concepts relevant to the Data Comm program, and examined the use of D-Taxi clearances for departure aircraft under three levels of data link equipage (Voice Only, 40% Data Comm, 75% Data Comm). In the simulation, study sixteen current controllers assessed the effects of D-Taxi on controller communications, workload, and performance. The primary findings were that D-taxi reduced ground control radio frequency usage, was preferred by the controllers because it reduced their communication responsibilities and removed the potential for read back and hear-back errors, and it did not negatively affect surface operations. The FAA will use the results from this experiment to develop and refine technical and human performance requirements for implementing D-Taxi, and to develop a cost-benefit analysis that can inform future decisions regarding Data Comm funding and deployment.

- **Staffed NextGen Towers (SNT) [FAA]:** The final field demonstration of SNT at Dallas Fort Worth International Airport (DFW) provided controllers an opportunity to evaluate the SNT concept using the Tower Flight Data Manager prototype in shadow-mode using live traffic. The SNT concept improves capacity limitations during low visibility and night conditions, maintains safety, and provides for cost-effective expansion of services as future traffic demands increase. The concept represents a paradigm shift from using the “out-the-window” view as the primary means for providing tower services to using surface surveillance approved for operational use. The field demonstration evaluated the suitability and acceptability of using cameras to augment visual information for supplemental operations and obtained valuable controller input regarding the use of cameras for contingency operations. The same controllers also participated in a HITL simulation using a controlled experimental design that examined additional camera capabilities for supplemental and contingency operations in a controlled environment. The FAA continues to analyze the data collected during these events so that they may drive further refinement of the concept.

<u>Plan</u>**:**

- **Location and Grouping of NextGen Displays [NASA and FAA]:** Initiate research to develop recommendations for the location and grouping of NextGen related displays relative to the primary field of view. This product will enable aircraft certification specialists to develop guidance for display location, grouping, and configuration of associated interfaces based on analysis of new flight crew tasks and responsibilities and experimental results.

- **Workstation Development and Requirements Definition [NASA and FAA]:** In FY12, researchers will have completed development of scenarios, storyboards, and initial functional requirements and will likely begin simulations to test and verify requirements and scenarios. Three workstation efforts along with automation and Collaborative Air Traffic Management (CATM) work will begin to tie together in end-to-end evolutions which inform workstation development and requirements definition underway by the Service Units (Tower, TRACON, En Route, etc).

- **Air Traffic Control Human Factors Challenges of Integrating Unmanned Aircraft Systems (UAS) [FAA]:** An effort is planned to identify future ATC Human Factors issues due to the integration of UAS in the NAS. This project will identify previous, ongoing, and planned research pertaining to these issues and develop a Human Systems Integration Plan (HSIP) which closes research gaps identified in the process. In FY11, this effort began the identification of research gaps and UAS integration issues. This process continues into FY11-12 as the HSIP identifies research targets, coordinating activities, and integration concepts developed by the Concept Development office.

- **Concept of Operations (ConOps) for the Integration of Unmanned Aircraft Systems (UAS) into the NAS [FAA]:** Efforts will be initiated to develop a ConOps for the integration of UAS into the NAS and to develop the framework for research to assess concept feasibility, relationship to other NAS concepts, and implementation in the operational environment. This document will present the vision for how UAS will be integrated into the NAS and will also provide the high-level requirements for services, systems, technologies, tools, procedures, and training. The focus is current and anticipated prevalent UAS types, described in terms of performance and mission, flying in all classes of airspace, from an air traffic management perspective. Operational scenarios will be included to illustrate the concept.

3. Safety Assessment and Management of Risks

Safety risk research develops and evaluates new methods that allow credible safety evaluations of highly complex, automation-intensive systems. Methods contribute to formal validation and verification of separation assurance operational concepts and DSTs. It involves safety assessments across different phases of flight across different levels of mixed-equipage aircraft and for off nominal scenarios. In addition, risk and error management research investigates opportunities for pilot error with the introduction of NextGen automated systems and procedures and the associated pilot roles and responsibilities. Examples of research results include recommendations for design standards and development of evaluation tools that identify and mitigate errors.

<u>Results</u>:

- **Laboratory Integration of Multiple Separation Assurance (SA) Algorithms into Simulation Test Beds [NASA]:** Research addressed the need for the ability to evaluate algorithms in an integrated fashion, including:
    - Testing ground-based strategic, tactical, and TCAS algorithms together
    - Testing airborne strategic, tactical, and TCAS algorithms together
    - Testing ground-based and airborne SA algorithms together
    - Testing ground-based strategic algorithms working in adjacent airspace regions (to probe boundary conditions).

  These integration studies require a test bed that is capable of operating the respective algorithms and will enable research to span a diverse set of aircraft types and weights with corresponding differences in performance and wake turbulence criteria. Results include full documentation of the Autonomous Operations Planner (AOP) and conflict detection and resolution algorithms. The documentation will facilitate technology transfer for separation assurance.

- **NextGen Solutions to Current NAS Problems [FAA]:** The FAA began identifying current problems within the NAS in order to associate them with proposed NextGen solutions (i.e., OIs). Over 1000 relevant reports filed by air traffic controllers over a four-year period have been identified in the Aviation Safety Reporting System (ASRS) public database. These reports are being analyzed to determine if proposed NextGen solutions address current problems.

- **Conflict Resolution Advisories (CRA) Project [FAA]:** The effort completed the third in a series of mini-evaluations to support development of an en route capability to aid controllers in formulating more efficient clearances while maintaining separation. The enhanced automation reduces controller workload through pre-probed altitude and speed amendments and other functionality to maintain safety when confronted with the predicted increases in traffic volume. The project uses an incremental approach to implement conflict resolution advisories, first over voice and data communications, and ultimately over data communications when equipage permits. Air traffic controllers participated in the simulation trials to assess the operational acceptability and usability of the CRA *search all*, *altitude*, and *heading* menus. The evaluation also investigated the projects' associated procedures, algorithms, and benefits. Participants found the tool to be operationally acceptable and to be capable of providing benefits to the ATM system. A HITL simulation will be conducted during 2012 to evaluate the utility of the CRA tool.

