National Aeronautics and Space Administration
Aeronautics Research Mission Directorate
Aviation Safety Program

Integrated Intelligent Flight Deck Technologies

"Tools, methods, principles, guidelines, and technologies for revolutionary flight deck systems that enable transformations toward safer operations"

Technical Plan Summary[1]

(FY2009 – FY2013)

Principal Investigator: Steven D. Young, PhD
Project Manager: Carrie K. Walker
Project Scientist: Barbara Burian, PhD

Contributors:
Randall E. Bailey
Michael S. Feary, PhD
Kara Latorella, PhD
Sandra C. Lozito
Robert Neece, PhD
Jessica L. Nowinski, PhD
Amy R. Pritchett, ScD

March 13, 2009

[1] This document is an update to the IIFDT Technical Plan Summary originally published on May 25, 2006.

TABLE OF CONTENTS

FORWORD

Methods for piloting aircraft will change dramatically over the coming decades with transition to the Next Generation Air Transportation System (NextGen). While many aircraft may have the same general configurations, their trajectories may be defined in distinctly new ways, including complex, frequently-changing specifications providing optimal efficiency, minimal environmental impact, and flight relative to other aircraft. Similarly, pilots' tasks may expand to include collaboration and negotiation with other aircraft and with air traffic controllers, and may require managing large disparate sets of information to support a wide range of decisions made both individually and collaboratively. Current projections also prescribe an increased use of automation, much of which will need to interact with, and support, the cognitive activities of pilots and air traffic controllers.

To simultaneously achieve NextGen's target levels of performance and safety, these changes require the systematic study and design of new technologies and new operating procedures, while also identifying implications for pilot and controller training. If addressed early in NextGen design, synergistic solutions may enhance safety while also facilitating goals for increased capacity and reduced environmental impact; conversely, if addressed too late, safety considerations will likely serve as constraints on NextGen operations. For this reason, the Integrated Intelligent Flight Deck Technologies (IIFDT) research plan leverages research planned within NASA's Airspace Systems Program (ASP) as well as the other elements of NASA's Aviation Safety Program (AvSafe).

1 INTRODUCTION

The goal of the IIFDT project is to develop tools, methods, principles, guidelines, and technologies for revolutionary flight deck systems that enable transformations toward safer operations. This includes developing novel methods of piloting aircraft, enabled by the rigorous, systematic design of new technologies and operating procedures. In doing so, IIFDT seeks to expand our ability to predict and create the comprehensive set of developments (technologies, procedures, and specifications for crew training) demanded for truly novel concepts of operation, such as those proposed for the Next Generation Air Transportation System (NextGen).

Two challenges that have historically hindered our ability to effectively predict and design for the effective support of human performance are (1) understanding, and accounting for, the inter-relationships not only within a specific system, but also with external systems and the operating environment; and (2) understanding, and accounting for, the context dependency of activities, including specific activities that can be beneficial in one situation but detrimental in another. IIFDT research takes an inter-disciplinary approach that builds on coordinated insights into human performance and technological capability. This approach is especially important given the project's focus on designing for safety because choices of mitigating risk via a mix of technology, procedures, or training can have long-term and profound impacts on many aspects of aviation operations.

To enable the design of truly novel concepts of operation for flight deck systems, IIFDT develops rigorous, predictive, generalizable methods and models for designing technologies and operating procedures, and for capturing assumptions and requirements for crew training. The resulting methods and models should be suitable for use by all within the aviation community to promote the systematic consideration of human and technology performance and other safety concerns throughout both the procedure and technology design communities.

As aircraft and airspace systems become more complex, the complexity of flight deck systems and procedures increase correspondingly. Solutions to identified problems or issues are commonly addressed by adding new systems or functions. Each addition can reduce the coherence of flight deck operations, increase the risk of undesired side-effects, and push more information and tasking to the pilot. Increasing information also creates new challenges regarding data sharing and dissemination among the crew, aircraft systems, and other decision makers such as air traffic controllers. This project seeks to provide a transformed view of piloting operations that establishes a coherent basis for designing technologies and procedures, and that considers both human performance and technological capability. Simultaneously, the project seeks revolutionary advancements in avionics technology capability and performance in selected areas where new demands for flight-critical high-integrity capabilities are required, such as external hazard detection.

The research described in this technical plan establishes transformative integrated display concepts, decision support functions, on-board/off-board information management, high-integrity external hazard detection, and effective mechanisms for human-automation interaction that enable safer flight deck systems for NextGen. These systems need to be robust and flexible to accommodate a wide range of operating conditions and classes of NextGen operations. Their design will be based on systematic (often formal) methods for analyzing for human and machine performance and human-system-integration issues and for identifying design requirements such as required technology-based functional behaviors and information/sensing requirements.

2 RELEVANCE, SCOPE, AND OBJECTIVES

Most airline accidents are attributed to errors made by the flight crew (Boeing, 2004). In a recent study, 64% of all major U.S. air carrier accidents were 'crew-caused' (NTSB, 2005). The corresponding accident rate is 1.8 times that of all other accident causes combined. These numbers are even worse for accidents that do not involve commercial airliners (e.g. small general aviation aircraft). However, there is no analogous statistics or metrics that account for how many accidents were *avoided* by the response of skilled pilots to failures or unexpected situations.

Overall, the level of safety achieved by aviation today is unmatched by any other form of transportation. This is achieved through the contributions of both humans and technology. As new operating concepts advocate changes to current operations, rigorous systematic research must address to what extent safety is maintained, improved, or potentially compromised.

As prescribed by the United States' National Aeronautics Research and Development Policy (OSTP, 2006), NASA has two roles:

1. "to conduct broad foundational research aimed at preserving the intellectual stewardship and mastery of aeronautics core competencies..."; and
2. "to conduct research in key areas related to the development of advanced aircraft technologies and systems that support DOD, FAA, the Joint Planning and Development Office (JPDO), and other executive departments and agencies."

Within these two roles defined by policy, the IIFDT research portfolio responds to challenges articulated by three sources: the President's Office of Science and Technology Policy (OSTP), the National Research Council (NRC), and the Joint Planning and Development Office (JPDO).

2.1 OSTP – U. S. National Aeronautics Research and Development Plan

(OSTP, 2007) provides a set of research goals and challenges to be overcome by the Aeronautics community at large. These are presented in five categories: Mobility, Security, Safety, Environment, and Infrastructure. IIFDT's research agenda responds to several of the noted challenges – particularly in the areas described below for Mobility, Safety, and Infrastructure.

Fundamental Mobility Challenges to Overcome

- Reducing separation distances between aircraft to increase traffic density and determining functions that can be moved to the cockpit to improve operations without compromising safety
- Developing more accurate and timely observations and forecasts of aviation-relevant weather to enable NextGen
- Increasing airport approach, surface, and departure capacity
- Improving the efficiency and performance of all classes of aircraft to take advantage of improved methods of operating aircraft within the NAS
- Defining appropriate roles for humans (notably air traffic controllers and pilots) in relation to automation, and developing automation that humans can reliably and fluidly interact with, monitor, and, when appropriate, override
- Understanding enterprise-level issues (e.g., environmental, organizational) and interactions critical to successful transformation

Plan Excerpts - Mobility

"Reduced aircraft separation will require a move to trajectory-based operations, performance-based navigation, and a paradigm shift in control with new allocation of responsibilities between air and ground and between humans and automation."

"Research into candidate concepts of operations and enabling technologies is needed for a shift in separation responsibility from ground controllers to the cockpit."

"Developing enhanced positioning, navigation, and timing capabilities, including identifying feasible backups, is a critical research focus. This research must investigate a means to take advantage of existing and future avionics capabilities to expand: (1) the rapidly growing set of applications such as Automatic Dependent Surveillance-Broadcast; and (2) area navigation and required navigation performance in the terminal and en-route environments. The research must also investigate impacts to pilot and controller (and other vital personnel, such as airline operators and remote aircraft operators) workload, and roles and responsibilities for automated route clearances."

"Another major research challenge is to define the proper balance in responsibility between the ground and the cockpit."

"Finally, this research must support the definition of new separation standards, procedures for trajectory-based operations, and certification of new ground- and cockpit-based systems, including the development of safety risk-management analyses."

"A key component of traffic flow management research will be to understand uncertainties due to weather. A common weather picture (shared situational awareness) of forecasts and observations from which all weather-related decisions can be made is needed. Research must determine the spatial and temporal resolution and accuracy required to integrate weather information with air traffic management automation systems. Focused research is necessary to develop real-time verification systems that quantitatively assess the accuracy and reliability of probabilistic weather forecasts."

Fundamental Safety Challenges to Overcome

- Rapidly and safely incorporating technological advances in avionics into the aircraft
- Applying novel sensing, control, and estimation techniques to assist in stabilizing and maneuvering next-generation aircraft in response to safety issues ranging from multiple-aircraft conflicts to on-board system failures in the NextGen airspace
- Understanding the key parameters of human performance in aviation to support the human contribution to safety during air and ground operations for appropriate situational awareness and effective human-automation interaction, including off-nominal and degraded situations
- Ensuring safe operations for the complex mix of vehicles anticipated within the airspace system enabled by NextGen

Plan Excerpts - Safety

"To allow more aircraft to operate in the limited airspace, aircraft users and developers will require: improved understanding of aircraft interaction dynamics; improved aircraft interfaces, including automation systems; and system adaptability to changing conditions. It is critical to develop improved human-machine interfaces while safely increasing flight deck and ground controller automation."

"It is also critical to assess the software verification and validation of automation systems to the operation of vehicles in the airspace system."

"To address this increased demand, research is needed to develop systems that improve pilot and controller awareness of airport surface conditions (aircraft locations, ground vehicle locations, runway occupancy, and pavement conditions), particularly in low-visibility situations."

"Research into understanding the human-machine integration requirements of weather data will be conducted for flight operations in the air, as well as for ground operations."

"In the NextGen system, many system functions, such as separation management, trajectory management and flow management, are contingent on the integrity and integration of data and information across many distributed air and ground systems. Moreover, those functions will be variable (e.g., variable separation standards) and based on the health and level of performance of the participating systems (e.g., the accuracy, integrity, and update rate of surveillance information from aircraft). Therefore, research is required to address the health of critical system functions and develop techniques for real-time monitoring and assessment."

Plan Excerpt – An Overarching Challenge
"Another major challenge will be to define the proper balance in responsibility between humans and automation. Research into the human-machine relationship does not appear as a set of separate research topics in the mobility goals and objectives table because it must be an integral part of research to define the details of new operational capabilities identified in Goals 1–4. Human-machine integration efforts are also identified in the national security and safety sections."

Plan Excerpt – Research, Development, Test, and Evaluation (RDT&E) Infrastructure
"The national aeronautics RDT&E infrastructure should support R&D by providing the capability and flexibility to test and evaluate a broad range of new aircraft and air transportation management systems, from component-level to full-scale, and to the extent practicable, to evaluate them at an enterprise level."

2.2 NRC – Decadal Survey of Civil Aeronautics

(NRC, 2006) is the result of a comprehensive assessment of state-of-the-art with respect to civil aeronautics research. As a component of this assessment, the NRC makes specific recommendations to NASA. One of these is that "NASA should use the 51 highest priority R&T Challenges as the foundation for the future of NASA's civil aeronautics research program during the next decade." The top 51 challenges, as determined by the NRC, are presented in five categories: A – Aerodynamics and aeroacoustics; B – Propulsion and power; C – Materials and structures; D – Dynamics, navigation, and control, and avionics; and E – Intelligent and autonomous systems, operations and decision making, human integrated systems, and networking and communications.

IIFDT research responds to aspects of 13 of the 51 highest-priority challenges (Figures 2-1 and 2-2). Moreover, all of these 13 R&T challenges received the highest rating ('9') for safety relevance and impact.

D1 Advanced guidance systems, excerpt (p136), "One concern, for example, is the need to develop improved technologies to avoid controlled flight into terrain, particularly in the case of all-weather operation of advanced rotorcraft."

D2 Distributed decision making, decision making under uncertainty, and flight path planning and prediction, excerpt (p138), "Improving the decision-making process used by pilots and aircraft systems, when coupled with improvements in flight path planning and prediction, has been theorized as an effective approach to improving air transportation system capacity and safety."

D6 Improved onboard weather systems and tools, excerpt (p143), "Pilots—and the avionics software that provides in-flight, four-dimensional trajectory re-planning and commands to the pilot or autopilot—require additional weather information to minimize the impact of weather on the control of flight in heavy traffic."

D7 Advanced communication, navigation, and surveillance technology, excerpt (p144), "Continuous improvement in situational awareness through advanced sensors, communication links, and human–system interfaces."

D8 Human-machine integration, excerpt (p145-146), "Develop improved system engineering processes and tools for determining optimum roles of humans and automation in complex systems and demonstrate the benefits of this improved methodology in a trial application. Conduct fundamental research on the causes of human error and on human contributions to safety and document design guidelines that will (1) help minimize the potential for design-induced error and (2) facilitate positive human intervention in the event of system failures. Transfer these guidelines to government program offices and industry. Develop and test enabling technologies for pilot workload management and reduced crew operations while keeping pilot awareness at the proper level. Develop display concepts for maintaining operator situational awareness while monitoring highly automated processes. Demonstrate the ability of operators to rapidly and accurately intervene in the event of system failures. Develop technologies and/or display concepts enabling effective fusion of information from multiple sources, including real-world and synthetic imagery (i.e., augmented reality). Demonstrate the effectiveness of these concepts in practical decision support applications with varying levels of information quality and uncertainty (in terms of accuracy, timeliness, etc.). Develop and demonstrate technologies for machine vision (image-based object detection). Develop tools and metrics to compare effectiveness of machine and human operators in see-and-avoid tasks to improve machine performance.

D9 Synthetic and enhanced vision systems, excerpt (p146), "Research topics of interest are as follows: Database integrity and quality; Information fusion; Object detection and avoidance; Human–machine interface issues; Verification of accuracy, fault tolerance, and reliability"

E1 Methodologies, tools, and simulation and modeling capabilities to design and evaluate complex interactive systems, excerpt (p152), "Methodologies, tools, and simulation and modeling capabilities suited for the design and integration of complex interactive systems are needed to understand the air transportation system as an integrated, adaptive, distributed system that includes aircraft, ATM facilities, and airports, each with its own complex systems, all of which interact with one another, the environment, and human operators."

E2 New concepts and methods of separating, spacing, and sequencing aircraft, excerpt (p155), "Expected growth in the demand for air transportation will require efficient, denser en route and terminal area operations. This necessitates procedures that reduce minimum spacing requirements during all phases of flight and in all weather conditions, through an integrated approach that leverages a suite of emerging technologies such as required navigation performance and automatic dependent surveillance broadcast (ADS-B)."

E3 Appropriate roles of humans and automated systems for separation assurance, including the feasibility and merits of highly automated separation assurance systems, excerpt (p155), "This

Challenge would determine the appropriate roles of humans and automated systems to assure separation in high-density airspace during nominal and off-nominal operations."

E4 Affordable new sensors, system technologies, and procedures to improve the prediction and measurement of wake turbulence, excerpt (p156), "This Challenge would complement that work (Challenge A10) by developing affordable new sensors, system technologies, and procedures to improve prediction and measurement of wake strength, location, motion, and aircraft upset risk in terminal and enroute airspace."

E5 Interfaces that ensure effective information sharing and coordination among ground-based and airborne human and machine agents, excerpt (p157), "The potential for sharing a wide range of information within the air transportation system raises additional questions about how multiple agents (pilots, controllers, other system users, and automated system elements) can coordinate and share information given their disparate viewpoints and contexts. For information sharing to be effective, information must be provided to the right agents, at the right time, and in a fashion that facilitates accurate interpretation regardless of the source of the information." Key milestone: "Document improved understanding of human cognitive control, judgment, and decision making in a variety of contexts and under a variety of stressors."

E8a Transparent and collaborative decision support systems, excerpt (p160), "This Challenge will identify the type of information to be shared between human operators and automated decision support systems and develop candidate designs for these systems." Key milestones include: "Identify the type of information to be shared between human operators and automated decision support systems and the most appropriate form of information representation and exchange" and "Develop, demonstrate, evaluate, and iteratively refine candidate designs in collaboration with operators."

E8c Interfaces and procedures that support human operators in effective task and attention management, excerpt (p161), "Pilots may begin to play a more active role in traffic separation or spacing and will need to coordinate their activities and intentions with other pilots and controllers. They will need to interact and exchange information, often interrupting each other and creating new tasks for one another. In general, more information will need to be distributed in a timely manner, task sets will increase, interruptions will become more likely, and the tolerance for delayed action or intervention will probably be reduced. It will be critical to ensure that operators are supported in properly scheduling and prioritizing their tasks, to improve attention management and avoid errors caused by unnecessary task switching, unnecessary interruptions, or inappropriate dismissals of demands (i.e., the failure to switch attention when appropriate and necessary) (Woods, 1995; McFarlane and Latorella, 2002; Ho et al., 2004)." Major milestones include: "Complete basic research to document how operators absorb information, process information, and prioritize tasks."

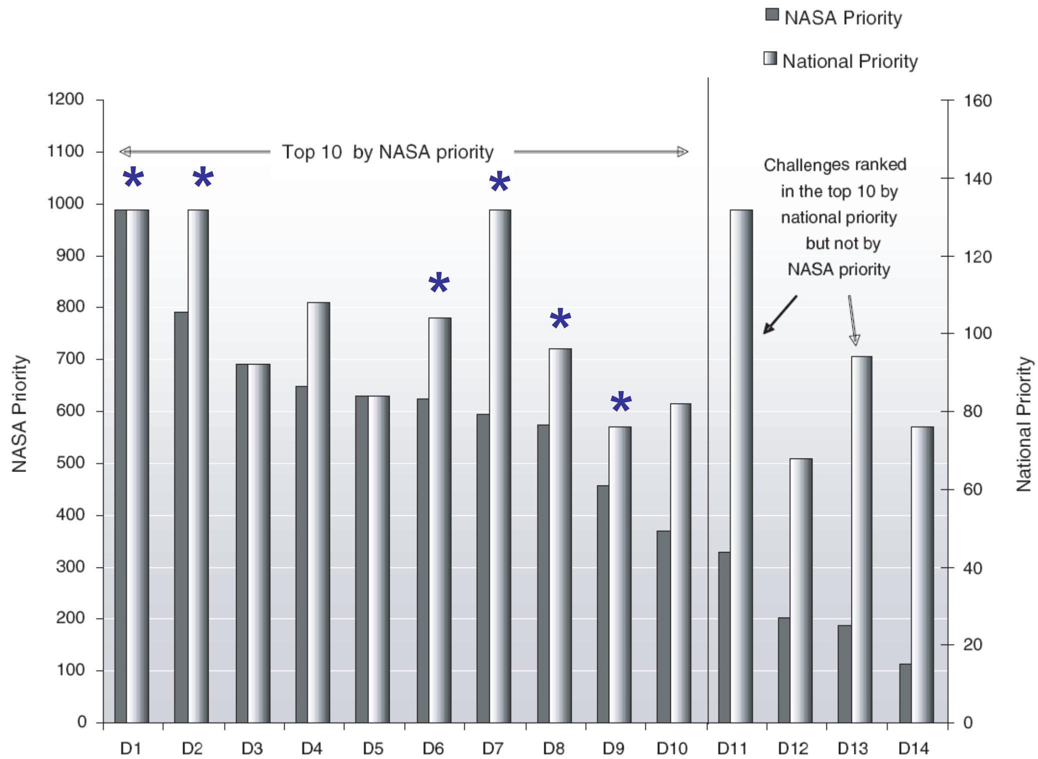

Fig 2-1. NRC Decadal Survey Rankings – Category D
(* indicates challenges addressed by IIFDT research)

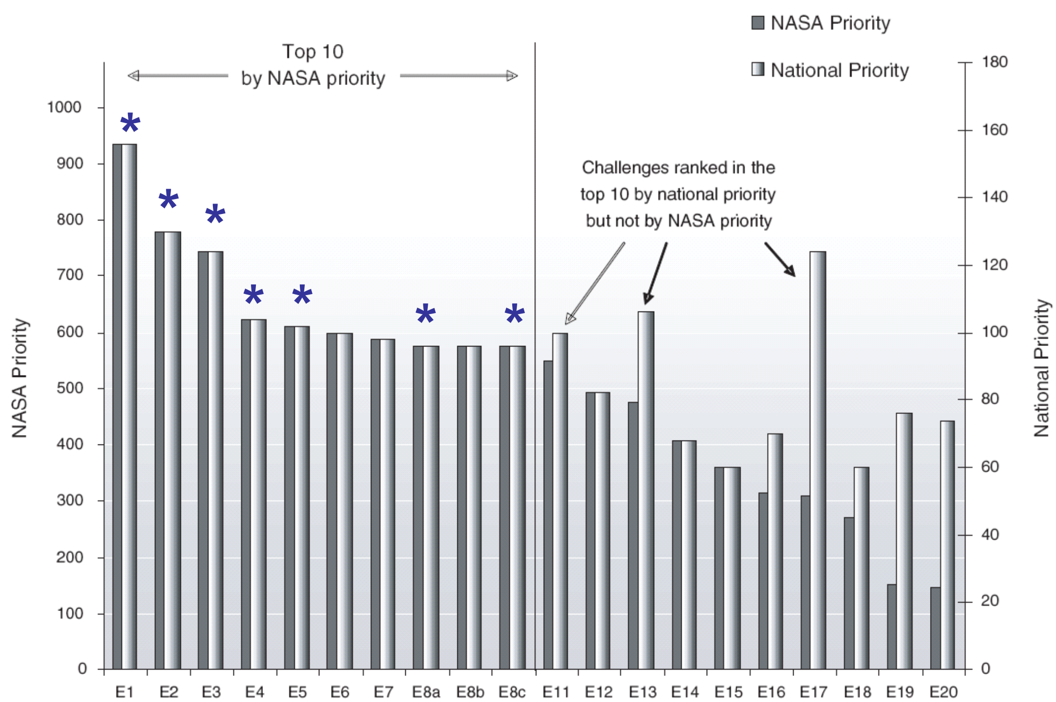

Fig 2-2. NRC Decadal Survey Rankings – Category E
(* indicates challenges addressed by IIFDT research)

2.3 JPDO – Flight Deck Design Challenges for NextGen

The JPDO envisions a safe, efficient and reliable air transportation system for 2025 that removes many of the constraints in our current system, supports a wider range of operations, and thus delivers an overall system capacity up to three times that of current operating levels. The concept requires a shift in the historical model of air transportation from a system based on established physical/technology infrastructure and the capabilities of service providers to a system that is flexible and adaptable to the varied needs and capabilities of its users. This concept also requires that safety be considered and predicted during design, constantly assessed during implementation through prognostic data analysis, and maintained through an effective safety culture.

As envisioned, the roles and responsibilities of flight deck system[2] agents (i.e. either human or automated) will need to be transformed. Further, the flight deck system will have access to increasing amounts of information and new and innovative means of communicating its desires to an ATM system; there will be more stringent performance requirements for avionics functions; and there will be a delegation of varying levels of responsibility to the flight deck for managing separation and generating/negotiating 4D trajectories relative to weather and other ATM constraints. Because of the complexity of NextGen, the degree of automation in the aircraft and in the ATM system will increase. Direct pilot/controller communications will be reduced and replaced by agent-based interactions between air and ground systems. Each of these new challenges is considered from a holistic flight deck system safety perspective by the IIFDT project.

To further illustrate the implications of NextGen concepts on the flight deck, (IIFD, 2009) provides a list of the JPDO-identified research and development activities, operational improvements, and enabling technologies, concepts, and procedures needed to enable NextGen's Trajectory-Based Operations (TBO) capability and are addressed to some degree by IIFDT research.

2.4 Role Within NASA

Commensurate with the roles prescribed by U. S. National Policy, and responsive to the challenges articulated by the OSTP, NRC, and JPDO, the role of IIFDT is defined by NASA in its strategic plan (NASA, 2006) to support subgoal 3E, which states, "Advance knowledge in the fundamental disciplines of aeronautics, and develop technologies for safer aircraft and higher capacity airspace systems." The strategic plan goes on to state specific expectations that are relevant to the IIFDT project.

3E.1. By 2016, identify and develop <u>tools, methods, and technologies</u> for improving overall aircraft safety of new and legacy vehicles operating in the Next Generation Air Transportation System (projected for the year 2025).

3E.2. By 2016, develop and demonstrate <u>future concepts, capabilities, and technologies</u> that will enable major increases in air traffic management effectiveness, flexibility, and efficiency, while maintaining safety, to meet capacity and mobility requirements of the Next Generation Air Transportation System.

3E.3. By 2016, develop <u>multidisciplinary design, analysis, and optimization capabilities</u> for use in trade studies of new technologies, enabling better quantification of vehicle performance in all flight regimes and within a variety of transportation system architectures.

---

[2]Flight Deck System - A system that includes (1) the entity(s) who have the authority and responsibility for directing the flight of an aircraft, (2) all sub-systems that directly interface to these entity(s), and (3) the interfaces between them.

3E.4. Ensure the continuous availability of a portfolio of NASA-owned wind tunnels/ground test facilities, which are strategically important to meeting national aerospace program goals and requirements.

Further, NASA's Aeronautics Research Mission Directorate (ARMD) requires that all ARMD-funded activities adhere to three guiding principles in the course of planning, executing, and reporting research (NASA, 2007). These are:

1. We will dedicate ourselves to the mastery and intellectual stewardship of the core competencies of Aeronautics for the Nation in all flight regimes;
2. We will focus our research in areas that are appropriate to NASA's unique capabilities; and
3. We will directly address the fundamental research needs of the Next Generation Air Transportation System (NextGen) in partnership with the member agencies of the Joint Planning and Development Office (JPDO).