Plan:

- **Laboratory Integration of Multiple SA Algorithms into Simulation Test Beds [NASA]:** The research plan is to conduct high fidelity evaluation of single airport operations using medium-term technologies and conduct advanced separation assurance simulation with mixed operations airspace under nominal conditions. The research objective is to identify, analyze, and validate hazards inherent to SA systems and concepts by methodically applying relevant safety-assessment techniques.

- **Verification and Validation of Airborne Self-Separation Procedures [NASA]:** NextGen may re-allocate some functions between the ground and the aircraft in order to increase capacity. The system includes distributed agents of differing levels of capability and authority in terms of computation, communication, and control. Fault models for agents can be complex with differing timing properties. The goal of this research is to develop composable, reusable models for formal analysis of distributed agents in the self-separation/merging air traffic management problem and to develop validated fault models (and scenarios) for communication, computation and control elements in the Air Traffic Management (ATM) separation context. The goal is to be able to assure safety and ascertain the level of graceful performance degradation in the context of both transient and sustained faults. This will be achieved by documenting and assessing all environmental, startup, and interface assumptions in terms of realistic operating conditions. Verification and validation of NextGen operations is important in order to prevent unforeseen safety consequences of distributing authority to a diverse set of operators.

- **Integrated Model Checking and Simulation of NextGen Authority and Autonomy [NASA]:** NextGen requires humans and automation interacting with flexibility in allocation of Authority and Autonomy. The plan is to develop an integrated suite of simulation, model checking, and trace analysis tools driven by models describing the interaction and capabilities of human, automated agents, and environmental factors. The goal of this research is to develop needed methods for verifying and validating distributed autonomous, semi-automated air and ground systems. Results to date include Continuous Descent Arrival (CDA) scenarios, top-level unified language (multi-method analysis, formal semantics), and data abstractions and hybrid systems methodology. This work is being done in partnership with the University of Virginia.

- **Human Error and Unintended Uses of NextGen Systems [NASA and FAA]:** Develop guidance to support certification personnel in evaluating risks and mitigation of human error and potential unintended uses of new technology in NextGen systems and procedures.

- **Traffic Alert and Collision Avoidance System (TCAS) in NextGen Procedures [NASA and FAA]:** Conduct initial research to evaluate the impact and potential risks associated with use of TCAS in NextGen procedures. This research will help provide recommendations for minimum design characteristics for improved TCAS function and operating procedures to enable aircraft certification and flight standards specialists and Air Traffic Operations (ATO) personnel to approve flight deck equipment and procedures, and develop operating limitations and guidance for TCAS use in NextGen applications.

- **Strategies to Identify and Mitigate Human-System Errors [FAA]:** Continue research to develop risk and error management strategies to identify and mitigate human-system errors. Research will help provide flight deck design guidelines and recommendations based on results of safety analyses and review of NextGen operational procedures to support aircraft certification and flight standards specialists who will develop minimum design requirements and procedures for NextGen applications, enabling multiple NextGen OIs.

- **Human Hazard Assessment [FAA]:** A Segment Bravo activity will focus on a human performance hazard analysis of NextGen Segment Bravo capabilities. A documented hazard analysis will identify specific NextGen OIs and increments that have an impact on the safety aspects of human performance in the NAS. The effort will identify:

  - New capabilities and functions that are introduced as a result of NextGen Segment Bravo
  - Hazards that stem from human performance or human error
  - New capabilities that erode the current level of safety
  - New human error modes that are introduced by NextGen technologies, techniques, or procedures.

- **Human Performance Effects of NextGen OIs [FAA]:** Researchers will assess the human performance effects associated with NextGen Segment-Bravo OIs, along with associated enablers. The purpose of this activity is to inform OI selection for maximum capacity increases in the NAS through strategic implementation of OIs at specific times. To gain this insight, the human performance impact of each OI must be investigated and understood, as well as the cumulative effect of multiple OI combinations.

4. Ground Operations Optimization

Ground operations research addresses pilot and controller situational awareness in the use of NextGen capabilities during imprecise surface movements for improved operations in all visibility conditions. Research focuses on human capabilities and limitations with regard to improvements to NextGen flight deck equipment displays and airfield signage/lighting during low visibility ground 25 operations. It examines the use of coordinated, optimized trajectory-based paths supported by high precision taxiing and conformance monitoring.

Results:

- **Evaluation of SEVS for NextGen [NASA and FAA]:** Limited awareness of runway environment in low visibility has led to weather minima that must be overcome for NextGen, and it is unknown how much these minima can be safely reduced when Synthetic/Enhanced Vision System (SEVS) capabilities are onboard. The goal of this research was to conduct flight operations in actual low visibility conditions to confirm or reject results of a pilot-in-the-loop simulation study regarding the operational feasibility, pilot workload, and acceptability issues of using SEVS in low visibility. A team led by NASA and consisting of FAA, Gulfstream, and Honeywell developed a complex flight test plan and system to enable rapid testing using a G-450 and operating in low visibility environments across the U.S. The first test flight was completed the summer of 2011, in reported quarter-mile visibility at Shenandoah Valley Regional Airport (KSHD) in Staunton, Virginia. To date, eight evaluation pilots have flown 65 approaches to 46 touchdowns, with 46 using Enhanced Flight Vision System (EFVS) and 19 using Synthetic Vision (SV), and at Runway Visual Ranges (RVRs) between 600-1200 feet. Testing is 65 percent complete. These are the first ever flights of this kind. The results will be used to define new RTCA standards, FAA rulemaking, and airport infrastructure needs for low visibility operations supportive of NextGen.

Plan:

- **Ground Operations Integration [NASA]**: A Better than Visual ConOps was developed following extensive research and development of enabling systems such as SEVS, EFVS, surface traffic displays, runway incursion alerting functions, as well as Advanced Surface Movement Guidance and Control Systems (A-SMGCS) concepts for surface guidance, control, and ATC interfaces. Ongoing research develops methods of seamless integration of these concepts with those for takeoff and approach/landing within a NextGen context.

- **Surface Technology Enhancements – Gate-to-Runway Conformance [NASA]:** NASA completed initial surface scheduling capabilities, and researchers will continue to develop further enhancements to increase gate-to-runway conformance. Enhancements will address efficient runway assignment scheduling algorithm development, fast-time capability to conduct trade-offs, electronic flight strips, hybrid closed loop and HITL simulation capability and adopting the Spot and Runway Departure Advisor (SARDA) tool to multiple airports.

- **Surface Technology Enhancements – Conflict Detection and Resolution (CD&R) [NASA]:** Researchers will evaluate aircraft-based CD&R algorithms via fast-time simulations, looking at the effect of position accuracy, levels of CD&R equipage, and directive alerting. In addition, researchers will develop flight deck capability to maintain and monitor trajectory conformance during surface operations. The next steps include completing a data analysis of NASA algorithm (currently underway), collecting data for Surface Indications and Alerts (SURF IA) algorithm in FY12, and beginning integration of CD&R and conformance monitoring capabilities.

- **Enhanced Flight Visibility System (EFVS) Head-Up Display (HUD) Clutter and Masking [NASA and FAA]:** Research will be conducted to evaluate the effects of EFVS HUD clutter and masking on detection of potential ground conflicts during taxi operations across a range of visibility and lighting conditions and develop recommended mitigations. Flight Standards is incorporating human factors research results into its rulemaking data package as operational credit for SVS and EFVS flight deck technologies are evaluated as part of the NextGen initiative to increase airport access and operations for approaches, departures, and taxi operations in low visibility conditions. Additional research is evaluating the use of these technologies in surface conditions as low as 300 RVR.

- **Mitigating Effects of Position Uncertainty in All-Weather Ground Operations [NASA and FAA]:** Conduct research to provide and evaluate alternatives and recommend minimum acceptable cockpit display method(s), alerts, and operational procedures to mitigate the effects of position uncertainty when degraded positioning information or other system failures introduce position uncertainty in closely-coupled all-weather ground operations.

5. Traffic Flow Management and Collaboration

Traffic flow research develops strategies and decision support tools (DSTs) that allow traffic flow managers to minimize disruptions caused by hazardous weather and to enhance collaborative decision making (CDM). It addresses sub-optimal strategic flow management decisions by developing modeling, simulation, and optimization techniques to minimize total system delay (or other performance functions) while accommodating increased levels of traffic in the presence of uncertainty.

Results:

- **Precision Departure Release Capability [NASA and FAA]:** Researchers continued the development, evaluation, and transition of the Precision Departure Release Capability (PDRC) and further collaboration with FAA. PDRC is expected to increase system performance and reduce departure OFF time uncertainty through improved en route departure scheduling. An initial field evaluation was completed in July with PDRC displays and NASA observers stationed at Fort Worth (ZFW) ARTCC, Dallas/Fort Worth International Airport (DFW) East Air Traffic Control Tower (ATCT) and the American Airlines Ramp Tower. Primary objectives were accomplished while traffic management coordinators (TMCs) provided positive feedback on system performance and potential benefits.

- **Tactical Runway Configuration Management [NASA and FAA]:** Researchers developed a decision support tool to assist air traffic personnel in the efficient management of airport runways to address runway configuration selection processes and coordinating traffic across runway configurations. The approach was to assess the current state of runway management, determine the information requirements, and evaluate the tool in both simulation and an operational environment. The Traffic Runway Configuration Management (TRCM) Algorithm was developed for configuration management of single airports with multiple runways and the interim algorithm was transferred to the FAA.

- **Controller Support Tools for Schedule-Based Terminal-Area Operations [NASA and FAA]:** A human-in-the-loop simulation was conducted to evaluate advanced controller support tools and display enhancements in terminal airspace. Three main controller support tools were developed and researchers anticipate successively increasing levels of innovation. The associated tool conditions were denoted 'timeline condition,' 'slot marker condition,' and 'advisory condition.' The Super Density Operations (SDO) concept requires precise control to arrival schedules and maintaining high route conformance in order to enable environmentally friendly and more economical Optimized Profile Descents (OPDs). The current study investigated the performance of three successively more advanced trajectory-based controller support toolsets designed to help controllers in achieving those goals. The outcome of the study shows that under the simulated conditions, the tools helped to make the SDO concept viable: subject controllers, in each case, were able to correct runway schedule errors that reflect the application of future en-route traffic management, and avoid spacing violations. Controllers used speed clearances alone, enabling aircraft to execute OPDs while remaining on their Area Navigation (RNAV) routes. The timelines received high usefulness and usability ratings, as did the associated early/late indications. Controllers preferred the slot markers, as they proved effective in translating the time-based schedule information to a spatial target for control.

- **SFO Stratus [NASA and FAA]:** An operational shadow-mode assessment of the San Francisco International Airport GPSM was conducted at the FAA's ATCSCC. The GPSM recommendations would have reduced overall delay by approximately 20 percent this season, a 57 percent reduction in unnecessary delay. Recommended Ground Delay Program (GDP) end times are usually earlier than those implemented operationally, but were achieved with minimal increase in risk. Lessons learned during shadow mode included the need to expect the unexpected in regards to weather type, the need to keep meteorologist-in-the-loop, and the importance of shadow mode.

- **Dynamic Weather Routing [NASA and FAA]:** Researchers completed prototype trajectory automation in Center TRACON Automation System (CTAS)/Future ATM Concepts Evaluation Tool (FACET) with Corridor Integrated Weather System (CIWS) and Convective Weather Avoidance Model (CWAM) weather models to provide improved weather avoidance routes for aircraft in flight. The trajectory automation continuously analyzes flights and finds simple time/fuel saving reroutes. Dynamic Weather Routing (DWR) considers modeled weather, traffic, flying time, and downstream sector loads and is configured for either data or voice communications.

- **Cleveland Airspace Redesign [NASA and FAA]:** In response to changing traffic and staffing conditions, supervisors dynamically configure airspace sectors by assigning them to control positions. The Sector Combining Advisory Algorithm can assist supervisors as they perform this task. Researchers performed a demonstration using the Cleveland Air Route Traffic Control Center (ZOB) redesign of airspace in response to traffic pattern changes. Proposed changes are based on operational knowledge and experience of staff. The revised sectors design provides better distribution of workload. Researchers then performed a quantitative analysis of proposed airspace changes to support data-driven decisions. The results quantified the effects of airspace changes and conducted "before and after" analysis of ZOB airspace configurations, based on analysis of summer 2010 traffic data, including airspace utilization, workload factors, and sector combinations. The sector algorithm validated several of the proposed airspace changes and the results also suggested potentially useful and viable combinations that arose with new Operational Support Service (OSS) designs.