More specifically, ARMD's Aviation Safety Program (AvSafe) identifies the following research needs where IIFDT contribution is expected: monitoring for problems before they become accidents; flight in or around hazardous conditions; modeling and sensing icing conditions; sensing and portraying environmental hazards; and, with respect to new NextGen operations, design of robust collaborative work environments; design of effective, robust human-automation systems; and information management and portrayal for effective decision making (AvSafe, 2008).

These needs, along with the ARMD guiding principles, have been used to derive and define a relevant goal, scope, and research agenda for the IIFDT project.

2.5 Statement of Scope

The overarching goal of IIFDT is to advance knowledge by producing tools, methods, principles, procedures, guidelines, and technologies, for revolutionary flight deck systems that enable transformations toward safer operations. Inter-disciplinary research pursues a greater understanding of behavioral relationships and context dependencies among and within flight deck system elements. The research process systematically explores methods for identifying requirements by exposing them and then testing the validity of both the methods and the requirements themselves (i.e. are suggested functions or capabilities really required?).

IIFDT uses as a guide an assumed future state of the U. S. National Airspace System (NAS). This future state is based upon the current, and evolving, vision described by the JPDO (JPDOc, 2007; JPDOi, 2008; JPDOr, 2007; JPDOe, 2007) and further specified by NASA's Airspace System Program research focus areas. Secondary references used to establish this assumed future state include (FAAo, 2008; FAAn, 2008; NASAn, 2007).

2.6 Objectives and Anticipated Contributions

IIFDT seeks to achieve five strategic objectives of particular importance to the safety of future flight deck operations (Table 2-1). While achieving these objectives, IIFDT considers the integration of IIFDT-developed capabilities or concepts with future communications, navigation, Air Traffic Management (ATM), and other technologies or operations being investigated by others. Selected anticipated contributions are reported as Annual Performance Goals (APGs) and Program Commitments in NASA's Integrated Budget and Performance Document (IBPD, 2009) (Table 2-2). This document is updated annually with accomplishments drawn from project milestones to be discussed in Section 4.

Table 2-1. IIFDT Strategic Objectives

SO-1	RDT&E of robust human-automation interaction concepts
SO-2	RDT&E of information integration, abstraction, and conveyance concepts that support effective decision-making (both individual and collaborative)
SO-3	RDT&E of enabling avionics technologies and functions to ensure and support safe operations
SO-4	RDT&E of flight deck system design and evaluation methods and tools
SO-5	Improve our understanding of human performance as it relates to safety of flight and operational efficiency

Table 2-2. IIFDT Annual Performance Goal and Program Commitment (IBPD, 2009)

APG 9AT03	Deliver findings on presentation formats and interaction methods for advanced display concepts that support effective decision-making during NextGen-based terminal area operations with statistically significant reductions in communication errors, mental workload, and flight technical error, as well as increases in usability and situation awareness compared with baseline capability
Program Commitment	In 2016, deliver tools and flight deck technologies to enable advanced automation to support NextGen

2.7 Community-wide Coordination and Collaboration

As research progresses and NAS evolutionary trends emerge, close coordination with NASA's Airspace Systems Program (ASP), the Federal Aviation Administration (FAA), and the JPDO is essential to synergistically study risks and develop mitigations. As a result, adjustments to this IIFDT plan are to be expected as research issues emerge or are resolved. Effective coordination across the community ensures an integrated relevant technology toolset and knowledge-base in support of NextGen as it comes on-line.

Further, it is expected that a significant amount of the planned research will be accomplished by collaborating closely with other NASA projects, academia, industry partners, and other government agencies. This is commensurate with the ideals of the project, whereby NASA leads community-wide concept development toward the future for flight deck systems, but NASA does not necessarily develop all of the physical products or research results.

As will be discussed further in Section 4, an active collaboration with NASA's Airspace Systems Program (ASP) is particularly important. This is evidenced by (1) coordination during the development of NextGen-based concepts of operations within which to test hypothesized flight deck solutions, (2) technical interchange forums to ensure coordinated advancement, and (3) joint activities or studies, such as human-in-the-loop simulation experiments, that can simultaneously achieve objectives of IIFDT and of projects or research focus areas in ASP.

For more details on IIFDT's existing coordination and collaboration activities, see Appendix B.

3 RESEARCH FRAMEWORK

Figure 3-1 illustrates the framework for IIFDT research and identifies research topics or areas (i.e. the block titles). In Figure 3-1, the four levels are used to represent and distinguish research with varying degrees of system complexity and integration across multiple disciplines. This framework is derived from principles for achieving predictive capability for complex system designs (Oberkampf, 2002).

Level 4 is at the highest level of flight deck system integration and brings together the results of all lower level research as well as developments of others across the community. The ultimate Level 4 research product includes not only specific designs, but also rigorous systematic methods and modeling environments for assessing complex system designs from various discipline perspectives. Level 4 is also where application domains, concepts of operation, and test scenarios are specified not only to focus all the supporting lower Level research, but also as contributions in their own right to the community.

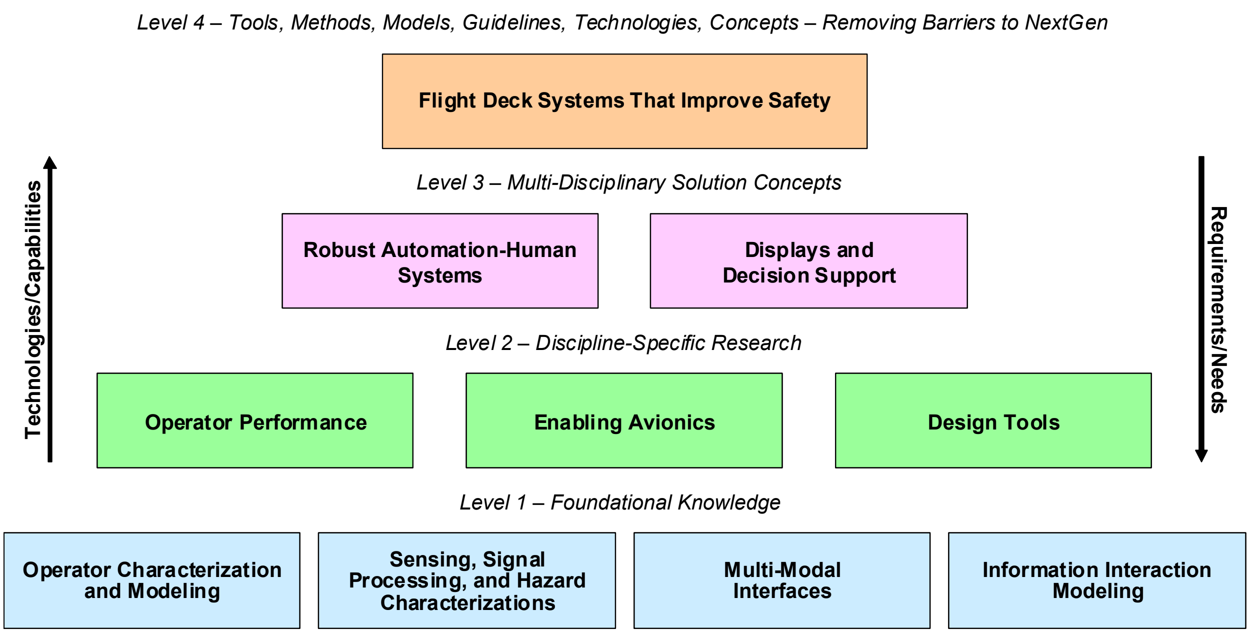

Fig 3-1. IIFDT Research Framework

Within the domain defined at Level 4, Level 3 research postulates novel multi-disciplinary solutions that have the potential to provide needed flight deck system capabilities or characteristics. Such solutions cannot be enabled by considering technology, operating procedures, or human performance and training separately. In other words, Level 3 research focuses on specific safety challenges or operational needs that require systematic study of the trade-offs that exist between and across discipline-specific concerns and measures of performance.

Research conducted at Level 2 is discipline-specific and targets identified gaps in understanding that inhibit development and/or evaluation of Level 3 solutions to operational challenges. Level 2 activities serve to bridge the gap between foundational research done at Level 1 and the highly integrated solution concepts developed at Level 3.

Level 1 is where science, engineering, mathematics, and human factors theoretical approaches are developed to address flight deck system-specific problems or gaps in our understanding or capability. Advancements at the foundational level determine, to great extent, uncertainties associated with performance or safety predictability as we move from Level 1 to Level 4. In other words, understanding higher-level abstractions, relationships, and behaviors is directly determined by the underlying physical, physiological, and/or psychological processes, and their interactions.

Appendix A provides a set of milestones and planned deliverables for the project over the period FY09-FY13. Milestones are defined such that lower-level research informs the higher-level research of new findings that may change conceptual designs; while the higher-level research provides a relevant domain within which the lower-level research can be applied. This give-and-take, iterative construct allows for long-term maturation of methods, testbeds, and skill-sets that can be applied to flight deck system challenges as they change over time – some will be resolved, while others will emerge. A more detailed description of planned activities is given in Section 4.

4 TECHNICAL APPROACH

The IIFDT project encompasses research across the spectrum from foundational to system level integrations, and participants include NASA researchers, industry collaborators, university researchers, and employees of other government agencies and official organizations. The technical approach to this diverse body of work is described in the context of the four research levels and their component elements (Figure 3-1). As the research level increases, complexity and integration requirements increase. Specifically, research at higher levels must address uncertainties identified and quantified at lower levels. It is important to note that research products (i.e. findings) at any level may, in their own right, improve some aspect of safety.

The following subsections describe the ten IIFDT research topics shown in Figure 3-1 in terms of each topic's long-term goal or strategic objective, planned activities, and expected outcomes. Research within each topic targets specific barriers or knowledge gaps associated with flight deck systems operating in NextGen that – if not overcome – would significantly limit performance gain potential.

4.1 Level 4 – Flight Deck Systems that Improve Safety

Reflecting its objectives, IIFDT's top-level vision is to create transformative flight deck system design concepts and methods that can enable safer operations. IIFDT accomplishes this by exploring the design space in a systematic manner based upon, and building from, foundational research findings.

The IIFDT project defines a *flight deck system* as "a system that includes (1) the entity(s) who have the authority and responsibility for directing the flight of an aircraft, (2) all sub-systems that directly interface to these entity(s), and (3) the interfaces between them." Given this definition, the study and design of future flight deck systems and operations must consider both onboard and off-board 'systems', how they interact with each other, and how human entity(s) interact with them. For example, consider a trajectory-based operational environment wherein pilots (or aircraft-based automation) are negotiating with ATC (or ground-based automation) a 4-D trajectory to be flown. Trajectories may be exchanged via voice or data link. In this case, it can be useful to consider pilots and controllers, as well as their interfaces and the communication systems between them, as components of the flight deck system per the given definition. The external environment must also be explicitly considered in designing the flight deck system as the relative proximity of traffic, terrain, airport features, and weather phenomena are integral to pilot decision making. Likewise, by this definition the flight deck need not be physically located on the aircraft.

Comprehensive treatment of Level 4 issues requires modeling, simulation, verification, and validation (V&V) activities to expose complex, often emergent, behaviors that result from the interactions of the disparate functions and services being advocated for each system. To this end, IIFDT develops a system-level evaluation testbed that allows for such studies to examine a parametric design space over the long-term. Such a capability is critical as it is unlikely that design of such complex systems can be sufficiently informed though physical testing of a single 'point' design.

Research in this area also tracks improvements in predictive capability (i.e. knowledge) through continuous identification and assessment of areas of uncertainty (i.e. knowledge gaps) that require investigation at Levels 1/2/3. This is accomplished through (1) the tracking of research progress both within IIFDT and across the community, and (2) on-going system analyses that identify emerging trends. The latter enables the project to identify phenomena of interest that may be hazard precursors, and to prioritize validation needs.

An important Level 4 research activity is to specify and regularly update, as appropriate, an assumed future state of the NAS as it relates to IIFDT research. This specification is to be coordinated closely with relevant contributors to NextGen developments, including the ASP-Airportal and ASP-Airspace projects, and referencing developments by the JPDO. This activity serves to define the scope of lower level research. Three terms are used for this specification: *Application Domain (AD)*, *Concept of Operations (ConOps)*, and *Scenario*. It is important to note that the research to specify future NAS states follows a systematic process of design and evaluation, with special attention to considering safety concerns from the start.

An *Application Domain* represents the design space for a system as constrained by a particular set of end-user requirements. For flight deck systems, IIFDT considers as the application domain a multi-dimensional design space spanning: Mission, Operating Environment, Target Level of Performance, Crew, Vehicle, and Equipage. Each of these parameters can vary, even within NextGen. The domain initially selected for IIFDT research is the *NextGen Terminal Area*. This scope is chosen to focus on future flight deck operations with the greatest risk exposure, complexity, and operator workload. An additional benefit of selecting this domain is the degree of collaboration and synergy it enables with multiple research focus areas within NASA's Airspace Systems Program – namely, all of ASP-Airportal's research focus areas, as well as ASP-Airspace's Super Density Operations (SDO) and System Level Design and Simulation Tools (SLDAST) research focus areas. A consistent view of a NextGen-based future state among all relevant research focus areas maximizes NASA's return-on-investment.

A *Concept of Operation (ConOps)* is a general description of how a system will operate (JPDOc, 2007). Given the selected domain (NextGen terminal area operations); IIFDT leverages ASP-Airportal and ASP-Airspace developments. Both have drafted, and continue to mature, ConOps for this domain (SDO, 2007; AP, 2007). IIFDT collaborates on these developments, contributing flight deck system-specific portions as required.

A *Scenario* is a description of an event or series of actions and events. Scenarios are developed to test plausible situations within a defined application domain where a system or ConOps requires either validation or analyses with respect to performance and safety. Specifically, scenarios are designed to allow researchers to expose, observe, and test hypothesized aspects of human or automation performance and/or interactions between flight deck components. Scenario descriptions include not only event/action sequences, but also metadata and attributes. Attributing the events within sequences may or may not be required, but timestamps, time delays, and temporal dependencies (i.e. if/then) within and across event sequences are attributes to consider. Metadata can provide information that is applicable to the entire scenario (e.g. night time, runway visual range). Depending on the scope of a given experiment, scenarios may include, for example, activities and operating procedures, and may describe not only events/actions within aircraft, but also events/actions within ATM/ANSP facilities and/or Airline Operations Centers (AOCs). IIFDT develops scenarios that are representative of event/action sequences within the defined AD and ConOps, with emphasis on potential off-nominal situations.

To re-iterate, a key Level 4 research product that drives all lower Level research is an assumed future state of the NAS. This state is captured as an application domain, a concept of operations, and a set of scenarios (milestone IIFD.FDS.1.1). Also, at regular intervals, re-assessments of flight deck system risk factors and barriers associated with transitioning to the NextGen-based domain are performed (milestone IIFD.FDS.2.1). A system-level evaluation testbed capability is advanced through incremental developments and integration of Level 3 solution concepts (milestone IIFD.FDS.3.1).

Because the advancement of flight deck system concepts benefits from leveraging and synergy across the broader community, activities in this Level 4 area include multiple forums (e.g. workshops, coordination meetings, and technical interchange meetings) involving representatives from industry, other government agencies, academia, and the other ARMD programs/projects – such as the ones mentioned above. Establishing an effective coordination and collaboration environment is essential for success in this research area. See Appendix B for current partnership activities.

Table 4-1. Level 4 Milestones – Flight Deck Systems that Improve Safety

Milestone	Title	Date	Exit Criteria
IIFD.FDS.1.1	Specification of NextGen-based flight deck system application domain, concept of operations and reference scenarios	Q4/FY09 Q4/FY11 Q4/FY13	Development and application of a systematic method for exploring the trade-space, designing and evaluating application domains, concepts of operation and scenarios for safety, capacity and efficiency; at a minimum, shall include a technical interchange meeting and/or workshop with relevant contributors from ARMD and external projects and programs; Results documented as reference information for subsequent L1/2/3 activities and made publicly available; Specifications should address, at a minimum, NextGen terminal area operations assumptions for domain and scenario parameters such as aircraft class, fleet mix, crew, weather, traffic, and airport environment, and equipage, and assumptions about, and performance metrics for, relevant entities in the system. (Decision Point, revised bi-annually)
IIFD.FDS.2.1	Assessment of flight deck system risk factors and barriers associated with enabling the NextGen-based application domain	Q4/FY10 Q4/FY12	Technical interchange meeting and/or workshop with relevant contributors from ARMD and external projects and programs; Results document risk factors and barriers considerate of L1/2/3 advances, and emerging trends or developments with respect to NextGen terminal area operations (see also IIFD.OP.4).

			(Decision Point, regarding re-scope of subsequent L1/2/3 research)
IIFD.FDS.3.1	Establish flight deck system evaluation testbed	Q3/FY10	Minimum success criteria: Simulator evaluation of at least one of the two L3 solution concepts (i.e. achieves IIFD.RAHS.1.2 or IIFD.DDS.1.2) and a conceptual design provided for integrating the other solution concept and accounting for potential interactions between solution concepts' functions and implementations.
IIFD.FDS.3.2	Demonstrate advanced flight deck system solution concept	Q3/FY12	Coordinated simulator evaluation of both L3 solution concepts as an integrated flight deck system (i.e. simultaneously achieves IIFD.RAHS.1.2 and IIFD.DDS.1.2, this evaluation would include assessing interactions between L3 concepts.

4.2 Level 3 – Multi-Disciplinary Solutions

Research at Level 3 postulates novel multi-disciplinary solutions that can increase performance, including safety, and represents far-term concepts currently facing development risk beyond industry's applied research portfolio. Such solutions cannot be enabled by considering technology, operating procedures, or human performance and training separately. Instead, an inter-disciplinary approach builds on the coordinated insights of human and machine performance and capability (such as integrating the products of Level 2 investigations). This inter-disciplinary approach is especially important given IIFDT's emphasis on designing for safety, as choices of mitigating risk via technology, procedures or crew training have long-term and profound impacts on many aspects of aviation operations.

Two Level 3 multi-disciplinary concepts are investigated: *Robust Automation-Human Systems (RAHS)* and *Displays and Decision Support (DDS)*. Research in these areas addresses key operational challenges associated with the NextGen-based domain identified at Level 4, and may be updated to reflect new knowledge or requirements identified by Level 4 activities.

Milestones are defined such that each Level 3 area embarks on parallel two-year RDT&E cycles. Within a given two-year period, a concept definition phase is followed by a development phase, and then an evaluation phase. Subsequent two-year periods may either refine the previous concept, switch to an alternate concept, or declare the research complete, at which time the project can move on to another Level 3 challenge. During the concept definition phases (every two years), research results and developments coming from Level 1 and 2 (and others outside IIFDT) will be considered, resulting in a design informed by state-of-the-art. Likewise, during the concept evaluation phases (every two years), results will be used to re-assess research issues that need to be addressed at Level 1 and 2 and the project may re-scope activities accordingly. This iterative process continues throughout the duration of the project – both horizontally (across time) and vertically (across levels). This process is clarified by the research milestones (to be discussed).

4.2.1 Robust Automation-Human Systems

Strategic Objective: Research, development, test, and evaluation of robust human-automation interaction concepts

Problem Statement: The term automation generally refers to a machine capability to perform functions normally attributed to humans. This research area considers, more specifically, automation that assumes functions that control some aspect of vehicle dynamics and/or operation of vehicle sub-systems. Of critical interest is the well-established tendency for this form of automation to not be robust, but instead limited to specific operating conditions and types of operation, and to a small set of fixed behaviors (i.e. modes). Because the automation cannot be proven to be safe in all potential conditions, the human is typically left responsible for supervising the automation and intervening in the event of any failure or operation outside the 'designed-for' operating conditions. Thus, the true robustness of automation can only be evaluated when the joint automation-human system is considered collectively.

Toward achieving this strategic objective within the Level 4-specified domain, research in this area begins by positing RAHS solution concepts for achieving safe Trajectory-Based Operations (TBO). TBO functions and procedures are a shift from clearance-based control to trajectory-based management, wherein aircraft fly negotiated trajectories while ATC manages flight progress with respect to these trajectories. Trajectory clearance data requirements, negotiation protocols, and compliance and monitoring become important factors to consider for designers of these operations and the systems that support them. Terminal area TBO requires strict adherence to flight path guidance due to traffic movement complexity, density, and limited airspace. Off-nominal events can have significant ramifications. In addition, the mix of aircraft equipage and performance capability poses particular challenges in the complex and compressed terminal airspace. To illustrate, consider the following as one possible concept. During the arrival phase, when an aircraft enters the terminal area**,** its onboard information management system (IMS) receives a conflict-free 4D trajectory from an ANSP to follow all the way to the gate. Simultaneously, the IMS computes an aircraft-specific trajectory that is deemed safe and efficient based on aircraft-based observations (e.g. traffic, weather, terrain information from sensors, databases, or datalink) and the IMS' knowledge of the aircraft flight envelope, dynamics, and context. The pilot is notified, if these two significantly differ, to initiate a negotiation until both agree to a specific trajectory, within limits on time and safety during the negotiation phase. A subsequent trajectory change may be necessary, for example, due to contextual changes in the environment (e.g., weather events) where safety may be compromised if the aircraft continues on the current path. Timing parameters, information quality requirements, and procedures may vary due to the increasingly tactical nature of such an operation as the aircraft gets closer to landing and taxi, and may include 'no negotiation' phases during critical junctures such as during final approach, landing, roll-out, and exit from the runway.

It is clear that automation will be required for the flight deck to achieve such TBO functions. Further, integrated human-automation functions must allow for accuracy, precision, and timeliness, and effective interaction between the human operator and the automation will be critical to aviation system safety. The design of current flight deck automation frequently establishes different operating modes that can lead to confusion for the pilot during flight and create opportunities for human error. During off-nominal events, automation complexity may lead to problems with graceful degradation and the ability to detect anomalies and mitigate their consequences. Therefore, the RAHS research topic will emphasize human-automation interaction principles and appropriate methods to investigate these principles as they are applied to the NextGen TBO terminal area operations; new automation solutions will be pursued that consider the roles and responsibilities of the operators and the automation, and may include such concepts as adaptive automation or "modeless" approaches to the design of flight deck automation.

Approach: Research within this topic applies methods, technology concepts, and operator performance lessons-learned from Level 2 to simultaneously design operating procedures and automated functions with particular emphasis on robust automation-human performance. Specifically, Level 2 research efforts associated with operator performance, such as human performance parameters associated with errors and their identification and mitigation, are critical to robust automation development and assessment. In addition, research within this topic will assist in addressing many of the research questions associated with human automation interaction and relevant design principles. Enabling avionics technologies and functions research at Level 2 is used by RAHS to assist in identifying appropriate flight deck tools to determine the necessary aircraft characteristics (e.g. equipage and capability) for addressing nominal and off-nominal events, and will help identify required performance of the necessary automation technologies for TBO in the terminal area. The Level 2 research area associated with design methods and tools assists in both the design and the evaluation of the robust automation concepts, procedures, and technologies.

Solutions posited and evaluated during RAHS research consider a range of possibilities from fully automated to partially-automated to perhaps even fully manual methods of flying aircraft along defined 4D paths. Solutions consider, for example, the potential benefits of allowing the automated functions to self-adapt or be adapted by the pilot in response to the needs of the pilot and the immediate situation. Systematic analysis establishes a detailed definition of the flight deck automation functions necessary for the NextGen operational environment. This analysis considers desired automation functions, including those that may not be possible, or practical, within current avionics architectures. As will be discussed, one of the research milestones in this area is to fully examine the trade-space of potential solutions. A number of operational environments may be considered as well, including, for example, continuous descent arrivals, closely-spaced parallel approaches and departures, metroplex operations, merging and spacing, and low visibility arrivals and departures. These will be largely influenced by close coordination with the ASP-Airspace and Airportal projects and their ConOps developments. Evaluations are made in the context of the application domain and reference scenarios established by the Level 4 activities previously noted (milestone IIFD.FDS.1.1).

Based on state-of-the-art, the initial set of challenges facing this area of research are:

- Unambiguous assignment of roles, responsibilities and functions, to human and automated agents; and systematic methods for predicting performance based on these assignments in both nominal and off-nominal conditions
- Rigorous and comprehensive methods for assessing human, automation, and joint human-automation performance, for structuring automation's functions to be comprehensible to pilots, and for designing automation to provide for robust human-automation interactions
- Methods to predict joint human-automation interaction performance in operating environments which have yet to be instantiated (such as NextGen's TBO)

These challenges to the design of RAHS solution concepts are periodically reviewed, helping to set requirements for supporting Level 1/2 research, as well as prioritizing activities within this area.

As prescribed by Level 4 (milestone IIFD.FDS.1.1), research in this area is tightly coordinated with the evolution of ASP ConOps developments. The operational environment is the NextGen terminal area; however, there are other parameters of the domain to consider. For example, single-pilot versus multiple-crew operations (including a mix of on-board and ground-based crew) may require dramatically different function allocation and human-automation interaction solutions.

To demonstrate the benefit of transformative changes in operation, the methods developed in this area are applied to designing solution concepts (milestone IIFD.RAHS.1.1) that are then tested in shared evaluation testbed(s) (milestone IIFD.RAHS.1.2). These testbed(s) allow for performance assessment of RAHS solutions in nominal and off-nominal conditions using a set of reference scenarios defined at Level 4 (milestone IIFD.FDS.1.1). Further, they support both larger integrative activities with other Level 3 areas, and smaller discipline-specific examination of Level 1 and Level 2 research questions.