- **Collaborative Air Traffic Management (CATM) [FAA]:** Researchers explored critical human factors issues in CATM, trying to identify how stakeholders can effectively utilize new roles and responsibilities, procedures, decision support systems, communication tools, and new forms of information access to improve performance in the future NextGen environment. Based on detailed operational sequences highlighting CATM human factors issues, storyboards are being developed for conducting cognitive walkthroughs. Cognitive walkthroughs will provide a structured method for understanding how key human factors considerations need to be incorporated into system design. Ultimately, this research will help to define human factors requirements to be applied to the design of ATC systems, including the development of procedures and the definition of policy.

<u>Plan</u>:

- **Precision Departure Release Capability (PDRC) [NASA and FAA]:** Researchers will enhance and extend the PDRC concept, collect quantitative PDRC benefits via operational evaluations, and support transition of PDRC technology to FAA. Enhanced electronic communications and tools will reduce workload and improve overall operator efficiency. Improved situational awareness in the tower, Terminal Radar Approach Control (TRACON), and ARTCC will provide consistent feedback, alerting the operator(s) to changes in operations that affect previously agreed-upon times. The FY12 plans include continuing operational field evaluations and transitioning product delivery to FAA.

- **Tactical Runway Configuration Management (TRCM) [NASA and FAA]:** NASA will develop the user interface, integrate TRCM with the Surface Management System (SMS), and conduct a shadow-mode evaluation.

- **SFO Stratus [NASA and FAA]:** FAA's ATCSCC has committed to integrating GPSM in operational decision-making in the 2012 stratus season for a full evaluation. ATCSCC also to initiate training, procedures, and software enhancement during the winter in anticipation of this start.

- **Dynamic Weather Routing [NASA and FAA]:** NASA will work with American Airlines, Fort Worth Air Route Traffic Control Center (ZFW) at NASA/FAA North Texas Research Station (NTX), and dispatchers, to prepare the system and develop the test plan for an upcoming demonstration of real-time dynamic weather routing.

- **Integrated Arrival/Departure Control Service (IADCS) Toolset [FAA]:** Researchers will investigate and validate the IADCS toolset to examine its benefits on operations during normal and less-than-optimal periods (e.g., inclement weather, periods of high traffic volume). IADCS provides tools to mitigate airborne and ground delays within a specific major metropolitan area (i.e., metroplex), and improve throughput by using dynamic arrival/departure procedures, and associated Arrival/Departure Transition Area route flexibility. The IADCS toolset increases airspace optimization and air traffic procedures to include expanded areas of three mile separation, dynamic sectorization, bi-directional routes/gates, optimized climbs and descents, and ATC assigned routing options. These tools will produce benefits supporting a wide range of Air Traffic Management environments, though most notably within the nation's metroplexes.

6. Human Interaction with Technology and Automation

NextGen technologies encompass research on data communications and human-computer interfaces for NAS actors in the NextGen environment. For example, the research supports the implementation of data communication functions in NextGen. It produces human factors data to determine minimum required data communications display characteristics and flight crew procedures to achieve the desired performance. Sample research results include recommendations for synthetic speech display and data communication procedures, graphical/symbolic display and control alternatives, and identification of potential operator training issues.

Results:

- **Human-Automation Interaction Analysis Tools [NASA]:** Automation designs do not always capitalize on the factors that affect human performance. The proposed NextGen environment may increase the probability that latent human-automation interaction errors will lead to incidents and accidents. The challenge is to develop more robust human-automation systems by incorporating known limitations of human performance into analysis tools. NASA has released the Automation Design and Evaluation Prototyping Tool (ADEPT) human-automation interaction analysis tool for developers world-wide. The ADEPT toolset enables the rapid development of an executable specification for automation behavior and user interaction. More specifically, a design of the system and its associated interface are described in ADEPT in a concise, hierarchical, and tabular form. ADEPT also supports a number of analysis capabilities that help in creating robust designs and prototypes that can be used as requirements for the construction of the actual system implementation. Boeing and Gulfstream have accessed the tool for use in avionics development.

- **Computational Situation Awareness Design Tool [NASA]:** This research incorporates a situational awareness (SA) component into the MIDAS v5 computational human performance model. The goal was to be able to computationally predict SA as a function of the ratio of Situation Elements perceived and comprehended relative to those required/desired to complete a task. Researchers were able to determine three ways in which flight deck display properties influence pilot SA acquisition. Quantitative effects of display properties on SA acquisition were estimated based on empirical human-in-the-loop (HITL) evidence (meta-analysis). Researchers determined that SA decay is an exponential function, similar to Long Term Working Memory, which can be approximated by two linear functions. Decay function was based on HITL SA data. The result was a tool for designers that will help predict how their flight deck display and task designs will impact an operator's situational awareness.

- **Multimodal Information Management [NASA]:** The goal of the research is to answer critical questions on how to best enable interaction with the propagation of audio communications (including synthetic speech) required for autonomous operation within the NextGen environment. Virtual (touch screen) buttons without audio feedback had the worst overall performance (greater number of accidental hang-ups, incorrect button presses, and slowest response times). Both conditions with audio feedback had the best overall performance. Research resulted in progress toward the development of reconfigurable interactive displays, using auditory haptic cueing to support message comprehension performance (speed and accuracy), ensure perceived quality, and minimize workload. The work was in collaboration with University of Michigan and completed in 2011.

- **Hazard and Integrity Monitoring and Integrated Alerting [NASA]:** Research was completed to develop and test new concepts and models for Hazard and Integrity Monitoring (HIM) and Integrated Alerting and Notification (IAN). A preliminary pilot-in-the-loop simulation study aimed to (1) evaluate feasibility, pilot performance, and usability; and (2) verify design tool capability and model results. An experimental system was installed in the Operator Performance Lab (OPL) facility at University of Iowa where twelve ATP-rated test subjects participated. The Experiment was completed on October 6, 2011, with complex use-case scenarios based on Chicago O'Hare International Airport (ORD) operations and with multiple hazards encountered. The results will be used to refine evaluation tool and models and to down-select and refine information integrity and aggregation concepts for second phase of testing to be conducted in FY12.