Table 4-2. Level 3 Milestones – Robust Automation-Human Systems

Milestone	Title	Date	Exit Criteria
IIFD.RAHS.1.1	Hypothesized solution concept within specified application domain for flight deck system function allocation and human-automation interactions during 4-D trajectory-based operations	Q4/FY09 Q4/FY11 Q4/FY13	Operations and conceptual system designs for flight management tasks, role/responsibility assignments, technology/human functions for the NextGen terminal area environment described at L4, and documented performance metrics that the solution concept seeks to improve (see IIFD.FDS.1.1); (Decision point, revised bi-annually).
IIFD.RAHS.1.2	Evaluation of RAHS solution concept in relevant environment	Q3/FY10 Q3/FY12	Within the domain and scenarios defined at L4 (IIFD.FDS.1.1): (1) Results of hypothesis testing with respect to system performance documented, to include, at a minimum, analysis of effects on path, velocity, and attitude deviations from accepted standards; and on detection and recovery performance during off-nominal events; (2) Results of hypothesis testing with respect to human performance indicators (e.g. workload, situational awareness, engagement, procedural errors); no reduction in operator performance across a representative set of nominal and off-nominal conditions as compared with 2009 baseline. [L2, Operator Performance]; (3) Verification of avionics functionality against design. [L2, Enabling Avionics]; (4) Comparison of actual performance (human and machine) against modeled expectations. [L2, Design Tools]; (Checkpoint – Does the concept show promise; where do we need further work at L1/2; or should we change to another solution concept).

4.2.2 Displays and Decision Support

Strategic Objective: Research, development, test, and evaluation of information integration, abstraction, and conveyance concepts that support effective decision-making (both individual and collaborative)

Problem Statement: The availability of information to the users of NextGen (e.g. pilots, controllers, and others including airline operations control and air traffic flow managers) via a 'Net-Centric' capability is intended to improve decision making, safety, and operational efficiency. On the flight deck, pilots and automation will have access to information that may come from many sources, including on-board sensors and databases, communication channels (both voice and data link), and even other users. Most, if not all, of this information must be analyzed extensively by either humans or automated functions to convert raw observations/data into useful information. However, current research results highlight the potential to overload the human with extraneous information, as well as the potential to inadvertently distort decision making through its representation and presentation. In addition, depending on the level of air-ground integration, many aspects of pilot decision making will need to be collaborative with air traffic controllers and traffic flow managers, other pilots, and other entities such as airline operations centers. Multi-disciplinary solutions are needed to support pilot decisions that will often need to be made under time-pressure and in critical situations, and based on uncertain information coming from, potentially, a number of sources.

Approach: Research addresses three operational challenges that that require new display and decision support solutions and are of critical interest to the Aviation Safety Program: 1) achieving a "Better Than Visual (BTV)" flight operations capability; 2) providing Integrated Alerting and Notification (IAN); and, 3) enabling a highly Collaborative Working Environment (CWE) for flight deck system operators. These three challenges, or capability goals, allow for stressing three associated fundamental flight deck system research issues:

- BTV – Conveying large volumes of information effectively
- IAN – Information management and integrity
- CWE – Effective communication and collaboration among decision-makers

Examining the first issue in detail, the NextGen ConOps discusses 'equivalent visual operations' (EVO) as a key capability. EVO seeks to provide capacity equivalent to what is achieved in visual conditions (i.e. VMC) regardless of actual visibility. BTV extends this concept to mitigate unsafe events that occur even when the pilot has an unobstructed view outside the aircraft (e.g. wake turbulence upset, controlled flight into terrain, inadvertent entry into restricted airspace), and to aid pilots with interpreting the myriad of raw data elements that represent the state of the aircraft and its onboard systems. Combining these in an appropriate form can allow, for example, the portrayal of hazards along the projected flight path relative to the aircraft's ability to maneuver as well as guidance along optimal avoidance trajectories. BTV can also support NextGen concepts through, for example, visualization of intricate trajectories providing continuous guidance along negotiated 4D paths or relative to other aircraft. A fundamental question to be addressed is – What should flight deck displays portray to best support pilot decision-making? Selecting BTV and considering a Net-centric environment allows us to test concepts in an information-rich environment. Conformal or spatially-integrated information display concepts are proposed, but RDT&E for these and other novel methods of representing information and conveying it across various multi-modal media interfaces are also considered.

While BTV stresses and exposes the problem of how to convey large volumes of data, IAN stresses and exposes the problem of how to effectively manage available information and to do so while ensuring appropriate levels of integrity. Research develops and evaluates concepts for the temporal management of information (e.g. highlighting and updating newly-relevant information), as well as the signal processing and management of information received from dissimilar on-board and off-board sources to assess the context of the flight with respect to potential hazards. Research considers the flight deck interface (e.g. alert modality and the alert level) and includes the assessment of detected hazards and providing appropriate warning, caution, or "notifications" (e.g., the addition of information to, or removal from, displays). However presented, information management is integrated across the flight deck and provides sufficient integrity to support pilot information needs without risk of misinterpretation or inappropriate interruption.

Aspects of decision making as prescribed by the NextGen ConOps is clearly expanded from that of today's operations – most notably regarding interactions between pilots and controllers. Future collaborations will be enabled by a range of communication mechanisms, including voice, text/graphical displays of digital communications, and use of automated agents (either on the ground, in the air, or both) to describe and negotiate flight management decisions. The roles and responsibilities of each party in such collaborative environments will be determined in part by the dynamics of their communications; for example, time-critical actions in the flight deck may not be able to involve others, and cumbersome communication mechanisms may inhibit full transfer of relevant information. Display and decision-support designs must reduce the likelihood of communication errors, interpretation errors, and mis-understandings in such an environment. Likewise, future flight deck systems should support collaborative decision making, recognizing that merely providing a shared representation of the same information does not necessarily lead to a common understanding of the situation and that collaborative decisions may require communication about each other's interpretations and objectives.

Hypothesized solution concepts consider these three challenges comprehensively to best support human decision making through information presentation and communication. Within these concepts, questions are posed and solutions are evaluated. Examples include the correct information to present and when; the abstractions by which it should be represented and integrated; the methods to display it; and the enabling technologies needed to generate it. Assumed distinctions between out-the-window visual acquisition and 'inside display' acquisition require careful examination. Known concerns with maintaining and improving situation awareness are fundamentally addressed in all aspects of design, and this design serves as a basis for assessment and validation of systematic methods and models for identifying design requirements. This process allows for contextually-relevant assessments of Level 1 and Level 2 research products and findings, while also identifying emergent Level 1 and Level 2 research needs.

Within the selected domain (NextGen Terminal Area Operations), DDS solution concepts specify an environment (both operational and architectural) that provides appropriate situation awareness, effective individual and collaborative decision-making, and resulting action by the pilot-vehicle system. Concepts are developed from two perspectives, operator performance and avionics performance, by applying integrated design methods and tools, reflecting the three Level 2 themes of the project. To illustrate, consider an example concept taking first the avionics perspective. An onboard information management system is conceived wherein it receives data from various sources while operating within the terminal area and this data is continuously updated until arriving at the gate or departing the terminal area. Data is received from multiple data links, onboard systems (e.g. both forward-looking and in-situ sensors, navigation systems), onboard databases/models, and crew members. Information types include aeronautical and meteorological information services (AIS/MET datalink), controller instructions, navigation information, aircraft systems status information, geo-spatial information (e.g. terrain, obstacles, and airport features), and traffic information. The information management system integrates and translates all inputs and supports crew decision-making by providing the required context-relevant information with appropriate levels of integrity and distributed across a multi-modal crew-vehicle interface.

Next, taking an operator performance perspective, context-specific information tailoring methods may enable effective decision-making with respect to all piloting functions. Spatial and temporal distribution of information across available display space is optimized to reduce clutter and to promote best use of attention resources and engagement levels. Although information may be primarily 'pushed' to the crew as-needed, the crew always is able to 'pull', or request, specific information elements as desired and to search though the information space to examine for patterns and trends. New concepts for communicating information via (or with) flight deck technology may use multiple modalities including, for example, text-to-speech and speech-to-text. Aural and visual modalities for alerts and information are balanced to fit the contextual needs of the flight crew. Novel display concepts (e.g., head-worn) are created to enable spatially distribution of information beyond what is available using only fixed cockpit displays of limited size and fixed location. Conformal display of information for spatial-context, and head-up virtual visual references are generated such that the need for a VFR/IFR transition is obviated. The flight crew also has visual awareness of abstract features of operational import, but not available even in VMC (e.g. airspace restrictions, active runways, wake and clear-air turbulence areas for optimal trajectory planning).

From conceptual DDS solutions - each building upon the lessons-learned of the past - refinements are continually identified and developed from this RDT&E process such that the end results are tested to confirm function and procedure designs that provide pilots (or automated agents) information they need, when and how they need it, and with quality they can trust. The solution refinement process addresses detection and resolution of erroneous information and actions, anticipation of key decision points, evaluation and refinement of potential actions, action selection, and reconfiguration of the other vehicle systems to implement selected actions. Additional considerations for effective support during terminal area operations include compatibility with uncertain, dynamic, time-varying situations and complex multi-tasking operations with competing demands on crew resources and attention.

As with the RAHS research approach, DDS concepts are developed to demonstrate the benefits of transformative changes in operations and to evolve methods for the design and evaluation of such concepts. The iterative approach begins by positing solution concepts (milestone IIFD.DDS.1.1) that are then tested in shared evaluation testbed(s) (milestone IIFD.DDS.1.2). These testbed(s) allow for performance assessment of DDS solutions in nominal and off-nominal conditions using a set of reference scenarios defined at Level 4 (milestone IIFD.FDS.1.1). Further, they support both larger integrative activities with other Level 3 areas, and smaller discipline-specific examination of Level 1 and Level 2 research questions.

Table 4-3. Level 3 Milestones – Displays and Decision Support

Milestone	Title	Date	Exit Criteria
IIFD.DDS.1.1	Hypothesized solution concept within specified application domain for flight deck system displays and decision-support functions providing for better than visual operations, integrated alerting and notification, and collaborative environments	Q4/FY09 Q4/FY11 Q4/FY13	Operations and system conceptual designs for information conveyance and avionics functional requirements for the NextGen terminal area environment described at L4, and documented performance metrics that the solution concept seeks to improve (see IIFD.FDS.1.1); (Decision point, revised bi-annually).
IIFD.DDS.1.2	Evaluation of DDS solution concept in relevant environment	Q3/FY10 Q3/FY12	Within the domain and scenarios defined at L4 (IIFD.FDS.1.1): (1) Results of hypothesis testing with respect to system performance documented, to include, at a minimum, analysis of effects on path, velocity, and attitude deviations from accepted standards; and on detection and recovery performance during off-nominal events; (2) Results of hypothesis

			testing with respect to human performance indicators (e.g. workload, situational awareness, engagement, procedural errors, flight technical error); no reduction in operator performance across a representative set of nominal and off-nominal conditions as compared with 2009 baseline. [L2, Operator Performance]; (3) Verification of avionics functionality against design. [L2, Enabling Avionics]; (4) Comparison of actual performance (human and machine) against modeled expectations. [L2, Design Tools]; (Checkpoint – Does the concept show promise; where do we need further work at L1/2; or should we change to another solution concept).

4.3 Level 2 – Discipline-Specific Research

Research conducted at Level 2 targets barriers that inhibit the development and/or evaluation of the posited Level 3 solutions to operational challenges. As described in Section 4.2, these barriers can be categorized as follows:

Robust Automation-Human Systems
- Roles and responsibilities
- Function allocation and performance
- Human-automation interaction

Displays and Decision Support
- Conveying large volumes of information
- Information management and integrity
- Effective communication and collaboration between decision makers

Consistent with the IIFDT research framework, Level 2 activities that address these barriers are distributed among three topics: (1) Operator Performance; (2) Enabling Avionics; and (3) Design Tools.

4.3.1 Operator Performance

Strategic Objective: Improve our understanding human performance as it relates to safety of flight and operational efficiency.

Problem Statement: Human flight deck functions are defined by safety, social, and economic motivations (Hancock, 1998), and as such they are a unique element of the flight deck system. When considering flight deck systems within the context of the NextGen terminal area, the performance of these functions may be affected by several factors including, for example, physical condition, state of awareness, emotional state, task demands, cognitive demands, and environment and operational context. Although extensively studied in various domains, the inter-relationship of these factors in their manifestation on performance remains largely unknown. IIFDT research addresses key unknowns that must be addressed to develop the previously-described Level 3 multi-disciplinary concepts. These key unknowns are shown in Table 4-4 as they relate to the barriers identified for each Level 3 concept. Also shown are supportive Level 1 foundational knowledge that will be discussed in Section 4.4

Table 4-4 can be summarized by observing that new methods hold the key to understanding operator performance and thereby ensuring the provision of both ‘robust human-automation interaction’ and ‘context-relevant decision support’ for future flight deck systems. In addition, several of the needed methods are applicable to multiple barriers facing both of these Level 3 capabilities.

Table 4-4. Keys to Understanding Human Performance for IIFDT Concepts

Level 3 Multi-Disciplinary Concept and Barriers to Overcome	Keys to Understanding Human Performance	Supportive Foundational Knowledge (Level 1)
Robust Automation-Human Systems • Roles and responsibilities • Function allocation and performance • Human-automation interaction	• Methods for fostering appropriate use of automation (IIFD.OP.2) • Methods for supporting communication and collaboration among multiple intelligent agents (human-automation) (IIFD.OP.3) • Methods for reducing the propensity for, or consequences of, human error via effective application of automation (IIFD.OP.4)	• Identifying operationally-relevant characteristics of NextGen operators (IIFD.OC.1) • Identifying information requirements to support operator roles (IIFD.OC.2) • Characterizing operator functional state (IIFD.OC.3) • Operator state sensing (IIFD.SS.5) • Methods for exploiting cross-modality information transfer (IIFD.MM.3) • Predictive modeling of human interactions (IIFD.IM.2)
Displays and Decision Support • Conveying large volumes of information • Information management and integrity • Communication and collaboration among decision-makers	• Methods for conveying and assessing situation awareness (IIFD.OP.1) • Methods for fostering appropriate use of complex information sources (IIFD.OP.2) • Methods for supporting communication and collaboration among multiple intelligent agents (human-human) (IIFD.OP.3) • Methods for supporting human decision-making; and reducing the propensity for, or consequences of human error (IIFD.OP.4)	• Identifying operationally-relevant characteristics of NextGen operators (IIFD.OC.1) • Identifying information requirements to support operator roles (IIFD.OC.2) • Evaluating interface technologies (IIFD.MM.1-.2) • Methods for exploiting cross-modality information transfer (IIFD.MM.3) • Theoretical approaches to presenting large volumes of data (IIFD.IM.1)

Improved and novel sensors and communication technologies promise to improve the quantity and quality of information available to pilots. Further, data fusion and automated information selection and filtering technologies aim to make multiple sources of raw data into useful information for pilots. This research element is concerned with the increasing, and increasingly important, need to ensure appropriate situation awareness given these new sources and forms of information, and as applied to the new NextGen operational concepts. A corresponding requirement is the ability to assess situation awareness in these operational contexts, especially an operator's awareness of operating conditions relative to the automation's boundary conditions (i.e., RAHS concepts) and relative to appropriate use of fused and/or uncertain information over imperfect communication channels (i.e., DDS concepts). Communication among humans is a crucial element of NextGen, and we must closely attend to designing interfaces that support such information transfer and collaboration, and to defining the roles and responsibilities among teams of operators that afford effective and efficient operations. Similarly, as automation becomes more sophisticated, such notions will extend to the design of collaboration within teams of automated agents and human operators. Finally, we focus on technologies that improve the quality of human operator decision-making in the flight deck, and support operators such that human errors are less likely.

With the development of the Level 3 RAHS and DDS concepts, we regularly assess the degree to which they support the performance objectives and the ability of operators to achieve these objectives. The novelty of these solution technologies and the operational context in which they are to be used may necessitate novel approaches to ascertaining the quality of responses (e.g., accuracy and timeliness of decisions) as well as the characteristics of human errors that may emerge.

Approach: The purview of this research topic, therefore, is to provide design guidance (e.g. data from empirical research) to developers that help enable a "better than visual" capability, a collaborative work environment, and integrated alerting/notification for pilots; that foster the appropriate use of advanced automation and information systems; and that result in robust automation/ human systems for the purpose of trajectory based operations. Developing such guidance will improve situation awareness, workload modulation, and human error resistance and resilience. The appropriate design of technologies to support operator performance requires a concomitant approach to evaluating related human performance constructs. Consequently, this research area also supports concept design development by improving operator performance assessment for conceptual design evaluations at Level 3 (milestones IIFD.RAHS.1.2 and IIFD.DDS.1.2).

Four research subtopics explicate the intended contributions within this Level 2 topic and correspond directly to research milestones and expected outcomes.

(IIFD.OP.1) Methods for conveying and assessing situation awareness. This research seeks to more sensitively and validly assess the abstract concept of situation awareness. A popular model of situation awareness defines three levels: the perception of the elements in the environment within a volume of time and space {Level 1 SA}, the comprehension of their meaning {Level 2 SA}, and the projection of their status in the near future {Level 3 SA} (Endsley, 1995). Most commonly, situation awareness has been assessed with subjective reports either by the subject or an observer (e.g., SART, SWORD, and SARS). More objective situation awareness assessment techniques use explicit probes (i.e., SAGAT) or performance-based metrics (e.g., Tenny et al. 1992; Pritchett & Hansman, 2000) developed through careful manipulation of scenarios. Observational techniques also include the direct observation of visual attention directing with oculometrics (Di Nocera et al, 2007), and have more recently begun to extend this approach to investigate neuro-physiological correlates of situation awareness, specifically operator expectancy, attention management, and appreciation of significant changes in their environment (c.f. Wilson, 2000). Research in this area improves on the methods and metrics used to assess safety-critical elements of a NextGen operator's situation awareness, specifically with respect to operating in the terminal environment and for the purpose of accomplishing safe TBOs, operating with a BTV capability,

appreciating hazards that impinge on their mission, and collaborating with others. Methods are developed for development of DDS and RAHS solution concepts and results inform Level 3 refinements (MS IIFD.OP.1.1, 1.2, 1.3, and 1.4). In addition, Level 3 concept evaluations (MS IIFD.RAHS.1.2 and IIFD.DDS.1.2) are supported by operator performance assessment methods.

(IIFD.OP.2) Methods for fostering appropriate use of automation and complex information sources. Level 1 and Level 2 research elsewhere in IIFDT, and externally, develop improved and novel sensors and communication technologies with the promise of improving the quantity and quality of information available to pilots. Data fusion and automated information selection and filtering functions will be designed to make this information more manageable for pilots. These new opportunities necessitate increased attention to ensure that pilots understand the limitations of data (e.g., data transmission errors, temporal and spatial resolution, uncertainty, and integrity) and, given these limitations, its appropriate use. This is particularly important for presentation elements that derive from the fusion of several data streams with different "information quality," and for presentation elements that may include parameters that express the uncertainty or conditionality of that data.

Some forms of automation can be considered "tools" that extend or amplify the capability of an operator (c.f. Boy). Concerns center on whether the tool is used appropriately, i.e., is the context in which it is employed consistent with the design boundaries for it, or operational modes selected within it. Thus, for these forms of automation it is equally important that their boundary conditions and modes of operation are transparent to the operators. Performance metrics would assess the capability provided by the operator when using this tool, rather than these as separate elements of the system.

Research in this area develops guidelines based on operator performance evaluations of new methods for encouraging the appropriate use of information (e.g., DDS solutions) and automation (e.g., RAHS solutions). This research is tightly coordinated with an associated design tool development activity to be discussed (see Section 4.3.3, IIFD.DM).

(IIFD.OP.3) Methods for supporting communication and collaboration among multiple intelligent agents. As noted earlier, future NextGen operational concepts will rely heavily on effective and efficient communication and collaboration of intelligent entities in the system. Most importantly and immediately, this implies a focus on research that improves the communication capabilities among human operators. Future collaborations will be enabled by a range of communication mechanisms, including voice, text/graphical displays of digital communications, and use of computer interfaces and automated agents (either on the ground, in the air, or both) to mediate between decision makers. The nature of such collaborations will be strongly impacted by concerns with operator performance; for example, time-critical actions in the flight deck may not be able to involve others, and cumbersome communication mechanisms may inhibit full transfer of relevant information. Specific concerns with communication among decision makers include interpretation errors and mis-understandings in the NextGen application domain. Providing a shared representation of the same information does not necessarily lead to shared situation awareness among operators given the differences in how they will interpret the information and in their goals and objectives. Research in this area will develop guidelines for appropriate distribution and sharing of situation awareness among team members relative to defined roles and responsibilities, and performance evaluations of collaborative decision making.

As automation becomes more sophisticated, we envision that some forms may be more appropriately considered "team members" than the "tools" addressed in IIFD.OP.2. Previous research in social constructs of trust and common understanding between human/human dyads (e.g., Barber, 1983) can be extended to human/automation interactions (e.g., Lee & Moray, 1994). This type of interaction has been termed a "joint cognitive system," to emphasize that both the "intelligence" of the human and the automation are contributing to system performance (c.f. Boy, 1997; Brezillon and Pomerol, 1997). Similar to research required for well-functioning human teams, an important aspect of research in this area addresses the appropriate roles assigned to human and automated agents in NextGen concepts, and the determinants as well as the dynamism of these roles. Research in this area must similarly not only attend to the interface issues associated with improving the coordination among human and automated agents, but also performance assessment in such mixed teams.

(IIFD.OP.4) Methods for supporting human decision-making and reducing the propensity for, or consequences of, human error. While the former research areas address the human operator's environment in terms of information, tools, and team structures, this latter one aims to improve and assess human performance directly. With the complexity of NextGen operations and the volume and forms of additional data potentially available to the pilot, we have opportunities and obligations to better support decision making processes, and ensure that the pilot can remain the most effective flexible problem solver in the flight deck. Given the scope of the RAHS and DDS concepts for NextGen terminal area operations, new, unexpected human error vulnerabilities may emerge. Previous research in this area has described characteristic failure modes in human information processing and action selection. For example, predictable error forms have been identified for automation mode confusion (e.g., Sarter & Woods, 1995; Leveson & Palmer, 1997). Research in this area aims to use such findings, and those produced in the related Level 1 operator characterization topic, to analyze IIFDT concepts for human-error predisposing conditions (this jointly with the Level 2 'Design Tools' topic); to develop methods for identifying error-likely conditions during operations; and to develop intervention concepts for reducing the probability of their manifestation, or to mitigate the magnitude and propagation of their deleterious effects.

Research within this Level 2 topic (Operator Performance) rests on foundational research discussed in the Level 1 Operator Characterization topic to derive user-centered design requirements. This Level 2 research also drives Level 1 Sensing, Signal Processing, and Hazard Characterization research to develop sensors that can sensitively, robustly and validly assess hazards associated with operator functional state, and Level 2 Enabling Avionics research with respect to integration into information management and function allocation capabilities.

Outcomes: Within the context of the IIFDT application domain – the NextGen terminal area – and the Level 3 solution concepts under investigation, research within this topic expects the following advancements over the course of study.