- **State and Data Visualization [NASA]:** Research develops new methods to enhance human pattern recognition of system events involved in monitoring, fault detection and integration of multiple information sources for discovery of emergent behaviors. Research generated different types of visualizations to correspond to different types of data (e.g. monotonic and non-monotonic functions), and applied these coding principles to two problem areas, visual detection of wiring faults and detection of aircraft trajectory conflicts. It is expected that these visualizations will help human operators interpret large amounts of information more quickly to support decision making. The next step is to confirm the value of these visualizations to that end.

- **Synthetic and Enhanced Vision Flight Testing [NASA and FAA]:** A team led by NASA and consisting of FAA, Gulfstream, and Honeywell conducted evaluation of the safety aspects of using vision system technology for reduced weather minima and developed a complex flight test plan and system to enable rapid deployment of a G-450 to low visibility environments across the U.S. A total of 9 flights were conducted resulting in 38 flight hours of collected data. Eight evaluation pilots flew 107 approaches to 73 touchdowns, with 80 approaches using EFVS and 27 using SVS. Visibility ranged from 600-2400 ft. Testing was completed on October 27, 2011. These were the first ever flights of this kind. Results will be used to define new RTCA standards, FAA guidance and procedures, and airport infrastructure needs for low visibility operations supportive of NextGen. Results will also serve to inform the direction of future VSST research activities.

- **Datalink En Route [NASA and FAA]:** Researchers analyzed the SC-214 datalink message set for use in en route operations. They identified thirty potential problem areas and provided some recommended solutions. The findings and recommendations are being briefed and mitigation strategies and message set changes are being considered as a result. The researchers used their analysis in providing ongoing human factors support to FAA in revision of the message set in ICAO Document 4444, *Procedures for Air Traffic Services, Air Traffic Management*

- **Data Communications (Data Comm) Effects on Situational Awareness [NASA and FAA]:** Researchers investigated the potential loss of situation awareness when switching from radio-based verbal communications between pilots and air traffic controllers (ATC) to Data Comm. Results suggest that some information presented over the party line is important to pilots' situation awareness, and it will be important to find ways to help replace it. Analysis also suggests that Data Comm can increase workload, so the design of the Data Comm interface will need to be done carefully to minimize effects on pilot workload. Additional findings pose that response time to Data Comm messages increases for the flight deck and ATC.

- **Challenges Implementing NextGen on Legacy Flight Decks [NASA and FAA]:** Since NextGen procedures and technologies will likely first be implemented on legacy flight decks now in operation; an analysis was conducted to determine potential challenges when incorporating the new with the old. For each NextGen operational concept and application, the various equipment configurations that could foreseeably be used by participating aircraft was described. Each equipment configuration and the procedural steps that must be carried out by the flight crew in order to use it is also described. Human factors considerations for each of these procedures and for each NextGen operational concept, application, and equipment configuration were presented.

- **Human Factors Guidelines for Automation and Task Aids for ATC [FAA]:** FAA identified existing human factors guidelines and requirements for automation that are directly applicable to near and mid-term implementation of task aids for ATC. Researchers also identified automation application areas where guidelines are needed, but there is insufficient data to support generation of those requirements. The major product of this work was a set of human factors requirements to guide development of automated systems for NextGen. These requirements are organized into categories so that developers and certification personnel can quickly and accurately identify requirements applicable to the automation being considered.

- **Separation Management Project [FAA]:** An effort to establish automation requirements for air traffic controllers to manage aircraft in the en route environment using NextGen separation criteria. Researchers completed a simulation study with 12 air traffic controllers and found controllers thought using variable separation standards depending upon aircraft types, equipment, and radar coverage was very complex. Controllers thought it was difficult to identify which aircraft could use and effectively apply reduced separation. They also indicated wake turbulence separation procedures were the most complex and presented the greatest risks for loss of aircraft separation. Controllers commented that wake tails and improved aircraft halo prototype tools helped support the variable separation concept.

Results will be used to identify automation requirements for separation management in a future release of the En Route Automation Modernization (ERAM) system.

Plan:

- **HIM/IAN Design Tool and Model [NASA]:** Research will design a tool to evaluate Hazard and Integrity Monitoring (HIM) and Integrated Alerting and Notification (IAN) systems. The tool will include models of both the avionics systems and the pilot, which is unique.

- **Human-Automation Interaction Analysis Tools [NASA]:** Researchers will focus on creating a testing framework for ADEPT models and their corresponding implementations and plan to generate both user/environment inputs and test oracles. Test and environment inputs attempt to drive the system through specific paths. It is a difficult task for a human to manually come up with the conditions that will exercise enough paths through the system so automated support is essential.

- **State and Data Visualization [NASA]:** Research will continue to confirm the value of visualizations applied to visual detection of wiring faults and detection of aircraft trajectory conflicts to determine if visualizations will help human operators interpret large amounts of information more quickly to support decision making.

- **HIM/IAN Development and Testing [NASA]:** Research will continue to refine evaluation tool and models for Hazard and Integrity Monitoring (HIM) and Integrated Alerting and Notification (IAN) and to down-select and refine information integrity and aggregation concepts for the second phase of testing to be conducted in FY12. The scope will be extended to include expected NextGen-based data-link services and off-nominal conditions.

- **Compression Monitoring and Terminal Conflict Alert [NASA and FAA]:** Researchers will improve the T-TSAFE algorithm and integrate and test lateral and speed resolution decision support functionality. In addition, researchers will conduct a high fidelity simulation evaluation, integrated with the flight deck.

- **Guidance for Data Communications Procedures, Training, Displays and Alerts [NASA and FAA]:** Recent human factors research identified recommended improvements to the RTCA SC-214 message set that would eliminate potentially confusing message elements. Recommendations that addressed en route and terminal message set elements were provided to the ICAO WG-84 committee. This upcoming research will help to further revise the message set and the Global Operational Datalink document, which seeks to resolve regional and/or State differences impacting seamless data link operations.

7. Human Automation Functional Allocation

Higher traffic levels and TBO will likely cause automation to take on a greater role in the NextGen environment. Humans, however, will continue to retain a prominent or leading role in many functions. Research in this area focuses on the proper allocation of functions to humans and automated systems, as well as human/machine roles and responsibilities within those functions. Exploratory design techniques consider ways to improve human understanding of complex automation decision making. Research also promotes common human/machine situational awareness, especially in cases of mixed equipage or off-nominal conditions. Human/automation considerations apply to both airborne and ground-based operations.