Table 4-5. Level 2 Milestones – Operator Performance

ID	Title	Date	Exit Criteria
IIFD.OP.1	Methods for conveying and assessing situation awareness	Q3/FY09	(IIFD.OP.1.1) IIFD report documenting literature review of out-of-the-loop performance problems, identifying concepts for rapid situation awareness spool-up and human resumption of control; this interim report would be made publicly-available via the IIFDT website or alternate means subject to NASA's public-release approval process. (IIFD.OP.1.2) Compare a haptic-multimodal interface concept for NextGen-

			based terminal area operations to a representative current-day interface by evaluating effects on operator performance and situation awareness (see also IIFD.MM.OC.3 and IIFD.MM.3). (IIFD.OP.1.3) Technical or contractor report submitted documenting relevant parameters to consider when presenting NextGen-unique alerts in future Level 3 evaluations (see IIFD.DDS.1.2 and IIFD.RAHS.1.2). (IIFD.OP.1.4) NASA TM or journal article submitted that documents evaluation of concepts to aid operator re-entry into automated operations; this assessment will address situation awareness prior to re-entry and situation awareness and performance after resuming control as compared to control conditions; These evaluations will be conducted using a low-fidelity aviation simulation experimental platform.
		Q4/FY10	(IIFD.OP.1.5) Contractor report submitted that describes requirements for presenting 4D+ uncertainties associated with potential hazards in the external environment; Requirements will consider uncertainties associated not only with 3D location and time; but also with the degree of hazard potential in an area at a point in time, and the certainty of this (e.g. as reflected by different sensing inputs); Additionally, there are uncertainties associated with how all of these characteristics would change over time and therefore for the ability to predict future impacts of potential hazards.
		Q1/FY11	(IIFD.OP.1.6) Contractor report submitted that describes results of human-in-the-loop evaluation of hazard conflict probes for their effects on operator situation awareness (conflict detection time) and performance (avoidance maneuver effectiveness & efficiency) during terminal area operations.
		Q1/FY11 Q3/FY13	(IIFD.OP.1.7 and IIFD.OP.1.8) NASA TM or conference paper submitted that identifies and summarizes remaining research questions with respect to improving situation awareness for future DDS and RAHS concepts; these questions will come from lessons-learned resulting from all relevant activities within the project, as well as tracking state-of-

			the-art.
IIFD.OP.2	Methods for fostering appropriate use of automation and complex information sources	Q3/FY09	(IIFD.OP.2.1) Open-source software release of an updated Multi-attribute Task Battery (MATB); This update redesigns the tool for current day operating systems and computers, and extends the researcher interface capabilities; A companion NASA TM submitted that provides guidelines for how to conduct studies with the MATB, and provides an annotated literature database of prior research results based on use of this experimental platform.
		Q4/FY09	(IIFD.OP.2.2) NASA TM or conference paper submitted that reviews methods and issues concerning operators' trust in the automation and/or complex display concepts relevant to the Level 3 concepts (e.g., temporal and spatial uncertainty inherent in displayed information from sensors and fused sources, and the explicit indications of such; explicit indications of the possibility of predicted states, and uncertainty regarding the function of automation); The report will review best practices in assessing appropriate and experienced trust for such systems, and highlight where further guidance and metrics are needed to support design, evaluation, certification, and training to optimally manage operator's trust of automated agents and complex information.
		Q1/FY10	(IIFD.OP.2.3) Contractor report submitted that documents recommended metrics for assessing human performance with a Bayesian IAN system for eventual flight deck evaluation at Level 3; A Bayesian-based IAN can produce certainty levels associated with indications, alerts and notifications, conditional on contextual factors, and therefore provides an opportunity to provide sensitive representations of information certainty; These metrics will be useful in subsequent HITL IAN evaluations which will characterize how human performance may differ when a level of certainty is conveyed by the system.
		Q3/FY11 Q3/FY13	(IIFD.OP.2.4 and IIFD.OP.2.5) NASA TM submitted that analyzes results of Level 3 evaluations of DDS and RAHS concepts for specific insights into ensuring appropriate use of automation and complex information sources (see

			IIFD.DDS.1.2 and IIFD.RAHS.1.2); Compares with the current state of knowledge in the field, and identifies the most pressing research questions in automation use relative to advancing the DDS and RAHS concepts.
IIFD.OP.3	Methods for supporting communication and collaboration among multiple intelligent agents	Q4/FY09	(IIFD.OP.3.1) NASA TM or conference paper submitted documenting variables that characterize operator and adaptive controller interplay; This work is collaborative with efforts in the IRAC project to design adaptive controllers that reconfigure in response to aircraft malfunction (see IRAC technical plan milestones IRAC-IDFC-1.1.1.1 and 1.1.2.1); The IIFD aspect focuses on supporting the human operator serving as a monitor and as an agent for intervention if necessary.
		Q4/FY09	(IIFD.OP.3.2) Contractor report documenting results of a fast time simulation (continuous descent approach in the NextGen environment with a modified FMS looking at typical human error scenarios) evaluation of static function allocation policies. Metrics include: workload based on task load, human performance modeled resource loading, contiguity of function allocation over time, consistency with actor's role, disruption to procedures, appropriateness with respect to human cognitive control mode or to automation's designated functional boundaries, stability of human experience (i.e., minimizing interruptions and disruptions), and team robustness to system disturbances. (IIFD.OP.3.3) Contractor report documenting results of a simulation evaluation comparing dynamic and static function allocation policies; Metrics include: workload based on task load, human performance modeled resource loading, contiguity of function allocation over time, consistency with actor's role, disruption to procedures, appropriateness with respect to human cognitive control mode or to automation's designated functional boundaries, stability of human experience (i.e., minimizing interruptions and disruptions), and team robustness to system disturbances. (IIFD.OP.3.4) NASA TM or contractor report submitted documenting interviews with NextGen stakeholders and

			investigators discussing requirements for supporting multi-agent coordination, communication and decision-making in future terminal area TBO environments.
		Q3/FY10	(IIFD.OP.3.5) Conference paper submitted describing proposed concepts to improve pilot use of adaptive controllers; This work interfaces with IRAC project milestones IRAC-IDFC-1.1.1.1 and 1.1.2.1 to design adaptive controllers that reconfigure in response to aircraft malfunction; The IIFD work focuses on how to design these to also support the requirements of the human operator acting as monitor and as an agent of intervention if necessary. (IIFD.OP.3.6) NASA TM or conference paper submitted documenting a human-in-the-loop laboratory-based simulator evaluation of concepts for ensuring effective team coordination, communication, and group decision making in NextGen terminal area operations; concepts to be considered include, at a minimum, those aspects of the Level 3 concepts related to these issues (see IIFD.DDS.1.1 and IIFD.RAHS.1.1); Recommendations will be provided in support of the Level 3 evaluations.
		Q3/FY11	(IIFD.OP.3.7) NASA TM or conference paper submitted documenting results of human-in-the-loop evaluation of pilot interaction with adaptive controllers to assess joint performance; This work is collaborative with IRAC project research to design adaptive controllers that automatically reconfigure in response to aircraft malfunction (see the IRAC project technical plan, milestones IRAC-IDFC-1.1.1.1 and 1.1.2.1); The IIFD aspect focuses on supporting the requirements of a human operator serving as a monitor and as an agent for intervention if necessary.
		Q3/FY11 Q3/FY13	(IIFD.OP.3.8 and IIFD.OP.3.9) NASA TM submitted that summarizes analysis of results of Level 3 evaluations of DDS and RAHS concepts for specific insights into ensuring appropriate and effective multi-agent communication and collaboration (see IIFD.DDS.1.2 and IIFD.RAHS.1.2); compares with the current state of knowledge in the field, and identifies the most pressing research questions in communication and coordination relative

			to advancing the DDS and RAHS concepts.
IIFD.OP.4	Methods for supporting human decision-making and reducing the propensity for, or consequences of, human error	Q4/FY09	(IIFD.OP.4.1) Contractor report submitted documenting an approach to evaluating human performance response to an IAN system based on deviations from modeled (predicted) operator behavior. (IIFD.OP.4.2) NASA TM or conference paper submitted documenting the design and effectiveness of the PICE (Preventing Inadvertent Commission Errors) technology to mitigate inadvertent commission errors by employing confirmation-of-intent guard(s) that employ an EEG-based determination of engagement; This report documents results of an initial laboratory test of a prototype to assess mitigation of this form of error in a desktop human-computer interaction task; The report concludes with a discussion of further developments required for such a system to be fielded in a flight-deck.
		Q2/FY10	(IIFD.OP.4.3) NASA TM submitted documenting an analytic model of emergency and abnormal checklist design features and human errors associated with some of these features; The model is designed to predict checklist design features that have been previously empirically-linked with increased human error in separate studies; Implementation guidelines will be provided for paper, stand-alone electronic, and integrated electronic checklists.
		Q4/FY10	(IIFD.OP.4.4) Journal article, NASA TM, or book chapter(s) submitted that detail the design of procedural and technological countermeasures for individual operators and avionics designers to reduce the vulnerability to prospective memory errors; These countermeasures will be based on analysis of errors and causes of errors in checklist execution, monitoring, and concurrent task management; This design guidance will be provided to Level 3 ConOps development activities (IIFD.DDS.1.1 and IIFD.RAHS.1.1).
		Q4/FY12	NASA TM or contractor report submitted that describes scenario elements and metrics for evaluating crew performance with respect to potential prospective memory errors; These will be identified for the evaluations of DDS and RAHS

			concepts; Relevant metrics and scenario elements will be based on prior literature reviews, jumpseat observations, and will use methods from Line Operational Safety Audits (LOSA) and Threat and Error Management (TEM).

4.3.2 Enabling Avionics

Strategic Objective (SO-3): Research, development, test, and evaluation of enabling avionics technologies and functions to ensure and support safe operations.

Problem Statement. Avionics can be simply defined as electronics designed for use in aerospace vehicles, and avionics are the fundamental technology in flight deck systems. Examples include communication, navigation, and surveillance (CNS) and vehicle system monitoring systems. The Level 3 concepts present some salient challenges for avionics. The overarching challenge is to develop a comprehensive system for integrating information from various sources for distribution to many agents, and to do so with a quality of service (e.g. integrity) commensurate to its use. This Level 2 research topic is specifically concerned with required advances in state-of-the-art avionics and avionics functions, for the purpose of making possible and practical the safest NextGen-capable cockpit.

Historically, information processing has been largely segregated by function (i.e. 'black boxes'), with the pilot serving as the information integrator. A key design trade that must be explored is the efficacy of more integrated designs versus traditional segregated designs. How far should we go with integration before we lose the benefit of independence? For example, consider today's capabilities with respect to detecting external hazards: TCAS, TAWS, X-band weather radar, radar altimeter, data link, EVS sensors, and ATC communication radios are almost exclusively independent 'black box' functions, with integration largely limited to issuing alerts singly according to a fixed priority scheme (e.g., Proctor, 1998). Each of these subsystems provides information about the external environment that the pilot must continually assess against visual out-the-window observations for a global safety perspective. Confounding this assessment, each of these subsystems provides information of differing quality. Most are certified as 'advisory-only,' hence pilots are trained to not use them as the sole means of determining safety of flight. A few (e.g. the radar altimeter on commercial transport aircraft) are certified to higher levels (i.e. 'flight critical') where a higher level of performance can be expected, but only for specific phases of flight (e.g. during landing flare). This example illustrates a limitation of segregated designs that has resulted in increased risk of inadvertent mis-interpretation or mis-use of information during flight.

Although more and more information management responsibility has been allocated to the automation for specific functions (e.g. communications, navigation, surveillance), it is becoming unreasonable to have all cockpit avionic subsystems operate independently, sending streams of information to the pilot and competing for attention and time. Integrated approaches are required, but several research questions must be addressed. For example, how can multiple input streams be best integrated to form the best estimates of environmental state, especially when these input streams may be internally conflicting, when different algorithms may lead to conflicting alerts or advisories, or when they may need to alert on several different types of hazards or situations whose mitigations may need to be coordinated (e.g., Song & Kuchar, 2003)? Likewise, how can 'hard' and 'soft' constraints, and deterministic and probabilistic representations, be coordinated? IIFDT research within this topic answers such questions by developing those new avionics functions required specifically to enable the previously-described Level 3 multi-disciplinary concepts. Such functions are shown in Table 4-6 as they relate to the barriers identified for each Level 3 concept. Also shown are supportive Level 1 foundational knowledge discussed in Sec. 4.4.

Table 4-6 illustrates that integrated information management is a key supportive capability enabling the provision of both ‘robust human-automation interaction’ and ‘context-relevant decision support’ for future flight deck systems. Research is driven by needs as they are identified, including periodic re-assessment to respond to unexpected discoveries that may have the potential to transform the cockpit in ways not imagined in the original drafting of this technical plan. As such, investment within this Level 2 topic (and the Level 1 research that supports it) includes both directed and exploratory research, but is bounded by the IIFDT application domain (NextGen Terminal Area Operations) and the Level 3 conceptual design and evaluation efforts. In addition to focused investigations, research also facilitates use of relevant new technology by surveying developments in the state-of-the-art so that work can be coordinated with others external to IIFDT and new developments can be exploited.

Table 4-6. RDT&E of Enabling Avionics Functions for IIFDT Concepts

Level 3 Multi-Disciplinary Concept and Barriers to Overcome	Enabling Avionics Functions RDT&E	Supportive Foundational Knowledge (Level 1)
Robust Automation-Human Systems • Roles and responsibilities • Function allocation and performance • Human-automation interaction Displays and Decision Support • Conveying large volumes of information • Information management and integrity • Communication and collaboration among decision-makers	*Integrated Alerting and Notification (IAN)* • Information collection and management for reliability and integrity of service (IIFD.EA.1) • Information processing for decision support (IIFD.EA.2)	• Identify information requirements (IIFD.OC.2) • Forward-looking remote sensing (IIFD.SS.1, SS.4) • Image processing (IIFD.SS.2) • External hazard char. (IIFD.SS.3, SS.4) • Operator state sensing (IIFD.SS.5) • Visual interface technologies (IIFD.MM.1) • Aural/speech interface technologies (IIFD.MM.2) • Methods for exploiting cross-modality information transfer (IIFD.MM.3) • Theory for presenting large volumes of data (IIFD.IM.1) • Predictive modeling of human interactions (IIFD.IM.2)

Approach. Research within this topic views the avionics element of the flight deck system from the perspective of an information system. Research at this level does not develop components or ‘back boxes’ per se. Rather, we investigate the development of high-level functions and systems that integrate the requisite avionics components and their associated products. Integrating components in this case means the incorporation of data and the coordination of function. In the NextGen cockpit, the product of the avionics system is a dynamic information management capability that can be drawn upon to support the human interface as well as supply other systems (e.g. control systems) with context-relevant data on demand.

Research considers in particular the concept of an Integrated Alerting and Notification (IAN) function supportive of both the DDS and RAHS concepts. NextGen flight deck systems require sophisticated information management, including new automation functions responsible for notification of both immediate hazards and situations requiring re-planning or coordination. Research in this topic develops an IAN function that continuously monitors information from all available sources to evaluate hazard potential and other constraints on normal operations. The IAN function draws information from on-board sources (e.g. sensors, databases, and the crew) as well as from off-board sources via data link, and potentially even voice communications, to provide context-relevant decision-support to the pilot and to other aircraft automation functions. Research in this topic is centered on the experimental development of such an IAN function, primarily in the form of a modeling and simulation environment. This environment allows for the concept to readily evolve over time to include or exclude particular functions or interfaces as the higher level (Level 3 or 4) ConOps or Application Domains change.

Research within this topic also leverages and integrates Level 1 investigations and results. Specifically, the IAN function concept incorporates models for data sources such as sensors (see Section 4.4.2) and includes a representation of a multi-modal interface design (see Section 4.4.3). The resulting IAN model becomes a scalable testbed for the incorporation and interfacing of various sensors, data links, and other data sources and provides for the development and experimentation in conjunction with a human interface design concept developed at Level 3. The results of this investigation allow for the realistic modeling and experimental instantiation of the IAN function to support the testing of solution concepts postulated at Level 3.

Research is decomposed into two subtopics both supportive of the study of an IAN design that can provide for safe NextGen operations: 1) information collection and management for reliability and integrity of service; and 2) information processing for decision support.

(IIFD.EA.1) Information collection and management for reliability and integrity of service. Research in this subtopic develops and evaluates an architecture that integrates the collection of operationally-relevant data from the various sources, and monitors for potential hazards to continued safe flight along likely future trajectories. This includes improving machine abilities to estimate situation and operational status, evaluate external hazard potential, evaluate vehicle state hazard potential (leveraging IVHM research), and evaluate operator state hazard potential. This function also applies information blending, fusion, and filtering as appropriate to provide for required accuracy, availability, integrity, and continuity of service. Data link information management and translation is also addressed. Although conceptual designs are realized for the purpose of evaluation, the primary objective of this research is requirements analysis and development of generalizable methods and models that can be applied during the design of information management functions across various application domains.

(IIFD.EA.2) Information processing for decision support. Research in this subtopic addresses the next level of functionality – providing a bridge between information that has been collected (IIFD.EA.1) and the information that must be provided to the crew (or an automated agent). This includes, for example, multi-hazard evaluation and prioritization, information classification, and tactical hazard recovery path (or guidance) generation, negotiation, selection, management, and tracking. All developments within this subtopic are coordinated with the development of the human interface information transfer

requirements derived for an IAN function supportive of NextGen operations, and more specifically the Level 3 DDS and RAHS concepts.

Outcomes: Within the context of the IIFDT application domain – the NextGen terminal area – and the Level 3 solution concepts under investigation, research within this topic expects the following advancements over the course of study.

Table 4-7. Level 2 Milestones – Enabling Avionics

ID	Title	Date	Exit Criteria
IIFD.EA.1 (Subtopic)	Information collection and management for reliability and integrity of service		
IIFD.EA.1.1	Develop and verify an initial Integrated Alerting and Notification (IAN) system model design suitable for design capture and evaluation against requirements Explanation: This is the first milestone in a series (EA 1.1, 1.3, 1.5, 2.1, and 2.2) that will track model development and application. The resulting model will be a tool for supporting both research and development activities. At the highest level, the model will allow capture of conceptual designs of information management techniques; at lower levels, coupled with a simulation capability, it will serve as a test bed enabling a variety of experiments, including scenario-based trade studies, system composition and operation studies involving the pilot interface, and integration studies of new sensors, information sources and data management methods.	Q2/FY10	Initial computational model developed for information collection and management functions that provides a capability for evaluation of alternate IAN designs against Level 3 requirements; Demonstrate a scalable, extendable, and modular model architecture (i.e. model structure and organization) by conducting an incremental development showing the successful addition of capabilities to a basic working model; Verify model design against requirements derived from representative scenarios defined at Level 4 (IIFD.FDS.1.1) and solution concepts defined at Level 3 (IIFD.RAHS.1.1 and IIFD.DDS.1.1) where the requirements are to incorporate the necessary information sources, information handling capability, and link to a user interface; all to facilitate scenario-based simulation studies; NASA TM or contractor report submitted documenting model design and evaluation results.
IIFD.EA.1.2	Develop and validate flight deck system information model to aid in understanding complex information redundancies and relationships Explanation: The model will be useful for examining how flight deck information from multiple independent sources can potentially be integrated into new avionics functions or otherwise managed to enable Level 3 RAHS and DDS concepts, or to improve performance (e.g. accuracy, availability, and integrity). This annotated graphical model will form the basis for the development an executable Cockpit Information	Q4/FY10	Model developed in UML (Unified Modeling Language), or similar language, that identifies and organizes the complex relationships, attributes, interactions, and dependencies among existing and potential new flight deck systems and the information elements used by these systems; Verify, at a minimum, a model that includes NextGen datalink services for aeronautical and meteorological information; Evaluate model completeness by comparing against all information required to support Level 3 solution concepts (IIFD.RAHS.1.1 and IIFD.DDS.1.1); NASA TM or conference paper submitted documenting model design, verification, and evaluation results.

	System Model (see milestone IIFD.EA.1.4).		
IIFD.EA.1.3	Evaluate IAN system model for determining context and hazard state	Q4/FY12	IAN system model (see IIFD.EA.1.1) revised to include a Caution Warning and Alerting (CWA) system model and a basic operator model; the revised IAN model is capable of supporting scenario-based computer-based simulations of information management and collection functions and pilot interface designs; Evaluate at least one such function against Level 3 solution concept requirements for reliability and integrity of services (see IIFD.EA.2.2); NASA TM or contractor report submitted documenting model design and evaluation results.
IIFD.EA.1.4	Demonstrate an executable Cockpit Information System Model (CISM) suitable for simulation-based trade studies of alternate information management function designs	Q3/FY13	The graphical model (see IIFD.EA.1.2) translated to an computer-executable form supportive of reliability and integrity of service trade studies for information management functions; Demonstrate the capability for test cases meeting at least one of the Level 3 solution concept's requirements, as provided by RAHS or DDS, and following Level 4-defined scenarios; NASA TM submitted documenting CISM design and specifying means of interfacing with other tools being developed (e.g. IAN) that make use of subsets of the total aircraft information environment.
IIFD.EA.1.5	Specify requirements for IAN information management	Q3/FY13	NASA TM or contractor report submitted documenting requirements; Developed to address, at a minimum, sensor information, hazard evaluation, off-board data, aircraft data, and pilot data; Requirements derived from experiments using the IAN modeling and simulation environment (IIFD.EA.1.1, 1.3, 2.1, and 2.2) and Level 3 evaluations (IIFD.DDS.1.2 and IIFD.RAHS.1.2).
IIFD.EA.2 (Subtopic)	Information processing for decision support		
IIFD.EA.2.1	Evaluation of the IAN model with a Caution Warning Alert (CWA) function incorporated	Q1/FY11	Validate the design and verify the capability to support future Level 3 designs and scenario-based experiments (see IIFD.DDS.1.2 and IIFD.RAHS.1.2) by comparing IAN modeling and simulation results against Level 3 requirements and scenario expectations; An initial simulation experiment will provide a test case designed to exercise the model, to demonstrate successful incorporation of the CWA functionality, and to determine

			what improvements or additional capabilities are needed to meet Level 3 needs; NASA TM or contractor report submitted documenting results.
IIFD.EA.2.2	Assessment of the IAN model functionality with respect to the meeting Level 3 human interface conceptual design requirements for information content, availability, timeliness, and integrity	Q4/FY12	As part of IIFD.EA.1.3, an IAN function design is implemented and included as part of at least one of the Level 3 human-in-the-loop system evaluations (see IIFD.DDS.1.2 and IIFD.RAHS.1.2); The function and design of the IAN model are validated and verified by demonstration of the capability to support the Level 3 conceptual design; experiment scenarios will be included that require execution of the IAN model for its intended Level 3 application; NASA TM or conference paper submitted documenting results of verification and validation of function and performance against design requirements.

4.3.3 Design Tools

Strategic Objective: Research, development, test, and evaluation of flight deck system design and evaluation methods and tools.

Problem Statement:
Aviation industry and certification authorities have recognized the need for new methods and tools that provide a systematic, efficient and repeatable approach to the design of future flight deck technologies (FAA, 1996), including identifying and addressing flight deck human-automation interaction issues early in the design phase. Also, the need for a predictive capability has become increasingly important as we forecast human performance concerns associated with NextGen operations. The development of design tools is still in a nascent stage, requiring translation from established theories and experimental practices into structures supporting design. Research conducted in this area serves a three-fold purpose: (1) by developing new methods and tools for the design of human-automation systems, information management and display systems, and operations needed to support NextGen, (2) by validating such methods and tools through their application both to the far-term Level 3 concepts developed within the project, and to the near-term concepts developed within the community at large; and (3) by using developed methods and tools to improve design quality though predictive methods that allow for a more rigorous exploration of the design space *a priori*.

Table 4-8 illustrates key research activities associated with the project's Level 3 concept design and development objectives. These represent gaps in current design tool capability, particularly with respect to projecting into NextGen domains. Also listed is how findings coming from foundational research inform these tool development activities.

Approach: Unlike the previously-described Level 2 topic, research in this area does not directly produce new functional capabilities for the flight deck system. In contrast, this research results in methods and tools that designers can utilize to clearly define requirements, understand subsystem relationships and dependencies, and diagnose or prognosticate flight deck system vulnerabilities that would otherwise remain unknown. Research applies, integrates, and validates theoretical approaches developed in at Level 1 (see section 4.4) into methods and tools that can be used by the design community, including IIFDT's Level 3 concept designers.

Table 4-8. RDT&E of Design Tools

Level 3 Multi-Disciplinary Concept and Barriers to Overcome	Design Tool RDT&E	Supportive Foundational Knowledge (Level 1)
Robust Automation-Human Systems • Roles and responsibilities • Function allocation and performance • Human-automation interaction	• Tools for the design and evaluation of human-automation interaction (IIFD.DT.1)	• Predictive modeling of human-automation interactions (IIFD.IM.2) • Formal models of fault-tolerant systems that include human elements (IIFD.IM.3) • Identifying operationally-relevant characteristics of NextGen operators (IIFD.OC.1) • Identifying information requirements to support the roles of NextGen operators (IIFD.OC.2)
Displays and Decision Support • Conveying large volumes of information • Information management and integrity • Communication and collaboration among decision-makers	• Tools for the design and evaluation of coordinated situational awareness (IIFD.DT.2)	• Theoretical approaches to presenting large volumes of data (IIFD.IM.1) • Identifying information requirements to support the roles of NextGen operators (IIFD.OC.2) • Evaluating interface technologies (IIFD.MM)

The focus of research in this area is to embed validated, repeatable analysis methods into existing and novel design tools, and to allow flight deck designers to quickly and easily assess designs without necessarily requesting specialized expertise in human interaction with similar systems. In addition, in the cases where experts are available, these tools would allow the experts to focus on answering specialized, complex questions.

Research applies the foundational theories and models developed and validated at level 1 by further developing and integrating models for direct use by designers, either as tools, methods or metrics.

Methods and tools are developed to support the Level 3 RAHS activity by enabling the latest advances from the human-computer interaction, cognitive science, software and systems engineering communities to be applied systematically in the automation functional design process. Methods and tools are not limited to hardware and software functions within the flight deck system, but address aspects of human-computer interaction including, for example, support for function allocation, roles and responsibilities, and task sequencing and procedure design tradeoffs.

Methods and tools are developed to support the Level 3 DDS activity by applying systematic, theoretical approaches to identifying methods of abstracting and representing information, complementing experimental approaches to identifying information abstractions to support pilot decision making, and by enabling via a design evaluation capability for the future flight deck display and decision support concepts under consideration. Likewise, systematic methods for identifying task and information requirements can provide early predictions of information requirements for new NextGen operations.

During the design phase, evaluations of candidate designs are based on modeled predictions of human performance, automation/avionics performance, and human-automation interaction performance. Such predictions are then validated against reference test cases (both representative current-day systems and those conceptualized by IIFDT at Level 3).

Although research in this topic targets generalizable systematic methods and tools that support design and evaluation of complex flight deck systems, initial research is directed at two specific needs for design tool capability associated with NextGen and the two Level 3 concepts.

(IIFD.DT.1) Tools that support the design and evaluation of human-automation interaction. HAI problems can have several sources. For example, mode confusion can have several sources, including FMS modes that do not correspond well to air traffic procedures, and interfaces that do not saliently present the mode and its implications for the aircraft behavior. Some of these HAI problems can be systematically analyzed and predicted. To this end, this research develops and validates methods and tools to help evaluate and predict HAI performance, and to help determine appropriate roles and responsibilities and function allocation. Tools will focus on aiding designers in assessing new automation designs to avoid the types of issues that have been discovered (i.e. mode confusion and mismatches between the task and the automation functionality in Flight Management Systems [FMS]) while drawing on innovations from the Level 1 research. Validation will be performed through application of the methods and tools to both current-day designs and the Level 3 robust automation-human system design concepts for NextGen.

(IIFD.DT.2) Tools that support the design and evaluation of operations and environments that provide for coordinated situational awareness across multiple agents. This research develops models and tools to support the design and evaluation of coordinated information requirements, presentation formats, procedures, and operational concepts. These models and tools support the development of designs for common, shared, distributed-user mental representations for flight deck systems, and provide for the design of coordinated situation awareness for both air traffic controllers and pilots. The research from this effort is applied to specific safety-critical issues associated with collaborative work environment concepts being developed at Level 3 (DDS and RAHS). For example, tools for measuring/predicting levels of coordinated situational awareness could be applied to help develop the required technology support for time-based (i.e. 4D) surface operations including the coordination between the surface traffic management and flight deck procedures.

Outcomes: Within the context of the IIFDT application domain – the NextGen terminal area – and the Level 3 solution concepts under investigation, research within this topic expects the following advancements over the course of study.