Results:

- **The Effect of Advanced Cockpit Systems on Pilot Workload and Error [NASA]:** Research determined the effect of increasingly complex cockpits on pilot performance. Experienced pilots flew conventional cockpit and glass cockpit versions of the same make and model airplane. Subjective workload measures, pilot preferences, and pilot errors were recorded. Pilots preferred increased levels of automation, but automation did not always support performance. In some phases of flight, some types of automation increased both workload and pilot error. The study clearly demonstrates the risk of increasing automation without assessing impact under all conditions.

- **Operator State Sensor Investigations for Actual Airborne Applications [NASA]:** The goal of this research is to develop tools to allow the flight deck to be more aware of operator states; deleterious (e.g., fatigue) as well as those that can be used to modulate information presentation and automation (e.g., engagement). The "Operator State Characterization and Feedback" (OSCAF) tool is being developed to synchronize physiological state data and allow for exploration of the physiological data. A sensor suite and operator state classification algorithms has been developed and tested in simulation and flight. A physiological data/behavioral data/simulation performance data integration tool has been improved and is available for use at NASA as a beta test site. This research achieved progress toward developing avionics that are aware of human operator real-time cognitive abilities and limitations. This work was performed in collaboration with the University of Iowa and completed in 2011.

- **NextDeck – Flight Deck Automation for NextGen [NASA]:** Research developed and tested a computational, function allocation analysis capability covering a broad spectrum of factors (i.e., not just one aspect of function allocation). The capability is compatible with analysis of both current and future allocation schemes. Research also developed a set of function allocation assessment metrics based on eight performance dimensions. When evaluated as part of an agent-based batch simulation, the metrics were found to be able to successfully discriminate function allocation schemes and identify areas of concern consistent with current flight decks and operations. This research was collaborative with Georgia Tech.

- **Dynamic Function Allocation Policies and Metrics [NASA]:** NextGen flight deck automation requirements and safety considerations were documented for two automation designs ("pilot as pilot" and "pilot as monitor/manager"). These were based on and derived from test cases that focused on realistic off-nominal events. The report also includes an initial set of guidelines or design principles for each of the two paradigms. Results highlight significant differences that will affect the design of future flight decks based on possible changes in the locus of control between automation and pilots. To conduct effective R&D in the future, assumptions must be made, and these findings can inform the impact of these assumptions on the design and evaluation of new concepts. This research was collaborative with Honeywell.

- **Ground-based Separation Assurance Concepts [NASA and FAA]:** A controller-in-the-loop study looked at different levels of human-automation interaction for a ground-based separation assurance concept. An interactive, semi-automated mode that featured automatic conflict detection with an initial resolution proposal, which could be refined by the controller, achieved the highest level of performance and was also preferred by controllers. Results from this study have helped refine the design space for separation assurance technologies that NASA is developing in coordination with FAA.

- **Generic Airspace Research [NASA and FAA]:** The Generic Airspace Research team completed the final phase of the jointly sponsored 5-phase research effort. During the first phase, the team defined controller information requirements and procedures for operating generic airspace and developed a controller information tool (CIT). This tool readily presents required sector specific and traffic flow information with a single keystroke. During the follow-on phases the team conducted human-in-the-loop experiments to validate the interface, assess the impact of off nominal conditions, and investigate the influence of sector familiarity. Phase 5, conducted this year, compared providing the CIT information integrated on the radar display versus on a separate stand-alone display. Results indicated the viability of either presentation method, but a preference for the CIT integrated on the radar display.

- **Air Navigation Service Providers (ANSP) as Monitors [FAA]:** The FAA examined the "monitoring" role that NextGen ANSP are likely to adopt since the literature shows that humans are poor monitors, often showing poor performance and a vigilance decrement in sustained attention tasks. Researchers thought that monitoring could be improved by adjusting the ANSP's involvement in the monitoring task, but additional involvement did not improve performance nor lessen the vigilance decrement. However, in a study where operators had much less experience with classic airspace control, their monitoring performance was high and did not show a decrement across the vigil, implying it was the amount of practice controlling classic airspace that hurt monitoring, not the particulars of the scenario. These results will be further investigated to determine what it may imply about selection and training of controller personnel for NextGen and how the monitoring role may be improved.

<u>Plan</u>:

- **Data Communications Use With Flight Management Systems [FAA]:** Based on pilot performance capabilities and limitations, develop recommendations for system performance requirements and operating limitations that should be applied when using data communications with integrated and non-integrated Flight Management Systems (FMS).

- **Air/Ground Separation Assurance Functional Allocation [NASA]:** Identify major failure modes to be considered in upcoming off-nominal functional allocation studies. Failure modes may be a function of technology, operating concept, and/or architecture. Analysis includes both component failure and human failure (e.g., human error). This effort will identify major automation failure modes of tactical and strategic separation assurance systems, considering ground, air, and space components. This work will emphasize the failure modes of the automated systems, and not mitigation strategies to address the failures.

8. Procedure Design and Training

NextGen implementation research centers on instrument procedures, training and personnel qualification, and single pilot research. It focuses on the special skills and knowledge needed by NAS actors to ensure the envelope of human performance considerations is adequately aligned with the development of NextGen capabilities in order to accrue intended benefits. This includes implementation of the Navigation Reference System including procedure design, naming conventions, and electronic depictions of NextGen procedures. It also includes training for new NextGen systems and procedures, as well as the potential for skill loss especially in the area of manual skills.

<u>Results</u>**:**

- **Checklist Design Principles [NASA]:** Improperly designed checklists have contributed to many aviation accidents. The goal of this research was to develop checklist design guidance based on human factors considerations. A set of 14 design factors was created to aid in development of checklists based on existing literature as well as an empirical test. These design criteria will be published in a Technical Memorandum and will support requests from a number of major airlines for checklist guidance.

- **Representative Upset Modeling Collaboration with NAVAIR [NASA]:** Researchers completed simulator development for Joint Calspan/Navy/NASA stall training research, with testing from October 24 to November 4, 2011. This included development of representative P-8 upset simulation based on Generic Transport Model (GTM) data, development of a stall buffet model for motion base facility, development of prototype training maneuvers, and simulator evaluation by 20 U.S. Navy pilots. This research supports modeling and simulation enhancements toward extending GTM upset models to other aircraft and provides visibility of NASA's upset modeling research to other government agencies and industry. This research also is relevant in the Human automation and functional allocation section.

- **Support of FAA Rulemaking for Upset Training [NASA and FAA]:** Over 50 piloted simulator demonstrations of the NASA/Boeing Enhanced Upset Recovery (EUR) aerodynamic model were completed, including participation by FAA, NTSB, CAST, manufacturers, airlines, and training providers. Research results support the International Committee on Aviation Training in Extended Envelopes (ICATEE) and FAA Aviation Rulemaking Committee. Technology transfer of NASA simulator modeling technology is enabling historical changes in pilot training for prevention of loss-of-control accidents due to inadvertent aerodynamic stall.

- **Navigation Reference System (NRS) [NASA and FAA]:** To support Area Navigation (RNAV) in NextGen and as an enabler for Trajectory Based Operations, the NRS and NRS waypoints were developed for high-altitude airspace. Initial findings by NASA have shown that pilots do not want to use the NRS waypoints enroute because of the high workload required, and that many FMS databases cannot hold all the waypoints needed. Air traffic controllers noted that NRS waypoints cannot be displayed on their radar scopes and they could not determine bearing and distance between aircraft and NRS waypoints. Controllers also had difficulty visualizing the location of NRS waypoints within their sectors and visualizing an aircraft's route. Finally, it was easy for controllers to make data entry errors since the numeric keypad was arranged differently than most computer keyboards. Recommendations are being developed to address these and other issues identified.

- **Weather Technology in the Cockpit (WTIC) [FAA]:** Research was conducted to identify gaps in current meteorological (MET) training and guidance material as a result of advancing technologies, enhanced MET information in the cockpit, and operating in the NextGen collaborative environment. WTIC research was conducted on current guidance for the training and education of General Aviation (GA) pilots on safe and effective use of meteorological (MET) information in the cockpit in a NextGen collaborative environment during various phases of flight. The research resulted in recommended changes to existing policies regarding knowledge testing and the updating of guidance material on meteorology and meteorological products and services. Many of the weather related Advisory Circulars were found to be 14 to 36 years old resulting in out of date content that needs to be updated. Other recommendations included adding written test questions regarding weather hazard product and product sources to knowledge exams, and testing pilots at higher cognitive levels (to include scenario-based questions) in order to train them to apply what they have learned in the basic guidance. The recommendations from this research will be presented to Flight Standards.

Plan:

- **Human Factors Guidance for Charting of Instrument Procedures Supporting NextGen Performance-Based Navigation (PBN) [FAA]:** This effort will collect and analyze service data to characterize problems pilot have encountered with performance-based navigation procedures, and conduct studies to develop guidelines for charting of PBN and instrument procedures. Results will help provide recommended mitigations to address PBN charting issues through improved crew training, procedures, and operations. This and other planned research will also support development of NextGen human factors instrument procedure guidance that will allow FAA and affiliated suppliers (i.e., avionics manufactures and flight information database providers) to develop products that will enable flight crews to comply with NextGen operational requirements.

- **Pilot Decision Making Relative to Meteorological (MET) Hazards and Events [FAA]:** Research will be conducted to assess the impact of the following on pilot decision making relative to MET hazards and events: 1) Lack of standardized presentations in current technology; 2) Probabilistic weather forecasts; 3) Cloud top information in remote and oceanic regions. The data from this research will be used to identify MET information that should be presented in a standardized manner and the benefits, if any, of providing Probabilistic forecasts and Cloud Top information. Results of these research efforts will be used by SAE G-10 Weather Information Systems Committee in their development of Aerospace Recommended Practice (ARP) for Cockpit Display of Data Linked Weather Information.

9. Trajectory-based Operations

NextGen operations research involves separation assurance and collision avoidance as well as trajectory based operations. It involves new operations under NextGen, such as pilot negotiation, selection, implementation, and monitoring of aircraft state relative to position, altitude, and time. This research explores greater levels of automation support to help mitigate controller workload. Trajectory research centers on requirements, uncertainty prediction, interoperability, and validation, and helps to develop 26 develop common protocols for exchanging trajectory information between ground-based and airborne systems.

Results:

- **NextSafe-2 Flight Simulation Study [NASA]:** This study achieved an evaluation of the Better than Visual flight deck concept applied to NextGen Merging and Spacing and Interval Management (M&S/IM), a collaboration between NASA's Aviation Safety and Airspace Systems Programs. The study collected data from October 12 to November 21 on twelve (airline) crews, measuring pilot workload, situational awareness, flight technical error, and safety and acceptability of NextGen M&S/IM using spacing only versus spacing and separation responsibility by pilot.

- **TBO Adaptive Information Display [NASA]:** Research develops an adaptive agent-driven context model that estimates pilot and hazard state in a trajectory-based operations (TBO) environment, suggests methods to effectively portray opportunities and constraints given the context, and enhances information communication through the use of multiple interface modalities. A planner function is developed that consists of context and uncertainty models that are integrated with a multi-modal display concept and tested using a vertical separation use-case.

- **Tactical FMS Concept [NASA]:** NextGen's Trajectory-Based Operations (TBO) concept provides a set of new challenges in regards to trajectory automation as aircraft will need to adhere to strict four-dimensional trajectory (4DT) constraints due to traffic movement complexity, density, and limited airspace. New capabilities like Flight Management System (FMS) are required to resolve what may otherwise become an over-constrained problem, with very few degrees of freedom from which a solution can be derived. Research develops needed airborne capabilities for increasing the resiliency and robustness of TBO, and to re-establish elements of path and speed control flexibility for ATC. To this end, a Tactical Flight Management System (T-FMS) concept was developed, along with a phased approach for implementing Tactical Trajectory Generation & Guidance (T2G2) technologies into FMS architecture in the future.

- **Flight Deck Interval Management [NASA and FAA]:** The FAA Surveillance Broadcast Services (SBS) Office has been leading a group representing airlines, pilots, controllers, researchers, and regulators to develop the Interval Management (IM) concept and coordinate with the international community. Flight-deck-based Interval Management (FIM) is the procedures and software component of Interval Management with Spacing (IM-S) on the aircraft. The Interval Management with Spacing to Dependent Parallel Runways (IMSPIDR) simulation was conducted in June, involved asking three groups of eight current commercial aircraft pilots to use IM-S procedures to conduct approaches to parallel dependent runways at a high-density airport. Initial results suggest that pilots successfully completed the approaches while maintaining safe but efficient intervals behind two preceding aircraft.