Table 4-9. Level 2 Milestones – Design Tools

ID	Title	Date	Exit Criteria
IIFD.DT.1 (Subtopic)	Tools that support the design and evaluation of human-automation interaction		
IIFD.DT.1.1	Develop and evaluate human-automation integration vulnerability prediction tools for NextGen flight deck technologies and concepts of operation	Q4/FY10	(IIIFD.DT.1.1.1) Demonstrate a cognitive modeling and simulation capability that provides a detailed assessment of the task, human cognitive performance, and the physical and procedural environment for at least one NextGen-based scenario; Proof-of-concept model and simulation results demonstrating the ability of models to systematically assess automation complexity, observability, and contextual appropriateness of a design early in the automation design process; Results documented in contractor report or as a journal article submission. (IIFD.DT.1.1.2) Develop task decomposition and human performance analysis software to enable prediction of probability of Failure-to-Complete task given a specified procedure and flight deck system interface design; Verify predictions for at least one design where the probability has been observed independently; Develop an aviation knowledge database/corpus that includes a representative set of aviation-related terms and acronyms and is drawn from relevant aviation textbooks and aircraft training materials; Evaluate corpus completeness for at least 90% hit success for a randomized query by an independent subject matter expert; Contractor report submitted documenting software design, evaluation results, and corpus access process. (IIFD.DT.1.1.3) Develop integrated computational model consisting of two components: an operator model and a system model; Complete experiment manipulating types/levels of automation and predicting resulting effects on HAI performance; Compare predictions against expected results for at least one NextGen-based scenario; Contractor report submitted documenting software design and evaluation results. (IIFD.DT.1.1.4) Perform gap analysis of empirical data to determine research needs with respect to FMS-related mode awareness problems and solutions; Analyze NextGen's key capability

			concepts and categorize them according to expected level/stage of flight deck automation; Deliver interim report documenting results; this interim report would be made publicly-available via the IIFDT website or alternate means subject to NASA's public-release approval process.
		Q3/FY11	(IIFD.DT.1.1.5) Validate cognitive models for ability to identify undesired or unsafe situations associated with at least one NextGen-based scenario (see IIFD.FDS.1.1); Integrate models into a design tool and engage stakeholders/industry to provide feedback and promote its use in real world design situations. (IIFD.DT.1.1.6) Extend task decomposition and analysis software to support automated saliency assessment and prediction; Verify against software design requirements. (IIFD.DT.1.1.7) Validate use of Multi-Variable Discriminant Analysis (MVDA) as a statistical technique to create initial model parameters; Validate a system dynamics computational model(s) of human-automation interaction that takes into account varying types/levels of automation and other relevant performance dimensions to make predictions of human-automation efficiency and corresponding safety-related impacts; Document validation results in contractor report or journal article submission. (IIFD.DT.1.1.8) Develop an Automation Implementation Matrix that identifies properties of the FMS that can contribute to breakdowns in pilots' mode awareness; Develop automation usage guidelines that provide recommendations for the use of automation in Human-Automation systems; Complete development of a Design Advisor Tool (DAT) that will predict potential human performance problems for a given HAI design and generate suggestions to designers for improvement/ mitigation; Verify DAT functionality against software design requirements; Compare predictions against expected results for at least one NextGen-based scenario; Contractor report submitted documenting software design, evaluation results, and tool use process.

		Q3/FY13	(IIFD.DT.1.1.9) Validation of human-automation integration vulnerability prediction for RAHS solution concept (see IIFD.RAHS.1.2) and a set of representative NextGen scenarios (see IIFD.FDS.1.1); HAI vulnerability predictions for the RAHS concept will be established using all previous developments in this subtopic; Validation will be limited to comparing empirical data obtained from the Level 3 RAHS evaluations (IIFD.FDS.1.2) against modeled predictions; NASA TM or journal article will compare design tool developments to date with the current state of knowledge in the field, highlight which predictions of human-automation vulnerabilities can and cannot be achieved by the design tools, and identify the most pressing research questions remaining in design tools relative to advancing the DDS and RAHS concepts.
IIFD.DT.2 (Subtopic)	Tools that support the design and evaluation of operations and environments that provide for coordinated situational awareness across multiple agents		
IIFD.DT.2.1	Develop and verify a model of coordinated multi-agent situation awareness	Q1/FY10	(IIFD.DT.2.1.1) Verify a Coordinated Situational Awareness (CSA) model and verify that it functions as specified in the CSA design specification by demonstrating changes in operator situation awareness as a function of information availability; NASA TM, conference paper, or journal article submitted documenting the model design and results of model verification.
		Q4/FY11	(IIFD.DT.2.1.2) Complete a sensitivity analysis to demonstrate the prediction of situation awareness for multiple agents using a representative set of terminal area operations scenarios (see IIFD.FDS.1.1); NASA TM, conference paper, or journal article submitted documenting results.
		Q4/FY13	(IIFD.DT.2.1.3) Compare CSA model capability with the current state of developments in the research community and industry, compare model-based predictions of multi-agent situation awareness against experimental data collected in relevant environment (see IIFD.DDS.1.2) providing evidence of achievable predictive accuracy for multi-agent situation awareness, and identify the most pressing research questions

			remaining in modeling and design tools relative to advancing multi-agent DDS concepts; NASA TM, conference paper, or journal article submitted documenting results.

4.4 Level 1 – Foundational Knowledge

Research at Level 1 is where science, engineering, mathematics, and human factors advances are applied to address flight deck system-specific problems or gaps in our understanding or capability. Foundational research in selected areas determines, to great extent, uncertainties associated with performance or safety predictability as we move from Level 1 to Level 4. In other words, our ability to understand higher-level abstractions, relationships, and behaviors is directly determined by the underlying physical, physiological, and/or psychological processes, and their interactions.

IIFDT Level 1 research addresses four topics: 1) Operator Characterization; 2) Sensing, Signal Processing, and Hazard Characterizations; 3) Multi-Modal Interfaces; and 4) Information Interaction Modeling. Research conducted in these four topics supports the previously-described Level 2 research as illustrated in Tables 4-4, 4-6, and 4-8.

4.4.1 Operator Characterization and Modeling

Problem statement: In order to ensure that IIFDT design concepts are user-centric, we must better characterize who the users are (or will be) and identify requirements for supporting the operational performance that will be required of them during NextGen operations. Foundational research is required to identify the characteristics of the piloting population and the classes of pilots to whom we will apply designs. In addition, an individual's contribution to system performance should be characterized, as with any other system element, in terms of their functional status and to characterize boundary conditions on readiness to perform. These constraints may derive from limitations in experience, permanent or temporary physical limitations, or temporary hazardous states induced by physiological or environmental factors. Operator states to be considered include fatigue, immersion/engagement, attention distribution, and human error precursors identified through analyses, as well as fluid states such as degrees of cognitive control which describe more subtle and dynamic responses, and correspond to both hazardous and non-hazardous states. These states can lead to deficiencies in functional capability that, in turn, can lead to reduced situation awareness, increased experienced workload and reduced capacity, and therefore, increased propensity to commit human errors – to include cognitively-based mistakes.

Approach: Research within this topic is decomposed into three subtopics that address: 1) improving our understanding of operationally-relevant characteristics of NextGen airspace operators to ensure that IIFDT designs are user-centered, 2) determining the information requirements to support posited roles of NextGen operators, and 3) enabling pre-flight and in situ characterization of human operator functional state.

(IIFD.OC.1) Identify the operationally-relevant characteristics of NextGen airspace operators.
The assertion that human information processing is situational has been affirmed in numerous contexts. Situational factors can be considered as not only the environmental conditions, but also the experiential models and expectations that an operator brings to his/her performance in a particular setting. This work topic, therefore, includes not only research aimed at better characterizing the mechanics of human information processing, but also addresses better understanding NextGen operators in terms of other

operationally-relevant characteristics (e.g., training and experience base, demographics, personal technologies) that may have implications for mental model use, risk assessment, and attention management, for example. An early focus of this work is to develop models of human prospective memory and interruption performance that will better predict the errors pilots are likely to make in a dynamic multi-tasking NextGen environment. Initially, these models will be derived from observations of checklist performance during piloting operations, where errors are more easily determined based on the linear characteristics of this secondary task.

(IIFD.OC.2) Identify information requirements to support the roles of NextGen operators. The intersection of operators' capabilities and NextGen concepts of operation determines the appropriate roles of human operators in this system and, as a result, the information requirements and automation functionalities needed to support these roles. Work in this area derives from these understandings and directly feeds the development of particular part-task solutions addressing Level 3 concepts. Knowledge of human information processing characteristics describes how to best convey information to operators, and how to best design controls to optimize the human/machine interface performance.

(IIFD.OC.3) Characterize the functional state of operators. IIFDT concepts of NextGen operations presume the involvement of human operators. As with any other critical element of the system, degradation in capability should be gracefully accommodated in design. The research in this topic addresses identifying operator states that degrade expected performance, and the ability to sensitively, robustly, and validly identify or predict the occurrence of these states. Assessment of functional status could initially occur in preflight, but could also occur in flight for evidence of degradation. Identification of operationally-relevant states would be communicated through the Level 2 Operator Performance research in terms of predicting human error and degradation of situation awareness, and may be used as an input to reallocation of tasks and responsibilities among intelligent agents to ensure safe and effective system performance. States that are identified as useful in maintaining team performance in response to individuals' variations, or to the assessment of performance level in an operator, may drive sensing requirements at Level 1 development of sensors, and resulting technologies may be incorporated in Level 2 Enabling Avionics.

Outcomes: Within the context of the IIFDT application domain – the NextGen terminal area – and the Level 3 solution concepts under investigation, research within this topic expects the following advancements over the course of study.

Table 4-10. Level 1 Milestones – Operator Characterization

ID	Title	Date	Exit Criteria
IIFD.OC.1 (Subtopic)	Identify the operationally-relevant characteristics of NextGen airspace operators	Q2/FY09	(IIFD.OC.1.1) Contractor report submitted documenting a model that relates features of environmental stimuli to human attention deployment; The utility of this model will be assessed relative to its suitability as a basis for designing interface features to direct attention commensurate with situation awareness requirements and temporal demands on responsiveness.
		Q4/FY09	(IIFD.OC.1.2) Journal article or NASA TM submitted documenting errors in checklist use and monitoring and describing countermeasures to errors; The basis of

			this report will be data obtained from jumpseat observations and review of relevant studies; The report will describe forms of monitoring and checklist executions failures, the conditions under which they occur, and the reasons they occur; and will suggest countermeasures to reduce vulnerability to such errors; Findings will be extrapolated to the use of future checklist platform designs (e.g. dynamic checklist displays driven by context-aware intelligent avionics functions).
		Q3/FY11	(IIFD.OC.1.3) Conference paper submitted that identifies features of the NextGen operator (e.g. experience levels, expected proficiency, personal equipment, methods of training) relevant to flight deck design; Identifying such characteristics are also important to experimenters (i.e. to determine appropriate testing populations and demographics); This effort intends to coordinate with FAA CAMI and to canvas flight operations and schools to determine projected characteristics of pilots in the NextGen era.
		Q2/FY10	(IIFD.OC.1.4) NASA TM or conference paper submitted summarizing recommendations for oculometric data collection and to measure visual attention distribution, thus improving ability to analyze results with respect to situation awareness and detection of annunciations; As devices become less intrusive, oculometry may be used in situ to inform the system of an operator's sampling of the environment; This report will provide "best practices" for oculometry to support RAH/DDS evaluations, and potentially new methods for analyzing oculometric data.
		Q4/FY10	(IIFD.OC.1.5) Journal article submitted which provides comprehensive review of literature related to advances in prospective memory research, future research needs, implications for operator performance, and ways to reduce vulnerability to error. (IIFD.OC.1.6) NASA TM or conference paper submitted describing visual attention modeling for salience prediction, and laboratory study results; The utility of this model is to serve as a basis for designing interface features to direct attention commensurate with the urgency

			required for requisite situation awareness requirements and temporal demands for response; Whereas the current state of the art primarily focuses on just-noticeable thresholds for peripheral perception, this research also addresses the motivational and cognitive influences that drive attention distribution; This experiment is a continuation of work described above in Q1/FY09 and will permit the parametric investigation of visual indicators for conveying information in future Level 3 DDS concepts. (IIFD.OC.1.7) Workload management is of paramount importance for single pilots who fly jets with advanced technology cockpits, such as very light jets. Workload demands come from three primary, often overlapping, sources: a) operational demands, such as lowering the flaps at the proper time, b) cognitive demands, such as remembering to contact the tower when passing over the outer marker as instructed by TRACON ATC, and demands imposed by the advanced technologies, such as entering waypoints in a flight plan correctly. A conference paper or journal article will be submitted that describes the workload management requirements related to managing these three types of demands in single-pilot jet operations; This information will be ascertained through a human-in-the-loop simulation study; Single jet pilot workload management best practices will be identified and countermeasures for workload management difficulties, such as training strategies and procedures, as well as suggestions for alternate automation and technology design approaches will be proposed; The implications for human operator performance will serve to inform higher level research in IIFD to improve safety of flight operations in NextGen.
		Q3/FY11	(IIFD.OC.1.8) Conference paper submitted describing an information processing model of interruption resilience; this model will be used to develop a theoretically-justified set of interventions and remediations for improving human performance in interruption management, resilience, and recovery; The paper will also report on results of HITL laboratory investigation of remediation concepts and these concepts will be provided to Level 3 ConOps development activities for potential evaluation.

IIFD.OC.2 (Subtopic)	Identify information requirements to support the roles of NextGen operators.	Q4/FY09	(IIFD.OC.2.1) The Cognitive and Operational Demands Analysis (CODA) is a qualitative analysis approach that has been developed to facilitate the identification, evaluation, and analysis of three types of workload demands encountered on advanced technology flight decks and cockpits: operational, cognitive, and technology driven (see IIFD.OC.1.8 above); Human factors experts with domain expertise will submit a conference paper or journal article submitted that describes the CODA approach, which was developed to more comprehensively identify and evaluate the varied and competing demands placed upon operators during NextGen terminal area operations than is possible using current approaches to cognitive, task, or work analyses; Subsequent studies will validate CODA experimentally (see IIFD.OC.2.3). (IIFD.OC.2.2) Contractor report submitted that documents a systems analysis of alert conditions required for NextGen aircraft operators; This set of conditions that require alerts will be initially identified analytically with SME input and review of existing NextGen documentation; These requirements will be used to determine the underlying parameters required to manage the presentation of these alerts in an integrated alerting and notification (IAN) system (see also IIFD.EA); Selected forms of IAN display concepts will be implemented in preparation for laboratory evaluation.
		Q4/FY10	(IIFD.OC.2.3) Journal article submitted describing a human-in-the-loop study conducted to validate the Cognitive and Operational Demands Analysis (CODA) predictions and explanations of workload bottlenecks in NextGen terminal area operations; Initially this methodology will be applied to Very Light Jet single-pilot operations; Extensive interchange with pilot populations and aircraft manufacturers is planned to substantiate the realism of this work. (IIFD.OC.2.4) NASA TM or conference paper submitted documenting operator interface requirements to support Level 3 concepts (see IIFD.DDS.1.1 and IIFD.RAHS.1.1); This document will record

			the information requirements, as based on task/decision analyses, and as demonstrated in display concepts, aural indications, and required supporting information systems/documentation that will allow others to develop competing methods of presenting this information.
		Q3/FY12	(IIFD.OC.2.5) NASA TM or conference paper submitted that audits the correspondence of the Level 3 DDS concept with previously-developed interface requirements; This audit will assess the degree to which previously-defined information requirements are met by the DDS concept and will serve to identify gaps and potential areas for improvement.
IIFD.OC.3 (Subtopic)	Characterize the functional state of operators	Q3/FY09	(IIFD.OC.3.1) Contractor report submitted that describes the system design for, and in flight evaluation results of, an operator state classification method; the evaluation will, at a minimum, include operator state detection performance and classification performance for states induced during controlled tasks during flight operations. (IIFD.OC.3.2) Contractor report submitted describing the utility of fNIRS and photrobe sensors for operator state characterization; utility will be assessed via a flight experiment where data from these sensors is recorded during controlled tasks and compared to other physiological measures commonly used to infer operator state. (IIFD.OC.3.3) Contractor report submitted describing operator state classification algorithms and documenting results of classification validation testing based on previously-collected data in a fatigue experiment.
		Q4/FY09	(IIFD.OC.3.4) NASA TM or journal article submitted describing effects of fatigue on operator performance and ability to reliably and comfortably ascertain fatigue levels during actual airline operations; Long-haul operational data on operator physiological effects will be combined with performance data to ascertain operational indicators, and operational effects of fatigued pilots (depends on IVHM collaborative research with EasyJet and ONERA in support of IVHM milestones 1.3.1.1, 1.3.3.2, and 3.1.3).

			(IIFD.OC.3.5) NASA TM, conference paper, or journal article submitted that describes best practices for fNIRS instrumentation design and data collection for operator state detection that is reliable, sensitive, and relevant to the flightdeck operating environment.
		Q2/FY10	(IIFD.OC.3.6) Conference paper submitted that describes the use of haptic interface devices to characterize operator state with respect to engagement in the control aspect of a simulated flight task; This report will document the results of a flight simulation-based investigation of the extension of an adaptive technique that has been previously tested in automobiles to explore the degree to which pilot engagement can be determined by measuring stick grip. (IIFD.OC.3.7) NASA TM, conference paper, or biomedical device journal article submitted that describes an fMRI-compatible fNIRS headgear design; Such headgear is required to permit coincidental fNIRS and fMRI data collection, which is necessary to select localization of fNIRS sensors for optimized operation. (IIFD.OC.3.8) Conference paper submitted describing operational methods for indicating an operator's task saturation/ engagement; Such methods are needed to effectively assess the efficacy of Level 3 (DDS/RAHS) concepts, and to provide a mechanism for adaptively configuring interface features, automation, and team dynamics in response to operator state; This effort will provide operator state indices relevant to evaluating the efficacy of flight deck technology/operating concepts and evaluative scenarios; These methods will be assessed in conjunction with subjective and performance measures. (IIFD.OC.3.9) Contractor report submitted describing the OSCAF operator state classification algorithm and associated artifact removal algorithms to permit effective fusion of data received from multiple neuro-physiological sensors. (IIFD.OC.3.10) NASA TM or conference paper submitted that describes a method for characterizing operator state by means of monitoring behavioral inputs (e.g. FMS/CDU inputs); This report will be

			supported by coordinating with developments in the IVHM project (e.g. the sequenceMiner algorithm) and models of operator behavior (NGOMSL and OFM).
		Q4/FY11	(IIFD.OC.3.11) Journal article submitted that describes fNIRS and fMRI correlation study to update previously-published best practices for the design and use of fNIRS for operator state assessment (see IIFD.OC.3.5). (IIFD.OC.3.12) Contractor report submitted updating system description for, and in flight evaluation results of, operator state classification and modulation system (see IIFD.OC.3.1).

4.4.2 Sensing, Signal Processing, and Hazard Characterizations

Problem Statement: In a modern commercial transport aircraft there are several advanced sensors and systems onboard that provide, among other things, communications, navigation, and surveillance support to the crew. Examples include TCAS, TAWS, GPS, INS, and radar altimeters. Imaging sensors (e.g. forward-looking infrared [FLIR]) can enhance human vision capability by seeing through many obscurations in certain ambient conditions. However, other than human vision-based means (enhanced or not), the only currently-certified forward-looking sensor capable of detecting external hazards is the weather radar. As a result, without advancement in sensing capability, recovery from unexpected conditions in the external environment in limited visibility will be constrained to the performance limits of weather radar technology and out-the-window human observations.

Signal processing is essential to capitalize on any sensor's capabilities. For example, early radar was a hardware system without significant signal processing, and the display was a rudimentary representation of reflectivity. The detection of phenomena such as wind shear and turbulence was not possible without advanced signal processing. Likewise, signal processing will be the key in many cases to unlocking a sensor's potential, and research is needed to develop new signal processing methods.

Hazard characterization has bearing on all the foregoing issues. Remote sensors do not measure a hazard directly, and hazard detection and measurement rely on associating measurable quantities to the actual hazard phenomena. In the case of radar, the primary measurable quantities are reflectivity and radial velocity. Signal processing extracts information from these measurables and provides a signature of the hazard for its detection and measurement. Hazard characterization is necessary to relate the physical characteristics of the hazard to sensor products. Thus, to support sensor technology development and Level 2 development of information integration, hazard characterization research is needed.

The Level 2 investigation of the IAN functionality also considers information coming from operator state sensors. Operator state sensing and signal processing serves to collect information about the operator allowing flight deck system agents (either pilots or automation) to be aware of hazardous operator states that may adversely affect performance, such as decreased situation awareness, or it might provide feedback to the automation that is useful in other ways. Research in Operator Performance and

Operator Characterization is investigating this aspect of the human-automation interface. In support of these research areas and to support Level 3 goals, research is required to find useful and effective sensors for operator state sensing and to relate sensor products to operator state.

Approach: Sensing, signal processing, and hazard characterization studies are applied and tested using the IIFDT application domain and supporting one or more of the Level 3 challenge area solution concepts. Level 1 research supports all three Level 2 areas, especially Enabling Avionics because of its strong connection to data collection and processing for information extraction, and hazard detection and monitoring. Research is driven both by specific needs or requirements established from higher levels and by exploratory studies seeking to expand the state-of-the-art to provide more options for flight deck system designers in the future. In both cases, efforts are prioritized to conceive potential solutions and applications to the problem domains established at Level 3 and Level 4. Therefore, sensor technology and hazard studies primarily target needs in the terminal area environment or problems associated with the Level 2 Enabling Avionics development of the IAN function. In addition, some research is associated with high-priority hazards to aviation in any setting.

Specifically, research within this topic is organized into five subtopics.

(IIFD.SS.1) Forward-looking remote sensing methods, models, and technologies. New and improved sensors and sensing capabilities seek to overcome technology hurdles associated with current detection and measurement capabilities, practicality and affordability, and operational effectiveness. Specifically, when considering a NextGen environment, because of the anticipated traffic densities and the need for an EVO (or BTV) capability, sensing performance must be improved for high-integrity detection of terminal area hazards, including objects on the runway, wake vortices, traffic, vertical obstructions (i.e. obstacles), and terrain. Models are developed for use in simulation studies and higher level research, such as the IAN functionality previously described at Level 2. Research includes tracking technology challenges, developing signal processing methods, and exploring new methods for hazard detection and measurement.

(IIFD.SS.2) Image processing and feature extraction. Research in this area provides new methods for processing imagery to reliably and predictably extract hazard information from imaging or video-based sensors without the requirement that the operator function as the sole detector (although this may still be done to provide a level of redundancy). Features of interest may include, for example, runway edges or markings, runway contamination, or obstacles. Image processing may also provide for improved visibility by displaying directly the processed video images. Developments include sensor blending and image processing techniques that improve image quality and provide consistent performance across a wide variety of ambient conditions.

(IIFD.SS.3) External hazard characterization. This research facilitates many of the outcomes in sensor research by providing an understanding of hazard phenomena and their relationship to sensor observables, especially as observed by multiple sensors. One example hazard of operational import in the terminal area is wake turbulence. Understanding wake behavior and how this behavior may be reflected into observable phenomena by airborne sensor(s) is essential to its detection.

(IIFD.SS.4) Icing remote sensing and characterization. This research investigates methods for remote detection of icing conditions to facilitate hazard avoidance and escape prior to entering icing condition. High Ice Water Content (HIWC) research seeks to characterize particularly dangerous icing conditions that have led to engine performance degradations; results can then be used to further develop the remote sensing capability. This activity is highly collaborative with IIFD.SS.1 and IIFD.SS.3 but is explicitly

called out here as a subtopic wherein significant investment is planned and coordinated with external agencies.

(IIFD.SS.5) Operator state sensing and signal processing. Also in support of the Level 2 Enabling Avionics IAN research and Level 2 Operator Performance research, operator state sensing methods are developed and evaluated. Studies evaluate emerging sensor capabilities and improvements in factors that affect deployability in the aviation domain. Research includes tracking technology challenges, developing signal processing methods, and new methods for state detection and measurement. Research is closely coordinated with Level 1 Operator Characterization (OC); where OC seeks to understand the states, this subtopic attacks technology challenges for sensors that can be used to measure and classify the states.

Outcomes: Within the context of the IIFDT application domain – the NextGen terminal area – and the Level 3 solution concepts under investigation, research within this topic expects the following advancements over the course of study.