<u>Plan:</u>

- **Flight Deck Interval Management [NASA]:** The research plan is to conduct a high fidelity evaluation of single airport operations using medium-term technologies, and conduct and analyze human-in-the-loop simulation for off-nominal recovery with mixed operations (TAPSS3).

- **Traffic Aware Strategic Aircrew Requests [NASA]:** Pilots lack onboard tools to aid in identifying and requesting preferred trajectories. The Traffic Aware Strategic Aircrew Requests (TASAR) concept is a set of tools for providing strategic user requests from aircraft-based automation using ADS-B in/out. The approach includes identifying use cases and potential benefit, developing a prototype on electronic flight bag, defining certification and operational improvement requirements, and performing pilot assessment through simulations. The plan is to conduct piloted simulations in FY12 and possible flight trials in FY13.

- **4D Trajectory-Based Environment [FAA]:** Develop and validate an integrated High Altitude mid-term concept that effectively leverages new automation, flexible airspace, and dynamic resource management into a high performance 4D trajectory-based environment. The concept builds upon capabilities and systems that will provide improvements in collaborative decision-making, routing options, surveillance accuracy, data communications, flight path accuracy, and the distribution of aeronautical information. Through a series of validation activities researchers will derive concept-level operational and technical requirements to support the concept. Researchers will identify airspace, procedural, operational, and standards modifications. The concept will result in improved accommodation of user-preferred trajectories, operational performance, and flexibility for both controllers and flight crews.

10. Air/Ground Integration

Air/ground integration research provides a systems approach to air-ground integration as the NAS transitions from current operations to new concepts, taking into account changes in responsibilities and procedures between controllers and pilots. It also addresses the balance of automation with NAS actors (pilots and controllers) as policies and procedures change during transitions across different types of airspace.

Results:

- **Air/Ground Separation Assurance Functional Allocation [NASA]:** Companion human-in-the-loop experiments compared the performance of ground-based and airborne separation assurance concepts using subject controllers and pilots, respectively. Performance across various safety, efficiency, and trajectory conformance metrics was similar and considered acceptable for the two concepts, with variance generally attributable to differences in applied technologies and operational procedures. This was the first study in a comprehensive series of experiments intended to better understand the air-ground trade space across various airspace operations (including mixed equipage), nominal, and off-nominal conditions. Results from this series are expected to inform key research actions from the JPDO Integrated Work Plan (IWP) as well as FAA investment decisions in the NAS Enterprise Architecture Automation Roadmap.

- **3D Path Arrival Management (3D-PAM) [NASA and FAA]:** Three controller-centric and three flight deck-centric human-in-the-loop simulations (HITLs) were executed in 2011. Flight deck simulations were conducted at the Boeing Facility in Seattle and the SkyWest Training Facilities in Utah and Atlanta. Pilots from United, Continental and SkyWest airlines participated in the HITLs. Air traffic control simulations were completed at the NASA Ames Research Center with Denver Center controllers. Results of these simulations are being used to develop the procedures, the concept of operations, the benefits case, and the system requirements for the Efficient Descent Advisor (EDA), a ground automation tool under development by NASA. Results and pilot/controller feedback from the simulations provided the guidelines and constraints for the functional requirements document, written collaboratively by NASA, FAA, and MITRE. The EDA software, simulation reports, and functional requirement recommendations have been delivered to FAA through the technology transfer process. EDA supports the FAA's 3-Dimensional Path Arrival Management (3D-PAM) project. 3D-PAM enables efficient arrivals into medium and high density airports by making use of current aircraft automation and EDA as the supporting ground automation. In this concept the air traffic controllers with the help of EDA provide a single "conflict-free", four-dimensional trajectory to send to the flight crew for entry into the aircraft flight management system for execution. The flight management system enables the aircraft to fly a fuel optimal lateral and vertical profile. The trajectory extends from the top of descent to meter fix. The Traffic Management Advisor provides the scheduled time of arrival at the meter fix and EDA provides the trajectory to meet that time. In January 2012, NASA's Research Mission Directorate officially transferred the EDA concept to the FAA.

Plan:

- **Air Traffic Management Technology Demonstration [NASA and FAA]:** The research plan is to conduct an operational demonstration of an integrated set of NASA arrival management technologies for planning and executing efficient arrival operations in the terminal environment of a high-density airport. This Air Traffic Management Technology Demonstration (ATD-1) will directly address terminal area congestion, and evaluate the benefits of advanced NASA-developed arrival management technologies across a range of aircraft equipage levels during moderate to high levels of traffic demand. The integrated technologies will allow pilots to achieve precise aircraft separation, and controllers to manage variability between flights and respond to disturbances to the schedule. FAA air traffic personnel will be asked to participate in the development and execution of the demonstration. Airspace user flight crews will be asked to fly aircraft during the demonstration and participate in preparatory human-in-the-loop (HITL) simulations.

- **Air-Ground Integration (AGI) Simulation Roadmap [FAA]:** Researchers will design a framework to support Human-In-The-Loop Simulations (HITLS) planning and developing an initial AGI

Simulation Roadmap. The roadmap will be used to identify, prioritize, and align AGI simulation activities. AGI HITLS will be executed based on the plan. The desired outcome discovery, understanding, and mitigation of potential AGI HF issues.

- **Oceanic and En Route Pair-Wise Delegated Separation [FAA]:** Continued research will evaluate and recommend procedures, equipage and training to safely conduct oceanic and en route pair-wise delegated separation. Research will help identify and predict human factors issues associated with the oceanic in trail procedure including review of completed, ongoing, and planned human factors research and operational experience with systems and procedures relevant to the procedure and its associated flight deck technologies.

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Additional information available at:

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FAA Human Factors Portfolio: https://www2.hf.faa.gov/HFPortalNew/HFPortfolioOverview.aspx

FAA Human Factors Website: http://www.hf.faa.gov

FAA NAS Enterprise Architecture Portal: https://nasea.faa.gov/

JPDO Website: http://jpe.jpdo.gov/

NASA Technical Reports and Papers (Including Human Factors): http://www.sti.nasa.gov/STI-public-homepage.html