Table 4-11. Level 1 Milestones – Sensing, Signal Processing, and Hazard Characterization

ID	Title	Date	Exit Criteria
IIFD.SS.1 (Subtopic)	Forward-looking remote sensing methods, models, and technologies		
IIFD.SS.1.1	Complete initial investigation of forward-looking interferometric (FLI) sensing, including results of ground testing, simulations, and characterization of sensor capabilities for detection of selected hazards Explanation: To meet the needs of the commercial fleet, a new airborne sensor should ideally address multiple hazards and provide benefits in efficiency of operations as well as improvements to safety to warrant the costs of development, certification, installation, training, and maintenance. This investigation will result in a judgment on the feasibility of an FLI as a sensor for several high priority hazards, and provide data to aid in ranking this technology against others for decisions on continuation of investigations.	Q2/FY09	Evaluate FLI for its potential to address multiple hazards including clear air turbulence (CAT), volcanic ash, wake vortices, low slant range visibility, dry wind shear, icy runway conditions, and in-flight icing conditions; Complete sensitivity studies to improve understanding of the potential capabilities and to determine requirements for an airborne FLI instrument; Obtain field measurements from prototype instruments; Develop analytical models that aid in the prediction of severity of detected hazards; Compare field measurements with modeled predictions in order to validate models and identify areas for improvement for either the model or the instrument design; NASA TP submitted documenting technology feasibility and supporting decisions on continuation of research leading to IIFD.SS.1.2 and IIFD.SS.1.8. (Decision Point)
IIFD.SS.1.2	Complete feasibility studies of forward-looking interferometric (FLI) sensing including terminal area ground and flight testing to quantify performance prediction uncertainty and to provide data to advance the development of hazard detection capabilities	Q3/FY10	Ground and flight tests of a prototype FLI instrument conducted to verify model capability to predict results and to verify model results predicting detection capability; Proposed instrument configuration developed and performance predictions made; Proposed sensor role/function developed and initial

	Explanation: This milestone depends on a decision to continue from IIFD.SS.1.1; this research will further hazard and sensor characterization studies, validate sensor and phenomenological models against measured data, determine the technology readiness level, and enable the development of hazard detection and severity algorithms.		requirements identified; Conclusions drawn about the efficacy and capability of the technology to provide useful information about each of the hazards addressed, and about the technology readiness of a FLI as a component of an airborne hazard detection system, including identification of technical barriers or challenges for a practical instrument; Recommendations made as to the need for further research and development required to achieve an operational sensor, and to support continuation of FLI research. Results are documented in a Contractor Report and/or NASA TM or Journal article. Report includes flight/field data verification of models, proposed sensor design and role in the cockpit, projected requirements, and performance predictions.
IIFD.SS.1.3	Evaluate the feasibility of Lidar sensor technology concepts for airborne wake vortex detection	Q1/FY11	Concepts for on-board (airborne) detection and measurement will be evaluated for ability to detect wake vortex hazards; Performance predictions will be developed and evaluated for range capability, range/azimuth resolution, wake classification capability (e.g. strength, motion, decay), and detection performance (e.g. probability of false/missed detection); Contractor report, conference paper, or journal article, submitted documenting results. (Decision Point)
IIFD.SS.1.4	Evaluate design of low-cost electronically-scanned radar antenna Explanation: The objective of this radar technology investigation is to remove technical and cost barriers to the application of these antennas on aircraft. The use of electronically-scanned radar antennas will improve antenna agility and versatility, facilitating such modes at track-while-scan, which will allow the radar to perform a normal scanning function while tracking or interrogating a specific target like another aircraft or an object on the runway.	Q1/FY11	Assess new designs and fabrication techniques to establish the viability of low-cost electronically scanned antennas for airborne radars; Mechanical scanning is the fundamental limiting component in current radar systems; Electronic scanning would enable or extend the numerous aviation safety benefits derived from radar systems; A contractor report will assess viability and detail the limiting factors for the development of a low-cost electronically scanned antenna/radar system; An engineering prototype will enable assessment of the fabrication principles and performance characteristics of the proposed design as documented in a contractor report.

IIFD.SS.1.5	Evaluate Near-Infrared (NIR) External Hazard Detection System	Q2/FY10	Investigate the use of gated lidar imaging to enable reduced visibility operations by imaging through obscurants and to identify aircraft risks due to obscurants such as super-cooled water droplets or volcanic ash. Evaluation of resulting design and prototype devices will be against operational requirements such as range and image resolution for making landing decisions and runway incursion detection; Contractor report submitted documenting results including lab, field, and flight test results.
IIFD.SS.1.6	Develop and evaluate methods and systems to detect and track non-cooperative traffic using enhanced ADS-B technology	Q1/FY11	Assess the performance of enhanced ADS-B technology to perform non-cooperative traffic surveillance; Build and test (in flight) an engineering prototype and assess the detection and tracking performance of a radar-like system based upon reflected ADS-B transmissions; Evaluation of performance would be against established, or under-development, surveillance requirements (such as those developed by the FAA or RTCA) for accuracy, availability, update rate, range, and false/missed detection rates.
IIFD.SS.1.7	Develop a pulsed-lidar model to support the investigation of the detection capabilities of lidar for icing, wake vortex, and clear air turbulence hazards	Q2/FY10	Develop numerical simulations of heterodyne-detection and direct-detection pulsed lidar sensors; Assess model capabilities by comparison between field test data and numerical simulation results; Document the models and simulations and establish a plan to evaluate the application of lidar systems for relevant hazards including icing, wake vortices, and clear air turbulence; NASA TM or TP submitted documenting model design and evaluation results.
IIFD.SS.1.8	Re-assess strategic plan and initiate follow-on sensor investigations based upon capability and performance predictions, models and technology development, quantification of uncertainties. This milestone is a decision point with regard to follow-on work and based on results of the initial studies reported in IIFD.SS.1.1 to IIFD.SS.1.7 as well as Level 3 concept evaluations and identified needs.	Q1/FY13	Follow-on work may continue for promising theoretical sensor concepts or, for technology that is already mature to the point where feasibility is established and technical hurdles to the practical development of airborne sensors still exist; Examples include: for work attacking a specific technical barrier, the focus will be on the effectiveness of the solution; For investigations advancing a technology from the establishment of feasibility to a proposed instrument capability/ configuration, the focus will be on the verification of expected results and capabilities through lab or field/flight tests; For studies involving advanced sensor capability development, the focus will be

			on salient sensor characteristics required for effective application, including probability-of-detection, probability-of-false alarm, hazard measurement, hazard location and extent, and accuracy; all of these compared against the Level 3 concept requirements that emerge through the course of study.
IIFD.SS.2 (Subtopic)	Image processing and feature extraction		
IIFD.SS.2.1	Develop and evaluate methods for FLIR image fusion and image processing to support Level 2 and 3 requirements for terminal area hazard awareness Explanation: The objective of this work is to develop image fusion and processing capability and apply objection detection to real imagery from flight tests and to evaluate against objection detection without image fusion.	Q3/FY09	Test the image fusion performance to determine its potential as a means to facilitate better hazard detection in the terminal area over non-fused imagery; Conference paper or contractor report submitted documenting FLIR information processing performance for operational scenarios taken from experimental data; Object detection performance will be documented comparing fused and non-fused cases, highlighting those cases where one detected objects and not the other.
IIFD.SS.2.2	Complete comprehensive design of Spatial Vision Tree (SVT) – a generic pattern recognition engine	Q4/FY09	Key objectives for this milestone are further development of the SVT to improve function and performance, testing to verify that the new SVT frequency-of-occurrence (FOO) distribution approaches that of treeless FOO distributions, measurements to facilitate an estimation of the time required for SVT processing of one image frame, and evaluation of the potential for SVT processing in real time based on the standard of 16 – 32 frames per second. Design, development, test results and conclusions will be published (NASA TM or open literature).
IIFD.SS.2.3	Develop and verify methods for runway detection and runway object detection for FLIR and color video imaging systems	Q4/FY11	Three or more methods for Retinex Visual Servo and edge detection/processing will be developed; Assess and compare performance of these competing methods for runway detection in recorded or inflight imagery; Evaluation will be performed by comparison of a detection product (a runway outline) to the actual runway boundaries; Contractor report submitted documenting the results of automatic imagery analysis for runway edge and runway hazard detection, including evaluation of preliminary work on analysis of runway object hazard characterization and hazard assessment.

IIFD.SS.2.4	Demonstration of real-time image enhancement and pattern recognition system during terminal area operations for FLIR and color video imaging systems	Q3/FY12	During actual flight or using recorded flight data, demonstrate, at a minimum, real-time performance (i.e., 16-32 frames per second) for image enhancement of the runway environment during approach and landing and across a representative set of ambient weather conditions; during these scenarios, runway edges and centerlines as well as any large object on the runway (e.g. an aircraft) and vertical obstructions near the flight path should be visible in the enhanced images as well as being captured, identified, and tracked by a pattern recognition system; Conference paper, NASA TM, or contractor report submitted documenting results.
IIFD.SS.3 (Subtopic)	External Hazard Characterization		
IIFD.SS.3.1	Assessment of external hazard detection and intensity algorithms for hazards in the terminal area Explanation: Anticipated potential threats to safety include: terrain and obstacles, air/ground traffic, objects on runways/taxiways (including runway incursions), turbulence (wake vortices and orographic clear air turbulence), low slant range visibility, dry wind shear, icy/wet runway conditions, in-flight icing conditions, and runway/taxiway mis-alignment. This work would largely be a part of sensor/detection studies (IIFD.SS.1), but also continuously monitor SOA capability as compared with NextGen requirements (vis-à-vis the Level 3 RAHS and DDS concepts).	Q4/FY10 Q4/FY11 Q4/FY12	Assessment of baseline external hazard detection and intensity algorithms for hazards in the terminal area; Includes multiple assessments that are part of sensor technology studies (see SS.1), visual-awareness investigations (see SS.2), and icing investigations (see SS.4) that are associated with specific hazards, and conducted and reported under milestones in these areas (see specifically, SS.1.2, SS.1.3, SS.1.5, SS.1.7, SS.2.1, SS.2.3, SS.2.4, SS.4.1, SS.4.4, and SS.4.5); Assessments are based on the predicted ability to detect hazards and quantify intensity and will be compared to flight data, ground measurements, and/or independent remote measurements relative to the accuracy needed to enable the Level 3 concepts, and in support of the IAN investigation under IIFD.EA; Results documented as described in the referenced milestones; Additional research may be identified as a result of these assessments and tracking state-of-the-art.
IIFD.SS.4 (Subtopic)	Icing Remote Sensing and Characterization		
IIFD.SS.4.1	Pre-flight assessment of the Multi-Frequency Radar (MFR) for characterization of atmospheric icing conditions, including ground operation and comparison with NIRSS radar performance	Q3/FY09	The established MFR is modified to ensure the stabilization of emission frequencies with active thermal control of critical components, replace significant portions of the data acquisition hardware, revise the data acquisition software, and calibrate the three frequency's subsystems; Ground testing of the modified MFR will be used to verify performance given these changes;

			Evaluation of the utility of the radar for characterization of atmospheric icing conditions will be accomplished through the comparison of the MFR's X-, Ka-, and W-band measurements (reflectivities) to ground-based X- and Ka-band radar systems with proven field test histories; A minimum success of the comparisons would be matching reflectivities at similar frequencies and matching cloud boundaries.
IIFD.SS.4.2	Assessment of the feasibility and benefit of a scanning, narrow-beam radiometer for the detection and classification of icing hazards Explanation: This objective of this milestone is to advance the current experimental radiometer capability into a 3-D scanning system that works in concert with meteorological radar and to test the detection capability versus other collocated instruments	Q3/FY10	NASA TM, contractor report, or journal article submitted documenting comparison of measured boundaries and intensities of regions of liquid water to values derived from co-located instrumentation and forecast models; a positive comparison would be the matching of cell boundaries and average liquid water content (LWC); The feasibility and benefit of operation of the radiometer based upon comparison criteria, along with synoptic weather analysis will also be documented.
IIFD.SS.4.3	Assess instrumentation performance and flight operation procedures for High Ice Water Content (HIWC) flight research Explanation: Flight testing to measure cloud properties that lead to engine icing and to develop methods for detecting the hazard is required to meet IIFD.SS.4.5 below, and to evaluate in flight performance of sensors previously described for the remote sensing of hazards (e.g. IIFD.SS.4.1).	Q1FY11	Both instrumentation effectiveness and operational procedures will be evaluated with respect to achieving the science objectives for characterizing the microphysical properties of core, or near-core, regions of deep convective clouds, determining small ice particle formation mechanisms, and testing ground- and satellite-based remote sensing methods of determining cloud properties in high-IWC regions in deep convection; A baseline science plan and requirements matrix will document objectives in FY09; this assessment will compare actual performance against those described in these documents; NASA TM or conference paper submitted documenting assessment results.
IIFD.SS.4.4	Measure and record cloud properties that lead to engine icing for the purposes of developing models or databases that can be used to replicate such conditions in controlled environments, and to predict effects of mitigation methods	Q3/FY11	Collect sufficient data from flight-, ground-, and satellite-based instruments to 1) develop a statistical database of microphysical cloud properties sufficient for engine icing modeling, engine testing and development, and engine certification; 2) develop means of detecting engine icing threats using remote sensing and or onboard measurement systems; and 3) to develop a knowledge-base of ice crystal environments to enable weather modeling and forecast/nowcast tools to predict regions where engine icing is a threat or hazard; Success requirements include

			gathering in-situ measurements that can yield 99 percentile statistics on ice water contents at three altitude levels; for validation purposes, correlated measurements from remote sensing via flight, ground, and satellite instruments will be obtained.
IIFD.SS.4.5	Methods for detection, prediction, and avoidance of atmospheric conditions that are conducive to HIWC engine icing based on analysis and characterization/ modeling of the hazard environment	Q1/FY13	Analyze flight-, ground- and satellite-based data collected previously (see IIFD.SS.1.6 and IIFD.SS.3.2); Provide methods for, and assessment and evaluation of, remote-sensing to detect high ice water content environments; Deliver statistics on ice water content levels and hydrometeor characteristics; Technologies examined for the remote detection of HIWC conditions shall include, at a minimum, satellite-based optical methods, airborne radar, and ground radar methods; Results documented in NASA TP and collaborative journal articles, and presented in a HIWC workshop with published proceedings.
IIFD.SS.5 (Subtopic)	Operator state sensing and signal processing		
	Determine critical needs and technical gaps for operator state sensing Explanation: Leverages work being conducted under IIFD.OC.3, “Characterize the functional state of operators” where important aspects of operator state are identified and COTS sensors for measuring these states are applied and evaluated. In the event that adequate sensing capability is not available, the sensor need and known requirements are reported here. An investigation may be initiated to determine what measurables can be associated with the operator state and what sensor technologies can be associated with the measurable. Following, a sensor technology investigation may be initiated (see IIFD.SS.5.2 below).	Q4/FY10 Q4/FY12	Identify operator state sensing needs that cannot be met by COTS devices; Recommend follow-on feasibility study or technology development with respect to these needs; This deliverable is contingent on IIFD.OC.3 research outcomes; i.e. when a sensor need is perceived in IIFD.OC.3, it is documented as a part of that milestone and serves as a catalyst for work here to determine whether there is a promising technology avenue to pursue either as a feasibility study or as technology development (see IIFD.SS.5.2 below). (Decision Point)
IIFD.SS.5.2	Conduct operator state sensor investigation to attack key technical barriers identified in previous work (see IIFD.SS.54.1)	Q4/FY11 Q4/FY13	Evaluate sensor performance against requirements delivered from Level 1 (OC), Level 2 (OP and EA), and Level 3 (RAHS and DDS) with respect to operator state sensing technology; NASA

	Explanation: This investigation may take the form of a feasibility study or technology development. Feasibility assessment will include model development and analyses of detection and measurement capability as related to operator state. Technology development is warranted when specific technology barriers must be overcome to make a sensor solution effective. Technology development expects clearly defined requirements for sensing capability in order to provide a measure of the success of the development (i.e. performance will be evaluated versus the requirements).		TM, journal article, or contractor report submitted documenting results including, for example, experiment descriptions and results, model verification, performance predictions, and recommendations and objectives for further investigation or development.

4.4.3 Multi-Modal Interfaces

Problem statement: Transformational changes in operational requirements will demand, and novel multi-modal interface technologies will enable, dramatic improvements in the effectiveness of information presentation to, and communication among, future NextGen operators. NextGen is envisioned as a 'net-centric' environment, where data link and other communication technologies provide seamless, nearly automated information transfer among functional agents, both human and automated. In this environment, the volume of information available to the flight deck will be vastly increased beyond what is available today. NextGen pilots will likely take a greater role with regard to traffic spacing and separation, and therefore, will require enhanced spatial awareness, particularly with respect to spacing from other aircraft and to avoid hazards. The challenge to this research area is to investigate methods and concepts for appropriately utilizing *all* human-machine interface modalities to present and consume information in support of new NextGen requirements (e.g., trajectory based operations in the terminal area), and to explore opportunities for improved performance and safety based on newly-available information and presentation methods and technologies in order to meet Level 3 goals (e.g. better-than visual operations, improved decision-making, and collaboration work environments).

Approach: Research within this topic seeks to identify the multi-modal interface needs of the flight crew, understand the potential (both positive and negative) of each modality, and determine how they may be intentionally modulated and tailored to best fit the needs of the flight crew during operations in the NextGen terminal area, and as a critical element of the two Level 3 flight deck system concepts being developed (DDS and RAHS). Requirements derived from this operational focus will be instantiated in novel interface concepts and evaluated for effectiveness. These concepts may be entirely developed in-house as part of this research effort, or may be novel uses of devices or assemblies of COTS components that have not been investigated in the aviation context. Research within this topic addresses advances in the future multi-modal flight deck interface in three inter-related subtopics: (1) visual interface technologies, (2) aural/speech interface technologies, and (3) multi-modal integration of novel interface technologies. An important aspect of this last effort is the consideration of flexible presentation of information across the available modalities to best effect. For example, appropriate attention directing and multi-tasking performance may be better affected by intelligently distributing information flexibly over the different perceptual modalities (*e.g.,* Spence and Driver, 1997), while also providing increased control over the pacing of information.

Research directly supports Level 2 research (Operator Performance) by determining the form that interface technologies should take to best support operator situation awareness (OP.1), appropriate use of information and automation (OP.2), collaboration/ communication (OP.3), and to reduce human error and aid decision-making (OP.4). For example, translation of operator communications into datalink messages implies performance considerations associated with the benefits of message "persistence," and control of access, and the potentially deleterious effects associated with not having passive auditory monitoring of "party line" information. As particular interface approaches prove promising, this research area communicates and collaborates with Level 2 Enabling Avionics research to assess such concepts for development/suitability as part of a complete flight deck information management and interface system.

(IIFD.MM.1) Visual interface technologies. Research addresses extant and novel technologies to improve the ability to convey visual information to pilots and support effective use of this information. Initially, empirically-based RDT&E activities assess concepts and methods for developing and evaluating head-slaved 3D perspective displays for improved spatial situation awareness, and for understanding and supporting change detection in displays. Perspective displays have shown promise in supporting pilot decision-making (Boyer & Wickens, 1994), but are still considered experimental. Integration of head and eye position extends the visual information available to pilots, allowing a pilot to "look behind" a displayed feature. Research is required to assess not only the design parameters for such a display, but also the opportunity cost of attention to other visual channels. A model of visual saliency, i.e., the parameters that predict an operator's exogenous visual attention directing, will be developed in the Operator Characterization research area. With knowledge of this model, research in this area will identify display characteristics that can best modulate visual attention. Research in this area may also investigate miniaturized electronics that could potentially allow increased levels of physical integration of operator perceptual and technological display and control capabilities; as well as methods and technology concepts for improved head-worn displays with integrated head-tracking and oculomotor control over information presentation.

(IIFD.MM.2) Aural/speech interface technologies. Empirically-based RDT&E activities assess methods for applying data-to-speech interface technology concepts in a net-centric environment. In investigating the utility of aural/speech I/O concepts, four areas of particular interest are: a) metrics for synthesized speech intelligibility, b) indicators of urgency, c) use of voice 'personalization' to code information, and d) the application of 3D speech localization for the purpose of enabling aurally-guided visual search. Research includes the development of a tool that is essentially a pallet of aural expressions (speech and non-speech), and the underpinning logic for their combination to aid operators in perceptually comprehending and grouping the indicators. This tool will guide empirical investigations of candidate annunciation sets. The Level 3 application may then be a particular static allocation of these indicators, or perhaps involve a method for selecting aural indicators dynamically.

(IIFD.MM.3) Cross-modal information distribution and novel interface technologies. While visual and aural interfaces are have more of a historic precedent and legacy, other modalities and novel forms of interfaces are being developed, and we will periodically assess the state of the art in such technologies to identify modalities and mechanisms for information presentation that may improve the quality of information transfer to and from the human operator. One of these technologies will receive immediate attention – haptic coding to improve joint human/automation control of a vehicle. Research is required

in this area to understand how to distinctly convey modes of automation and intent to operators clearly and without being distracting.

More generally, advances made in commercially-available interface technologies, or through the efforts of the aforementioned research, must be considered in terms of the overall impact on the operator. Therefore, this research subtopic also addresses how to best integrate and coordinate information presentation across a set of interface technologies that load different perceptual modalities. This research is critical in light of the potential for NextGen operational concepts to overload selected interface modalities (e.g. visual displays) while others are not impacted or are neglected. Research will investigate both static and dynamic allocations across modalities. That is, designs could determine a best static mapping of information streams for available interface channels, or these may be adaptive based on behavioral models or knowledge of context/state changes in the environment. A special case of this information/presentation mapping decision pertains to representing the relative priorities of the ongoing and interrupting tasks, as well as the ability to resume ongoing activities post-interruption. We leave open the possibility that planned state-of-the-art surveys will reveal capabilities that will further improve the flight deck system interface for NextGen pilots.

Outcomes: Within the context of the IIFDT application domain – the NextGen terminal area – and the Level 3 solution concepts under investigation, research within this topic expects the following advancements over the course of study.

Table 4-12. Level 1 Milestones – Multi-Modal Interfaces

ID	Title	Date	Exit Criteria
IIFD.MM.1	Develop and evaluate improved visual interface capabilities	Q3/FY09	(IIFD.MM.1.1) Conference paper submitted that documents results of initial lab assessment of prototype head-slaved stereoscopic device for improved 3D perspective information display; This formative assessment will investigate the impact of this technology on spatial situation awareness, tunneled attention, and navigational decision making; as well as how behavior differs from a baseline configuration.
		Q3/FY10	(IIFD.MM.1.2) NASA TM, conference paper, or journal article submitted documenting results of human-in-the-loop evaluation of the new perspective display in full mission simulation to assess impact on spatial situation awareness and potential deleterious effects on monitoring other systems. (IIFD.MM.1.3) NASA TM or conference paper submitted summarizing results of a laboratory study evaluating methods for improving the ability to obtain information from displays adjacent to that which is foveal, and characterizing the limitations for presenting peripheral information on distributed displays; Prior research has focused on perceptual threshold limits for

			peripheral targets; This document reports extending such research to determine new methods for improving the use of the periphery, and for modeling the probability of detection with these new methods at various eccentricities.
IIFD.MM.2	Develop and evaluate improved aural/speech interface capabilities	Q3/FY09	(IIFD.MM.2.1) Conference paper or journal article submitted documenting a laboratory-based evaluation of speech quality and comprehension effort for parameters of prosody and rate-synthesized voice messages to use in a real-time speech display for future flight deck systems; This document reports the interaction among the independent variables characterizing speech that are hypothesized to affect intelligibility, comprehension, and discriminability; Metrics will include performance and subjective measures associated with these three constructs, with a threshold of 95% for objective data and "high" ratings on subjective data initially set as the criteria for successful information conveyance. (IIFD.MM.2.2) NASA TM or conference paper submitted documenting results of a part-task simulation study completed using a representative user population and initial audio display technology integrated with data link, weather, and traffic merging & spacing display concepts; Report will include initial guidelines for use of auditory displays as part of Level 3 concepts and evaluations.
		Q1FY10	(IIFD.MM.2.3) NASA TM or journal article submitted that describes the method and outcome for designing a comprehensible set of aural stimuli for conveying NextGen alerting conditions; This report will consider aural parameters (including those for speech and non-speech alerts) for detection, discriminability, and intelligibility in isolation and as part of an integrated auditory display and based on differences in communication requirements for future displays as compared to state-of-the-art; The report will be based on a combination of literature review, evaluation of current technology, and laboratory evaluation of new technologies; Simulation studies are not included here, but may be considered as part of a Level 3 DDS concept evaluation.

		Q3FY10	(IIFD.MM.2.4) NASA TM or journal article submitted that evaluates theoretically-indicated applications of aural indicators to NextGen IAN requirements (see OC.2) for detection, intelligibility, distinguishability, perceptual grouping, and as supportive of response effectiveness (speed and accuracy); Initial investigations will be laboratory studies with aims to incorporate into future Level 3 DDS integrated simulation studies.
IIFD.MM.3	Develop and evaluate novel and multi-modal interface capabilities	Q4/FY09	(IIFD.MM.3.1) Book Chapter submitted on the design and human performance considerations in the development of dynamic operating documents; Dynamic operating documents use sensed data, or operational context, to alter previously static checklists and documents in real-time to increase their applicability and utility for operators; This chapter will focus on design and development issues associated with this concept and will cover the full range of flight deck operational documents which might be made dynamic; The aspect of this effort that contributes to this research element is to determine how dynamic, potentially multi-modal information presentation devices can best support operator requirements.
		Q3/FY10	(IIFD.MM.3.2) NASA TM or journal article submitted that recommends parameters for effectively coding haptic interfaces for improved joint human/automation control; These recommendations will derive from a laboratory study that compares various configurations of haptic interface codings and baseline conditions for their effect on pilot workload, control efficacy, responses to off-nominal conditions (e.g. automation failures), and subjective measures of preference for comfort. (IIFD.MM.3.3) IIFD report submitted documenting state-of-the-art review of interface technologies that may permit more effective presentation of information to operators, or may permit more effective attention distribution among perceptual modalities to best maintain situation awareness; This review will canvas technologies under development and used in other application domains, and posit the utility for future flight deck systems; Such a review will be used as a decision point with respect to future research in this area; this interim report would be made publicly-available via the IIFDT website or

			alternate means subject to NASA's public-release approval process. (Decision Point)

4.4.4 Information and Interaction Modeling

Problem statement: This effort seeks to establish a foundation for the development of system models and methods to be used in the design tools under development at Level 2 (Design Tools) and validated against the Level 3 RAHS and DDS conceptual designs. Additional connections to other IIFDT research are also noted throughout, such as the relationship between processing and displaying information noted in the Sections 4.4.2 (Sensing) and 4.4.3 (Multi-Modal) and approaches to visualizing information noted below. In contrast to Level 2 research, research in this area is intended to develop theoretical approaches, methods and models that can be validated, but are not intended for direct use by designers. Required capabilities will be identified from the RAHS and DDS concepts as they are developed. Meeting these capabilities will face two challenges. The first challenge will be to develop an effective and feasible approach incorporating the most advanced models of human performance and technology functioning, and the second challenge will be to present a means of integrating an approach into a tool or method (at Level 2) that can be used by the design community. Research addresses operator needs, technological capabilities, and the demands of the operating environment. This second challenge requires collaboration with the research conducted at Level 2 (Design Tools). The term 'Information and Interaction' refers both to reducing and presenting large quantities of data in limited display space, as well as understanding and providing metrics for evaluating user interaction with complex systems.

Approach: Research is decomposed into three subtopics with particular importance and criticality to the higher Level topics. These investigate 1) theoretical approaches to information extraction, integration, and abstraction, 2) predictive modeling of interaction performance, and 3) modeling fault-tolerant human/machine systems.

(IIFD.IM.1) Theoretical approaches for presenting large volumes of data in limited display space. When considering the information-rich displays of the future and the potential need for adaptive displays based on context and user needs, research addresses: methods for integration of several sources of information into a single display in a way that reveals coherence and wholeness without cluttering the screen; methods for visualizing dynamic processes; the use of structure invariants and transformation invariants in the process of designing (and populating) an interface with information; formal methods for describing and modeling some of these structure- and transformation-invariants in condensing information to a given display; developing computational methods to support conceptualization of new interfaces; and methods and tools for representing caution and warning information to the pilot such as might be generated by an IAN function (see Enabling Technologies). Such methods must address the context of the situation and the problem of multiple failures by synthesizing and interleaving procedures and recovery sequences (see also IIFD.OP.4).

One vital issue is to find effective means of extracting and abstracting information from raw (often analog) data received from sensors and other sources. A formalized theory can explicitly state and exploit the underlying semantics of each data source to be integrated. Correspondences between the different semantic representations can then form the basis of integration. These correspondences are dynamically combined to re-express information from an underlying data model to the desired integrated model. In the process, data provenance (i.e., source and traceability) can be preserved since the derivation of data is explicitly and analytically defined. These representations may also be contrasted with the processing of visual imagery noted earlier in Section 4.4.2 (Sensing), and the potential for new presentations afforded by new visual and multi-modal display interfaces as noted earlier in Section 4.4.3 (Multi-Modal). Once data are re-expressed in terms of a unified information model, it can be used to support other capabilities, such as information browsing and search, display customization, and knowledge discovery (Wolfe, 2004). In particular, derived concepts defined in the models provide more meaningful features and structures than traditional methods.

(IIFD.IM.2) Predictive modeling of human interaction performance. State-of-the-art computational human performance models can not yet provide accurate predictions of training time, difficulty or operational error. Foundational research is needed on computational methods that provide human performance predictions for the objective functions (e.g. operational errors, training time, time on task) requested by the flight deck design community. The objective for this research is to provide models that can be integrated into the tools developed at Level 2 (Design Tools), which allows aircraft automation designers to rapidly change and receive optimized sequences for performing tasks for a given objective function. A particular emphasis on computing optimized sequences requires development of methods that enable understanding and description of the mission tasks for which the automation is being designed. These methods are particularly useful in determining the feasibility of automation designs and the concepts of operation envisioned by IIFDT (e.g. Level 3 RAHS and DDS).

(IIFD.IM.3) Formal models of fault-tolerant systems that include human elements. In recent years, NASA has developed new analysis techniques that have contributed to the understanding of so-called distributed fault-tolerant computing systems. The results of these analyses include a deeper understanding of the interaction between the behavior of faulty components and system-level properties. Specifically the analyses have helped with the understanding of how to manage redundant elements such that the system is most effective under a specific fault (or failure) scenario. Due to the generality of these analyses, they may be applicable to a complete flight deck system (i.e. including both human operators and automation/avionics). Research in this area supports and contributes to the Level 2 (Design Tools) objective and is applied to IIFDT system-level conceptual designs.

Outcomes: Within the context of the IIFDT application domain – the NextGen terminal area – and the Level 3 solution concepts under investigation, research within this topic expects the following advancements over the course of study.

Table 4-13. Level 1 Milestones – Information and Interaction Modeling

ID	Title	Date	Exit Criteria
IIFD.IM.1 (Subtopic)	Theoretical approaches for presenting large volumes of data in limited display space		
IIFD.IM.1.1	Development and validation of general theory and executable model for data extraction, integration, and abstraction against baseline practices and Level 3 application	Q4/FY09	(IIFD.IM.1.1.1) Demonstrate application of the theoretical approach to information abstraction and presentation using representative recorded flight data and indicating performance deviations from expected norms; NASA TM or TP submitted documenting generalized approach to information abstraction for analog signals.
		Q4/FY11	(IIFD.IM.1.1.2) Verification of the approach and performance against design requirements utilizing an operationally-relevant number of sensor/data streams and considering three main criteria: failure

			sensitivity to a single data stream change, preservation of individual stream identification capability, and detection of deviations from expected signatures; NASA TM or TP submitted documenting revised approach and verification results.
		Q4/FY13	(IIFD.IM.1.1.3) Validate the approach as instantiated within the IAN function (see IIFD.EA) and using data from at least one Level 3 concept evaluation (IIFD.RAHS.1.2 or IIFD.DDS.1.2) by confirming that operators are able to maintain awareness of single data stream changes, identify the source of the changes, and detect deviations from expected signatures as predicted by the model; NASA TP or journal article submitted documenting design and validation results.
IIFD.IM.2 (Subtopic)	Predictive modeling of human interaction performance		
IIFD.IM.2.1	Development and validation of integrated model of automation and operator performance defined for Level 3 conceptual designs	Q4/FY10	(IIFD.IM.2.1.1) Demonstration of initial task performance prediction model using at least one NextGen-based scenario (see IIFD.FDS.1.1).
		Q4/FY13	(IIFD.IM.2.1.2) Validation of task performance model predictions for at least one NextGen-based scenario; Empirical data obtained from the Level 3 evaluations (IIFD.RAHS.1.2 and IIFD.DDS.1.2) will be compared against modeled predictions of automation and operator performance to assess the extent to which the model provides insights valuable to automation design; NASA Technical Paper or journal article submitted documenting model design, assumptions/limitations, and validation results.
IIFD.IM.3 (Subtopic)	Formal models of fault-tolerant systems that include human elements		
IIFD.IM.3.1	Development and validation of representative fault, error, and communication analysis models for both human and automation system components	Q4/FY10	(IIFD.IM.3.1.1) Framework defined for designing machine-checkable formal models sufficient for capturing relevant aspects of human error persistence and effect; Framework reviewed by subject matter experts for completeness and sufficiency either via workshop process or journal article peer review.
		Q4/FY11	(IIFD.IM.3.1.2) Models developed and verified against design requirements for at least one Level 3 concept.

		Q4/FY13	(IIFD.IM.3.1.3) Validation of representative set of failure/error predictions in relevant environment; Empirical data obtained from the Level 3 evaluations (see IIFD.RAHS.1.2 and IIFD.DDS.1.2) will be compared against modeled predictions for human and machine error and resulting effects to assess the extent to which the model provides insights valuable to automation design; NASA TM, TP, or journal article submitted documenting model design, assumptions/ limitations, and validation results.

5 SUMMARY

In response to the implications of the JPDO vision as well as safety issues identified by industry/government agencies, NASA believes that future flight deck systems and operations should systematically incorporate integrated displays, decision support functions, information management, and appropriately-allocated human/automation task responsibilities. The future flight deck system is aware of the vehicle, operator, and air traffic management system state and responds appropriately. The system senses internal and external hazards, evaluates them, and provides key information to facilitate timely and appropriate responses. The system is robust and adaptable to the addition of new functions and information sources as they become available.

To achieve this vision, IIFDT comprises a multi-disciplinary research effort to develop flight deck technologies, procedures, and concepts of operation that mitigate operator-, automation-, and environment-induced hazards for future operational concepts such as NextGen. Specific enduring long-term objectives include: (1) robust human-automation interaction concepts that provide context-relevant levels of awareness and engagement; (2) information integration, abstraction, and conveyance concepts that support effective decision-making; (3) enabling avionics technologies and functions for hazard prediction, detection, and mitigation; (4) flight deck system design and evaluation methods and tools that reduce risks associated with design errors; and (5) an improved understanding of human performance as it relates to safety of flight and operational efficiency.

IIFDT leads by sharing and applying research products to support industry and government in the progression towards more capable and safer flight deck systems and operations. Products are documented and published for wide dissemination throughout the industry. Publication is via NASA-led authorship of conference papers, journal articles, and NASA technical papers; or via national and international regulatory or standards organizations wherein NASA results and expertise are used to develop large-sector consensus on new policies, standards, or recommended practices that can be applied in the industry to improve aviation safety.

RESEARCH MILESTONES

Table A-1 provides a summary list of the IIFDT research milestones along with dates and exit criteria. Whenever possible, quantitative metrics are given as exit criteria to assess progress. However, in some cases, exit criteria entries are more appropriately identified as checkpoints or decision points indicating delivery of baseline information needed to proceed, or an opportunity to change direction.

Table A-1. IIFDT Research Milestones

Flight Deck Systems that Improve Safety (FDS) – Level 4			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.FDS.1.1	Specification of NextGen-based flight deck system application domain, concept of operations and reference scenarios	Q4/FY09 Q4/FY11 Q4/FY13	Development and application of a systematic method for exploring the trade-space, designing and evaluating application domains, concepts of operation and scenarios for safety, capacity and efficiency; at a minimum, shall include a technical interchange meeting and/or workshop with relevant contributors from ARMD and external projects and programs; Results documented as reference information for subsequent L1/2/3 activities and made publicly available; Specifications should address, at a minimum, NextGen terminal area operations assumptions for domain and scenario parameters such as aircraft class, fleet mix, crew, weather, traffic, and airport environment, and equipage, and assumptions about, and performance metrics for, relevant entities in the system. (Decision Point, revised bi-annually)
IIFD.FDS.2.1	Assessment of flight deck system risk factors and barriers associated with enabling the NextGen-based application domain	Q4/FY10 Q4/FY12	Technical interchange meeting and/or workshop with relevant contributors from ARMD and external projects and programs; Results document risk factors and barriers considerate of L1/2/3 advances, and emerging trends or developments with respect to NextGen terminal area operations (see also IIFD.OP.4). (Decision Point, regarding re-scope of subsequent L1/2/3 research)
IIFD.FDS.3.1	Establish flight deck system evaluation testbed	Q3/FY10	Minimum success criteria: Simulator evaluation of at least one of the two L3 solution concepts (i.e. achieves IIFD.RAHS.1.2 or IIFD.DDS.1.2) and a conceptual design provided for integrating the other solution concept and accounting for potential interactions between solution concepts' functions and implementations

IIFD.FDS.3.2	Demonstrate advanced flight deck system solution concept	Q3/FY12	Coordinated simulator evaluation of both L3 solution concepts as an integrated flight deck system (i.e. simultaneously achieves IIFD.RAHS.1.2 and IIFD.DDS.1.2, this evaluation would include assessing interactions between L3 concepts.

Robust Automation-Human Systems (RAHS) – Level 3			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.RAHS.1.1	Hypothesized solution concept within specified application domain for flight deck system function allocation and human-automation interactions during 4-D trajectory-based operations	Q4/FY09 Q4/FY11 Q4/FY13	Operations and conceptual system designs for flight management tasks, role/responsibility assignments, technology/human functions for the NextGen terminal area environment described at L4, and documented performance metrics that the solution concept seeks to improve (see IIFD.FDS.1.1); (Decision point, revised bi-annually).
IIFD.RAHS.1.2	Evaluation of RAHS solution concept in relevant environment	Q3/FY10 Q3/FY12	Within the domain and scenarios defined at L4 (IIFD.FDS.1.1): (1) Results of hypothesis testing with respect to system performance documented, to include, at a minimum, analysis of effects on path, velocity, and attitude deviations from accepted standards; and on detection and recovery performance during off-nominal events; (2) Results of hypothesis testing with respect to human performance indicators (e.g. workload, situational awareness, engagement, procedural errors); no reduction in operator performance across a representative set of nominal and off-nominal conditions as compared with 2009 baseline. [L2, Operator Performance]; (3) Verification of avionics functionality against design. [L2, Enabling Avionics]; (4) Comparison of actual performance (human and machine) against modeled expectations. [L2, Design Tools]; (Checkpoint – Does the concept show promise; where do we need further work at L1/2; or should we change to another solution concept).

Displays and Decision Support (DDS) – Level 3			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.DDS.1.1	Hypothesized solution concept within specified application domain for flight deck system displays and	Q4/FY09 Q4/FY11 Q4/FY13	Operations and system conceptual designs for information conveyance and avionics functional requirements for the

	decision-support functions providing for better than visual operations, integrated alerting and notification, and collaborative environments		NextGen terminal area environment described at L4, and documented performance metrics that the solution concept seeks to improve (see IIFD.FDS.1.1); (Decision point, revised bi-annually).
IIFD.DDS.1.2	Evaluation of DDS solution concept in relevant environment	Q3/FY10 Q3/FY12	Within the domain and scenarios defined at L4 (IIFD.FDS.1.1): (1) Results of hypothesis testing with respect to system performance documented, to include, at a minimum, analysis of effects on path, velocity, and attitude deviations from accepted standards; and on detection and recovery performance during off-nominal events; (2) Results of hypothesis testing with respect to human performance indicators (e.g. workload, situational awareness, engagement, procedural errors, flight technical error); no reduction in operator performance across a representative set of nominal and off-nominal conditions as compared with 2009 baseline. [L2, Operator Performance]; (3) Verification of avionics functionality against design. [L2, Enabling Avionics]; (4) Comparison of actual performance (human and machine) against modeled expectations. [L2, Design Tools]; (Checkpoint – Does the concept show promise; where do we need further work at L1/2; or should we change to another solution concept).

Operator Performance (OP) – Level 2			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.OP.1	Methods for conveying and assessing situation awareness	Q3/FY09	(IIFD.OP.1.1) IIFD report documenting literature review of out-of-the-loop performance problems, identifying concepts for rapid situation awareness spool-up and human resumption of control; this interim report would be made publically-available via the IIFDT website or alternate means subject to NASA publication approval; this interim report would be made publicly-available via the IIFDT website or alternate means subject to NASA's public-release approval process. (IIFD.OP.1.2) Compare a haptic-multimodal interface concept for NextGen-based terminal area operations to a representative current-day interface by evaluating effects on operator performance and situation awareness (see

			also IIFD.MM.OC.3 and IIFD.MM.3). (IIFD.OP.1.3) Technical or contractor report submitted documenting relevant parameters to consider when presenting NextGen-unique alerts in future Level 3 evaluations (see IIFD.DDS.1.2 and IIFD.RAHS.1.2). (IIFD.OP.1.4) NASA TM or journal article submitted that documents evaluation of concepts to aid operator re-entry into automated operations; this assessment will address situation awareness prior to re-entry and situation awareness and performance after resuming control as compared to control conditions; These evaluations will be conducted using a low-fidelity aviation simulation experimental platform.
		Q4/FY10	(IIFD.OP.1.5) Contractor report submitted that describes requirements for presenting 4D+ uncertainties associated with potential hazards in the external environment; Requirements will consider uncertainties associated not only with 3D location and time; but also with the degree of hazard potential in an area at a point in time, and the certainty of this (e.g. as reflected by different sensing inputs); Additionally, there are uncertainties associated with how all of these characteristics would change over time and therefore for the ability to predict future impacts of potential hazards.
		Q1/FY11	(IIFD.OP.1.6) Contractor report submitted that describes results of human-in-the-loop evaluation of hazard conflict probes for their effects on operator situation awareness (conflict detection time) and performance (avoidance maneuver effectiveness & efficiency) during terminal area operations.
		Q1/FY11 Q3/FY13	(IIFD.OP.1.7 and IIFD.OP.1.8) NASA TM or conference paper submitted that identifies and summarizes remaining research questions with respect to improving situation awareness for future DDS and RAHS concepts; these questions will come from lessons-learned resulting from all relevant activities within the project, as well as tracking state-of-the-art.

IIFD.OP.2	Methods for fostering appropriate use of automation and complex information sources	Q3/FY09	(IIFD.OP.2.1) Open-source software release of an updated Multi-attribute Task Battery (MATB); This update redesigns the tool for current day operating systems and computers, and extends the researcher interface capabilities; A companion NASA TM submitted that provides guidelines for how to conduct studies with the MATB, and provides an annotated literature database of prior research results based on use of this experimental platform.
		Q4/FY09	(IIFD.OP.2.2) NASA TM or conference paper submitted that reviews methods and issues concerning the portrayal of uncertain information in support of pilot decision making; aspects of information uncertainty to be considered include aggregated information fused from multiple data sources, quality of information (QOI) estimates in general, and uncertainty in information portrayed by or about automated systems in particular; the review shall span best practices in portraying uncertain information and will highlight where further guidance and metrics are needed to support design and evaluation (at the level required for certification), and to support corresponding training on the appropriate interpretation of uncertainty.
		Q1/FY10	(IIFD.OP.2.3) Contractor report submitted that documents recommended metrics for assessing human performance with a Bayesian IAN system for eventual flight deck evaluation at Level 3; A Bayesian-based IAN can produce certainty levels associated with indications, alerts and notifications, conditional on contextual factors, and therefore provides an opportunity to provide sensitive representations of information certainty; These metrics will be useful in subsequent HITL IAN evaluations which will characterize how human performance may differ when a level of certainty is conveyed by the system.
		Q3/FY11 Q3/FY13	(IIFD.OP.2.4 and IIFD.OP.2.5) NASA TM submitted that analyzes results of Level 3 evaluations of DDS and RAHS concepts for specific insights into ensuring appropriate use of automation and complex information sources (see IIFD.DDS.1.2 and IIFD.RAHS.1.2); Compares with the current state of knowledge in the field, and identifies the

			most pressing research questions in automation use relative to advancing the DDS and RAHS concepts.
IIFD.OP.3	Methods for supporting communication and collaboration among multiple intelligent agents	Q4/FY09	(IIFD.OP.3.1) NASA TM or conference paper submitted documenting variables that characterize operator and adaptive controller interplay; This work is collaborative with efforts in the IRAC project to design adaptive controllers that reconfigure in response to aircraft malfunction (see IRAC technical plan milestones IRAC-IDFC-1.1.1.1 and 1.1.2.1); The IIFD aspect focuses on supporting the human operator serving as a monitor and as an agent for intervention if necessary.
		Q4/FY09	(IIFD.OP.3.2) Contractor report documenting results of a fast time simulation (continuous descent approach in the NextGen environment with a modified FMS looking at typical human error scenarios) evaluation of static function allocation policies. Metrics include: workload based on task load, human performance modeled resource loading, contiguity of function allocation over time, consistency with actor's role, disruption to procedures, appropriateness with respect to human cognitive control mode or to automation's designated functional boundaries, stability of human experience (i.e., minimizing interruptions and disruptions), and team robustness to system disturbances. (IIFD.OP.3.3) Contractor report documenting results of a simulation evaluation comparing dynamic and static function allocation policies; Metrics include: workload based on task load, human performance modeled resource loading, contiguity of function allocation over time, consistency with actor's role, disruption to procedures, appropriateness with respect to human cognitive control mode or to automation's designated functional boundaries, stability of human experience (i.e., minimizing interruptions and disruptions), and team robustness to system disturbances. (IIFD.OP.3.4) NASA TM or contractor report submitted documenting interviews with NextGen stakeholders and investigators discussing requirements for supporting multi-agent coordination, communication and decision-making in

			future terminal area TBO environments.
		Q3/FY10	(IIFD.OP.3.5) Conference paper submitted describing proposed concepts to improve pilot use of adaptive controllers; This work interfaces with IRAC project milestones IRAC-IDFC-1.1.1.1 and 1.1.2.1 to design adaptive controllers that reconfigure in response to aircraft malfunction; The IIFD work focuses on how to design these to also support the requirements of the human operator acting as monitor and as an agent of intervention if necessary. (IIFD.OP.3.6) NASA TM or conference paper submitted documenting a human-in-the-loop laboratory-based simulator evaluation of concepts for ensuring effective team coordination, communication, and group decision making in NextGen terminal area operations; concepts to be considered include, at a minimum, those aspects of the Level 3 concepts related to these issues (see IIFD.DDS.1.1 and IIFD.RAHS.1.1); Recommendations will be provided in support of the Level 3 evaluations.
		Q3/FY11	(IIFD.OP.3.7) NASA TM or conference paper submitted documenting results of human-in-the-loop evaluation of pilot interaction with adaptive controllers to assess joint performance; This work is collaborative with IRAC project research to design adaptive controllers that automatically reconfigure in response to aircraft malfunction (see the IRAC project technical plan, milestones IRAC-IDFC-1.1.1.1 and 1.1.2.1); The IIFD aspect focuses on supporting the requirements of a human operator serving as a monitor and as an agent for intervention if necessary.
		Q3/FY11 Q3/FY13	(IIFD.OP.3.8 and IIFD.OP.3.9) NASA TM submitted that summarizes analysis of results of Level 3 evaluations of DDS and RAHS concepts for specific insights into ensuring appropriate and effective multi-agent communication and collaboration (see IIFD.DDS.1.2 and IIFD.RAHS.1.2); compares with the current state of knowledge in the field, and identifies the most pressing research questions in communication and coordination relative to advancing the DDS and RAHS concepts.

IIFD.OP.4	Methods for supporting human decision-making and reducing the propensity for, or consequences of, human error	Q4/FY09	(IIFD.OP.4.1) Contractor report submitted documenting an approach to evaluating human performance response to an IAN system based on deviations from modeled (predicted) operator behavior. (IIFD.OP.4.2) NASA TM or conference paper submitted documenting the design and effectiveness of the PICE (Preventing Inadvertent Commission Errors) technology to mitigate inadvertent commission errors by employing confirmation-of-intent guard(s) that employ an EEG-based determination of engagement; This report documents results of an initial laboratory test of a prototype to assess mitigation of this form of error in a desktop human-computer interaction task; The report concludes with a discussion of further developments required for such a system to be fielded in a flight-deck.
		Q2/FY10	(IIFD.OP.4.3) NASA TM submitted documenting an analytic model of emergency and abnormal checklist design features and human errors associated with some of these features; The model is designed to predict checklist design features that have been previously empirically-linked with increased human error in separate studies; Implementation guidelines will be provided for paper, stand-alone electronic, and integrated electronic checklists.
		Q4/FY10	(IIFD.OP.4.4) Journal article, NASA TM, or book chapter(s) submitted that detail the design of procedural and technological countermeasures for individual operators and avionics designers to reduce the vulnerability to prospective memory errors; These countermeasures will be based on analysis of errors and causes of errors in checklist execution, monitoring, and concurrent task management; This design guidance will be provided to Level 3 ConOps development activities (IIFD.DDS.1.1 and IIFD.RAHS.1.1).
		Q4/FY12	NASA TM or contractor report submitted that describes scenario elements and metrics for evaluating crew performance with respect to potential prospective memory errors; These will be identified for the evaluations of DDS and RAHS concepts; Relevant metrics and scenario elements will be based on prior literature reviews, jumpseat observations, and will

			use methods from Line Operational Safety Audits (LOSA) and Threat and Error Management (TEM).

Enabling Avionics (EA) – Level 2			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.EA.1 (Subtopic)	Information collection and management for reliability and integrity of service		
IIFD.EA.1.1	Develop and verify an initial Integrated Alerting and Notification (IAN) system model design suitable for design capture and evaluation against requirements Explanation: This is the first milestone in a series (EA 1.1, 1.3, 1.5, 2.1, and 2.2) that will track model development and application. The resulting model will be a tool for supporting both research and development activities. At the highest level, the model will allow capture of conceptual designs of information management techniques; at lower levels, coupled with a simulation capability, it will serve as a test bed enabling a variety of experiments, including scenario-based trade studies, system composition and operation studies involving the pilot interface, and integration studies of new sensors, information sources and data management methods.	Q2/FY10	Initial computational model developed for information collection and management functions that provides a capability for evaluation of alternate IAN designs against Level 3 requirements; Demonstrate a scalable, extendable, and modular model architecture (i.e. model structure and organization) by conducting an incremental development showing the successful addition of capabilities to a basic working model; Verify model design against requirements derived from representative scenarios defined at Level 4 (IIFD.FDS.1.1) and solution concepts defined at Level 3 (IIFD.RAHS.1.1 and IIFD.DDS.1.1) where the requirements are to incorporate the necessary information sources, information handling capability, and link to a user interface; all to facilitate scenario-based simulation studies; NASA TM or contractor report submitted documenting model design and evaluation results.
IIFD.EA.1.2	Develop and validate flight deck system information model to aid in understanding complex information redundancies and relationships Explanation: The model will be useful for examining how flight deck information from multiple independent sources can potentially be integrated into new avionics functions or otherwise managed to enable Level 3 RAHS and DDS concepts, or to improve performance (e.g. accuracy, availability, and integrity). This annotated graphical model will form the basis for the development an executable Cockpit Information System Model (see milestone IIFD.EA.1.4).	Q4/FY10	Model developed in UML (Unified Modeling Language), or similar language, that identifies and organizes the complex relationships, attributes, interactions, and dependencies among existing and potential new flight deck systems and the information elements used by these systems; Verify, at a minimum, a model that includes NextGen datalink services for aeronautical and meteorological information; Evaluate model completeness by comparing against all information required to support Level 3 solution concepts (IIFD.RAHS.1.1 and IIFD.DDS.1.1); NASA TM or conference paper submitted documenting model design, verification, and evaluation results.

IIFD.EA.1.3	Evaluate IAN system model for determining context and hazard state	Q4/FY12	IAN system model (see IIFD.EA.1.1) revised to include a Caution Warning and Alerting (CWA) system model and a basic operator model; the revised IAN model is capable of supporting scenario-based computer-based simulations of information management and collection functions and pilot interface designs; Evaluate at least one such function against Level 3 solution concept requirements for reliability and integrity of services (see IIFD.EA.2.2); NASA TM or contractor report submitted documenting model design and evaluation results.
IIFD.EA.1.4	Demonstrate an executable Cockpit Information System Model (CISM) suitable for simulation-based trade studies of alternate information management function designs	Q3/FY13	The graphical model (see IIFD.EA.1.2) translated to an computer-executable form supportive of reliability and integrity of service trade studies for information management functions; Demonstrate the capability for test cases meeting at least one of the Level 3 solution concept's requirements, as provided by RAHS or DDS, and following Level 4-defined scenarios; NASA TM submitted documenting CISM design and specifying means of interfacing with other tools being developed (e.g. IAN) that make use of subsets of the total aircraft information environment.
IIFD.EA.1.5	Specify requirements for IAN information management	Q3/FY13	NASA TM or contractor report submitted documenting requirements; Developed to address, at a minimum, sensor information, hazard evaluation, off-board data, aircraft data, and pilot data; Requirements derived from experiments using the IAN modeling and simulation environment (IIFD.EA.1.1, 1.3, 2.1, and 2.2) and Level 3 evaluations (IIFD.DDS.1.2 and IIFD.RAHS.1.2).
IIFD.EA.2 (Subtopic)	Information processing for decision support		
IIFD.EA.2.1	Evaluation of the IAN model with a Caution Warning Alert (CWA) function incorporated	Q1/FY11	Validate the design and verify the capability to support future Level 3 designs and scenario-based experiments (see IIFD.DDS.1.2 and IIFD.RAHS.1.2) by comparing IAN modeling and simulation results against Level 3 requirements and scenario expectations; An initial simulation experiment will provide a test case designed to exercise the model, to demonstrate successful incorporation of the CWA functionality, and to determine what improvements or additional capabilities are needed to meet Level 3 needs; NASA TM or contractor report

			submitted documenting results.
IIFD.EA.2.2	Assessment of the IAN model functionality with respect to the meeting Level 3 human interface conceptual design requirements for information content, availability, timeliness, and integrity	Q4/FY12	As part of IIFD.EA.1.3, an IAN function design is implemented and included as part of at least one of the Level 3 human-in-the-loop system evaluations (see IIFD.DDS.1.2 and IIFD.RAHS.1.2); The function and design of the IAN model are validated and verified by demonstration of the capability to support the Level 3 conceptual design; experiment scenarios will be included that require execution of the IAN model for its intended Level 3 application; NASA TM or conference paper submitted documenting results of verification and validation of function and performance against design requirements.

Design Tools (DT) – Level 2			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.DT.1 (Subtopic)	Tools that support the design and evaluation of human-automation interaction		
IIFD.DT.1.1	Develop and evaluate human-automation integration vulnerability prediction tools for NextGen flight deck technologies and concepts of operation	Q4/FY10	(IIIFD.DT.1.1.1) Demonstrate a cognitive modeling and simulation capability that provides a detailed assessment of the task, human cognitive performance, and the physical and procedural environment for at least one NextGen-based scenario; Proof-of-concept model and simulation results demonstrating the ability of models to systematically assess automation complexity, observability, and contextual appropriateness of a design early in the automation design process; Results documented in contractor report or as a journal article submission. (IIFD.DT.1.1.2) Develop task decomposition and human performance analysis software to enable prediction of probability of Failure-to-Complete task given a specified procedure and flight deck system interface design; Verify predictions for at least one design where the probability has been observed independently; Develop an aviation knowledge database/corpus that includes a representative set of aviation-related terms and acronyms and is drawn from relevant aviation textbooks and aircraft training materials; Evaluate corpus completeness for at least 90% hit success for a randomized query by an independent subject matter expert; Contractor report

			submitted documenting software design, evaluation results, and corpus access process. (IIFD.DT.1.1.3) Develop integrated computational model consisting of two components: an operator model and a system model; Complete experiment manipulating types/levels of automation and predicting resulting effects on HAI performance; Compare predictions against expected results for at least one NextGen-based scenario; Contractor report submitted documenting software design and evaluation results. (IIFD.DT.1.1.4) Perform gap analysis of empirical data to determine research needs with respect to FMS-related mode awareness problems and solutions; Analyze NextGen's key capability concepts and categorize them according to expected level/stage of flight deck automation; Deliver interim report documenting results; this interim report would be made publicly-available via the IIFDT website or alternate means subject to NASA's public-release approval process.
		Q3/FY11	(IIFD.DT.1.1.5) Validate cognitive models for ability to identify undesired or unsafe situations associated with at least one NextGen-based scenario (see IIFD.FDS.1.1); Integrate models into a design tool and engage stakeholders/industry to provide feedback and promote its use in real world design situations. (IIFD.DT.1.1.6) Extend task decomposition and analysis software to support automated saliency assessment and prediction; Verify against software design requirements. (IIFD.DT.1.1.7) Validate use of Multi-Variable Discriminant Analysis (MVDA) as a statistical technique to create initial model parameters; Validate a system dynamics computational model(s) of human-automation interaction that takes into account varying types/levels of automation and other relevant performance dimensions to make predictions of human-automation efficiency and corresponding safety-related impacts; Document validation results in contractor report or journal

			article submission. (IIFD.DT.1.1.8) Develop an Automation Implementation Matrix that identifies properties of the FMS that can contribute to breakdowns in pilots' mode awareness; Develop automation usage guidelines that provide recommendations for the use of automation in Human-Automation systems; Complete development of a Design Advisor Tool (DAT) that will predict potential human performance problems for a given HAI design and generate suggestions to designers for improvement/ mitigation; Verify DAT functionality against software design requirements; Compare predictions against expected results for at least one NextGen-based scenario; Contractor report submitted documenting software design, evaluation results, and tool use process.
		Q3/FY13	(IIFD.DT.1.1.9) Validation of human-automation integration vulnerability prediction for RAHS solution concept (see IIFD.RAHS.1.2) and a set of representative NextGen scenarios (see IIFD.FDS.1.1); HAI vulnerability predictions for the RAHS concept will be established using all previous developments in this subtopic; Validation will be limited to comparing empirical data obtained from the Level 3 RAHS evaluations (IIFD.FDS.1.2) against modeled predictions; NASA TM or journal article will compare design tool developments to date with the current state of knowledge in the field, highlight which predictions of human-automation vulnerabilities can and cannot be achieved by the design tools, and identify the most pressing research questions remaining in design tools relative to advancing the DDS and RAHS concepts.
IIFD.DT.2 (Subtopic)	Tools that support the design and evaluation of operations and environments that provide for coordinated situational awareness across multiple agents		
IIFD.DT.2.1	Develop and verify a model of coordinated multi-agent situation awareness	Q1/FY10	(IIFD.DT.2.1.1) Verify a Coordinated Situational Awareness (CSA) model and verify that it functions as specified in the CSA design specification by demonstrating changes in operator situation awareness as a function of information availability; NASA TM, conference paper, or journal article submitted documenting the model design and results of model verification.

		Q4/FY11	(IIFD.DT.2.1.2) Complete a sensitivity analysis to demonstrate the prediction of situation awareness for multiple agents using a representative set of terminal area operations scenarios (see IIFD.FDS.1.1); NASA TM, conference paper, or journal article submitted documenting results.
		Q4/FY13	(IIFD.DT.2.1.3) Compare CSA model capability with the current state of developments in the research community and industry, compare model-based predictions of multi-agent situation awareness against experimental data collected in relevant environment (see IIFD.DDS.1.2) providing evidence of achievable predictive accuracy for multi-agent situation awareness, and identify the most pressing research questions remaining in modeling and design tools relative to advancing multi-agent DDS concepts; NASA TM, conference paper, or journal article submitted documenting results.

Operator Characterization (OC) – Level 1			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.OC.1 (Subtopic)	Identify the operationally-relevant characteristics of NextGen airspace operators	Q2/FY09	(IIFD.OC.1.1) Contractor report submitted documenting a model that relates features of environmental stimuli to human attention deployment; The utility of this model will be assessed relative to its suitability as a basis for designing interface features to direct attention commensurate with situation awareness requirements and temporal demands on responsiveness.
		Q4/FY09	(IIFD.OC.1.2) Journal article or NASA TM submitted documenting errors in checklist use and monitoring and describing countermeasures to errors; The basis of this report will be data obtained from jumpseat observations and review of relevant studies; The report will describe forms of monitoring and checklist executions failures, the conditions under which they occur, and the reasons they occur; and will suggest countermeasures to reduce vulnerability to such errors; Findings will be extrapolated to the use of future checklist platform designs (e.g. dynamic checklist displays driven by context-aware intelligent avionics functions).

		Q3/FY11	(IIFD.OC.1.3) Conference paper submitted that identifies features of the NextGen operator (e.g. experience levels, expected proficiency, personal equipment, methods of training) relevant to flight deck design; Identifying such characteristics are also important to experimenters (i.e. to determine appropriate testing populations and demographics); This effort intends to coordinate with FAA CAMI and to canvas flight operations and schools to determine projected characteristics of pilots in the NextGen era.
		Q2/FY10	(IIFD.OC.1.4) NASA TM or conference paper submitted summarizing recommendations for oculometric data collection and to measure visual attention distribution, thus improving ability to analyze results with respect to situation awareness and detection of annunciations; As devices become less intrusive, oculometry may be used in situ to inform the system of an operator's sampling of the environment; This report will provide "best practices" for oculometry to support RAH/DDS evaluations, and potentially new methods for analyzing oculometric data.
		Q4/FY10	(IIFD.OC.1.5) Journal article submitted which provides comprehensive review of literature related to advances in prospective memory research, future research needs, implications for operator performance, and ways to reduce vulnerability to error. (IIFD.OC.1.6) NASA TM or conference paper submitted describing visual attention modeling for salience prediction, and laboratory study results; The utility of this model is to serve as a basis for designing interface features to direct attention commensurate with the urgency required for requisite situation awareness requirements and temporal demands for response; Whereas the current state of the art primarily focuses on just-noticeable thresholds for peripheral perception, this research also addresses the motivational and cognitive influences that drive attention distribution; This experiment is a continuation of work described above in Q1/FY09 and will permit the parametric investigation of visual indicators for conveying information in future Level 3 DDS concepts.

			(IIFD.OC.1.7) Workload management is of paramount importance for single pilots who fly jets with advanced technology cockpits, such as very light jets. Workload demands come from three primary, often overlapping, sources: a) operational demands, such as lowering the flaps at the proper time, b) cognitive demands, such as remembering to contact the tower when passing over the outer marker as instructed by TRACON ATC, and demands imposed by the advanced technologies, such as entering waypoints in a flight plan correctly. A conference paper or journal article will be submitted that describes the workload management requirements related to managing these three types of demands in single-pilot jet operations; This information will be ascertained through a human-in-the-loop simulation study; Single jet pilot workload management best practices will be identified and countermeasures for workload management difficulties, such as training strategies and procedures, as well as suggestions for alternate automation and technology design approaches will be proposed; The implications for human operator performance will serve to inform higher level research in IIFD to improve safety of flight operations in NextGen.
		Q3/FY11	(IIFD.OC.1.8) Conference paper submitted describing an information processing model of interruption resilience; this model will be used to develop a theoretically-justified set of interventions and remediations for improving human performance in interruption management, resilience, and recovery; The paper will also report on results of HITL laboratory investigation of remediation concepts and these concepts will be provided to Level 3 ConOps development activities for potential evaluation.
IIFD.OC.2 (Subtopic)	Identify information requirements to support the roles of NextGen operators.	Q4/FY09	(IIFD.OC.2.1) The Cognitive and Operational Demands Analysis (CODA) is a qualitative analysis approach that has been developed to facilitate the identification, evaluation, and analysis of three types of workload demands encountered on advanced technology flight decks and cockpits: operational, cognitive, and technology driven (see IIFD.OC.1.8 above); Human factors experts with domain expertise will submit a conference paper or journal article submitted that describes the CODA

			approach, which was developed to more comprehensively identify and evaluate the varied and competing demands placed upon operators during NextGen terminal area operations than is possible using current approaches to cognitive, task, or work analyses; Subsequent studies will validate CODA experimentally (see IIFD.OC.2.3). (IIFD.OC.2.2) Contractor report submitted that documents a systems analysis of alert conditions required for NextGen aircraft operators; This set of conditions that require alerts will be initially identified analytically with SME input and review of existing NextGen documentation; These requirements will be used to determine the underlying parameters required to manage the presentation of these alerts in an integrated alerting and notification (IAN) system (see also IIFD.EA); Selected forms of IAN display concepts will be implemented in preparation for laboratory evaluation.
		Q4/FY10	(IIFD.OC.2.3) Journal article submitted describing a human-in-the-loop study conducted to validate the Cognitive and Operational Demands Analysis (CODA) predictions and explanations of workload bottlenecks in NextGen terminal area operations; Initially this methodology will be applied to Very Light Jet single-pilot operations; Extensive interchange with pilot populations and aircraft manufacturers is planned to substantiate the realism of this work. (IIFD.OC.2.4) NASA TM or conference paper submitted documenting operator interface requirements to support Level 3 concepts (see IIFD.DDS.1.1 and IIFD.RAHS.1.1); This document will record the information requirements, as based on task/decision analyses, and as demonstrated in display concepts, aural indications, and required supporting information systems/documentation that will allow others to develop competing methods of presenting this information.
		Q3/FY12	(IIFD.OC.2.5) NASA TM or conference paper submitted that audits the correspondence of the Level 3 DDS concept with previously-developed interface requirements; This audit will assess the degree to which previously-defined information requirements are met

			by the DDS concept and will serve to identify gaps and potential areas for improvement.
IIFD.OC.3 (Subtopic)	Characterize the functional state of operators	Q3/FY09	(IIFD.OC.3.1) Contractor report submitted that describes the system design for, and in flight evaluation results of, an operator state classification method; the evaluation will, at a minimum, include operator state detection performance and classification performance for states induced during controlled tasks during flight operations. (IIFD.OC.3.2) Contractor report submitted describing the utility of fNIRS and photrobe sensors for operator state characterization; utility will be assessed via a flight experiment where data from these sensors is recorded during controlled tasks and compared to other physiological measures commonly used to infer operator state. (IIFD.OC.3.3) Contractor report submitted describing operator state classification algorithms and documenting results of classification validation testing based on previously-collected data in a fatigue experiment.
		Q4/FY09	(IIFD.OC.3.4) NASA TM or journal article submitted describing effects of fatigue on operator performance and ability to reliably and comfortably ascertain fatigue levels during actual airline operations; Long-haul operational data on operator physiological effects will be combined with performance data to ascertain operational indicators, and operational effects of fatigued pilots (depends on IVHM collaborative research with EasyJet and ONERA in support of IVHM milestones 1.3.1.1, 1.3.3.2, and 3.1.3). (IIFD.OC.3.5) NASA TM, conference paper, or journal article submitted that describes best practices for fNIRS instrumentation design and data collection for operator state detection that is reliable, sensitive, and relevant to the flightdeck operating environment.
		Q2/FY10	(IIFD.OC.3.6) Conference paper submitted that describes the use of haptic interface devices to characterize operator state with respect to engagement in the control aspect of a simulated flight task; This report will document the results of a flight simulation-based investigation of the

			extension of an adaptive technique that has been previously tested in automobiles to explore the degree to which pilot engagement can be determined by measuring stick grip. (IIFD.OC.3.7) NASA TM, conference paper, or biomedical device journal article submitted that describes an fMRI-compatible fNIRS headgear design; Such headgear is required to permit coincidental fNIRS and fMRI data collection, which is necessary to select localization of fNIRS sensors for optimized operation. (IIFD.OC.3.8) Conference paper submitted describing operational methods for indicating an operator's task saturation/ engagement; Such methods are needed to effectively assess the efficacy of Level 3 (DDS/RAHS) concepts, and to provide a mechanism for adaptively configuring interface features, automation, and team dynamics in response to operator state; This effort will provide operator state indices relevant to evaluating the efficacy of flight deck technology/operating concepts and evaluative scenarios; These methods will be assessed in conjunction with subjective and performance measures. (IIFD.OC.3.9) Contractor report submitted describing the OSCAF operator state classification algorithm and associated artifact removal algorithms to permit effective fusion of data received from multiple neuro-physiological sensors. (IIFD.OC.3.10) NASA TM or conference paper submitted that describes a method for characterizing operator state by means of monitoring behavioral inputs (e.g. FMS/CDU inputs); This report will be supported by coordinating with developments in the IVHM project (e.g. the sequenceMiner algorithm) and models of operator behavior (NGOMSL and OFM).
		Q4/FY11	(IIFD.OC.3.11) Journal article submitted that describes fNIRS and fMRI correlation study to update previously-published best practices for the design and use of fNIRS for operator state assessment (see IIFD.OC.3.5). (IIFD.OC.3.12) Contractor report submitted updating system description for,

			and in flight evaluation results of, operator state classification and modulation system (see IIFD.OC.3.1).

Sensing, Signal Processing, and Hazard Characterization (SS) – Level 1			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.SS.1 (Subtopic)	Forward-looking remote sensing methods, models, and technologies		
IIFD.SS.1.1	Complete initial investigation of forward-looking interferometric (FLI) sensing, including results of ground testing, simulations, and characterization of sensor capabilities for detection of selected hazards Explanation: To meet the needs of the commercial fleet, a new airborne sensor should ideally address multiple hazards and provide benefits in efficiency of operations as well as improvements to safety to warrant the costs of development, certification, installation, training, and maintenance. This investigation will result in a judgment on the feasibility of an FLI as a sensor for several high priority hazards, and provide data to aid in ranking this technology against others for decisions on continuation of investigations.	Q2/FY09	Evaluate FLI for its potential to address multiple hazards including clear air turbulence (CAT), volcanic ash, wake vortices, low slant range visibility, dry wind shear, icy runway conditions, and in-flight icing conditions; Complete sensitivity studies to improve understanding of the potential capabilities and to determine requirements for an airborne FLI instrument; Obtain field measurements from prototype instruments; Develop analytical models that aid in the prediction of severity of detected hazards; Compare field measurements with modeled predictions in order to validate models and identify areas for improvement for either the model or the instrument design; NASA TP submitted documenting technology feasibility and supporting decisions on continuation of research leading to IIFD.SS.1.2 and IIFD.SS.1.8. (Decision Point)
IIFD.SS.1.2	Complete feasibility studies of forward-looking interferometric (FLI) sensing including terminal area ground and flight testing to quantify performance prediction uncertainty and to provide data to advance the development of hazard detection capabilities Explanation: This milestone depends on a decision to continue from IIFD.SS.1.1; this research will further hazard and sensor characterization studies, validate sensor and phenomenological models against measured data, determine the technology readiness level, and enable the development of hazard detection and severity algorithms.	Q3/FY10	Ground and flight tests of a prototype FLI instrument conducted to verify model capability to predict results and to verify model results predicting detection capability; Proposed instrument configuration developed and performance predictions made; Proposed sensor role/function developed and initial requirements identified; Conclusions drawn about the efficacy and capability of the technology to provide useful information about each of the hazards addressed, and about the technology readiness of a FLI as a component of an airborne hazard detection system, including identification of technical barriers or challenges for a practical instrument; Recommendations made as to the need for further research and development required to achieve an operational sensor,

			and to support continuation of FLI research. Results are documented in a Contractor Report and/or NASA TM or Journal article. Report includes flight/field data verification of models, proposed sensor design and role in the cockpit, projected requirements, and performance predictions.
IIFD.SS.1.3	Evaluate the feasibility of Lidar sensor technology concepts for airborne wake vortex detection	Q1/FY11	Concepts for on-board (airborne) detection and measurement will be evaluated for ability to detect wake vortex hazards; Performance predictions will be developed and evaluated for range capability, range/azimuth resolution, wake classification capability (e.g. strength, motion, decay), and detection performance (e.g. probability of false/missed detection); Contractor report, conference paper, or journal article, submitted documenting results. (Decision Point)
IIFD.SS.1.4	Evaluate design of low-cost electronically-scanned radar antenna Explanation: The objective of this radar technology investigation is to remove technical and cost barriers to the application of these antennas on aircraft. The use of electronically-scanned radar antennas will improve antenna agility and versatility, facilitating such modes at track-while-scan, which will allow the radar to perform a normal scanning function while tracking or interrogating a specific target like another aircraft or an object on the runway.	Q1/FY11	Assess new designs and fabrication techniques to establish the viability of low-cost electronically scanned antennas for airborne radars; Mechanical scanning is the fundamental limiting component in current radar systems; Electronic scanning would enable or extend the numerous aviation safety benefits derived from radar systems; A contractor report will assess viability and detail the limiting factors for the development of a low-cost electronically scanned antenna/radar system; An engineering prototype will enable assessment of the fabrication principles and performance characteristics of the proposed design as documented in a contractor report.
IIFD.SS.1.5	Evaluate Near-Infrared (NIR) External Hazard Detection System	Q2/FY10	Investigate the use of gated lidar imaging to enable reduced visibility operations by imaging through obscurants and to identify aircraft risks due to obscurants such as super-cooled water droplets or volcanic ash. Evaluation of resulting design and prototype devices will be against operational requirements such as range and image resolution for making landing decisions and runway incursion detection; Contractor report submitted documenting results including lab, field, and flight test results.

IIFD.SS.1.6	Develop and evaluate methods and systems to detect and track non-cooperative traffic using enhanced ADS-B technology	Q1/FY11	Assess the performance of enhanced ADS-B technology to perform non-cooperative traffic surveillance; Build and test (in flight) an engineering prototype and assess the detection and tracking performance of a radar-like system based upon reflected ADS-B transmissions; Evaluation of performance would be against established, or under-development, surveillance requirements (such as those developed by the FAA or RTCA) for accuracy, availability, update rate, range, and false/missed detection rates.
IIFD.SS.1.7	Develop a pulsed-lidar model to support the investigation of the detection capabilities of lidar for icing, wake vortex, and clear air turbulence hazards	Q2/FY10	Develop numerical simulations of heterodyne-detection and direct-detection pulsed lidar sensors; Assess model capabilities by comparison between field test data and numerical simulation results; Document the models and simulations and establish a plan to evaluate the application of lidar systems for relevant hazards including icing, wake vortices, and clear air turbulence; NASA TM or TP submitted documenting model design and evaluation results.
IIFD.SS.1.8	Re-assess strategic plan and initiate follow-on sensor investigations based upon capability and performance predictions, models and technology development, quantification of uncertainties. This milestone is a decision point with regard to follow-on work and based on results of the initial studies reported in IIFD.SS.1.1 to IIFD.SS.1.7 as well as Level 3 concept evaluations and identified needs.	Q1/FY13	Follow-on work may continue for promising theoretical sensor concepts or, for technology that is already mature to the point where feasibility is established and technical hurdles to the practical development of airborne sensors still exist; Examples include: for work attacking a specific technical barrier, the focus will be on the effectiveness of the solution; For investigations advancing a technology from the establishment of feasibility to a proposed instrument capability/ configuration, the focus will be on the verification of expected results and capabilities through lab or field/flight tests; For studies involving advanced sensor capability development, results will focus on salient sensor characteristics required for effective application, including probability-of-detection, probability-of-false alarm, hazard measurement, hazard location and extent, and accuracy; all of these compared against the Level 3 concept requirements that emerge through the course of study.
IIFD.SS.2 (Subtopic)	Image processing and feature extraction		

IIFD.SS.2.1	Develop and evaluate methods for FLIR image fusion and image processing to support Level 2 and 3 requirements for terminal area hazard awareness Explanation: The objective of this work is to develop image fusion and processing capability and apply objection detection to real imagery from flight tests and to evaluate against objection detection without image fusion.	Q3/FY09	Test the image fusion performance to determine its potential as a means to facilitate better hazard detection in the terminal area over non-fused imagery; Conference paper or contractor report submitted documenting FLIR information processing performance for operational scenarios taken from experimental data; Object detection performance will be documented comparing fused and non-fused cases, highlighting those cases where one detected objects and not the other.
IIFD.SS.2.2	Complete comprehensive design of Spatial Vision Tree (SVT) – a generic pattern recognition engine	Q4/FY09	Key objectives for this milestone are further development of the SVT to improve function and performance, testing to verify that the new SVT frequency-of-occurrence (FOO) distribution approaches that of treeless FOO distributions, measurements to facilitate an estimation of the time required for SVT processing of one image frame, and evaluation of the potential for SVT processing in real time based on the standard of 16 – 32 frames per second. Design, development, test results and conclusions will be published (NASA TM or open literature).
IIFD.SS.2.3	Develop and verify methods for runway detection and runway object detection for FLIR and color video imaging systems	Q4/FY11	Three or more methods for Retinex Visual Servo and edge detection/processing will be developed; Assess and compare performance of these competing methods for runway detection in recorded or inflight imagery; Evaluation will be performed by comparison of a detection product (a runway outline) to the actual runway boundaries; Contractor report submitted documenting the results of automatic imagery analysis for runway edge and runway hazard detection, including evaluation of preliminary work on analysis of runway object hazard characterization and hazard assessment.
IIFD.SS.2.4	Demonstration of real-time image enhancement and pattern recognition system during terminal area operations for FLIR and color video imaging systems	Q3/FY12	During actual flight or using recorded flight data, demonstrate, at a minimum, real-time performance (i.e., 16-32 frames per second) for image enhancement of the runway environment during approach and landing and across a representative set of ambient weather conditions; during these scenarios, runway edges and centerlines as well as any large object on the runway (e.g. an aircraft) and vertical obstructions near the flight path should be visible in the enhanced images as well as being captured, identified, and tracked by a pattern recognition system; Conference

			paper, NASA TM, or contractor report submitted documenting results.
IIFD.SS.3 (Subtopic)	External Hazard Characterization		
IIFD.SS.3.1	Assessment of external hazard detection and intensity algorithms for hazards in the terminal area Explanation: Anticipated potential threats to safety include: terrain and obstacles, air/ground traffic, objects on runways/taxiways (including runway incursions), turbulence (wake vortices and orographic clear air turbulence), low slant range visibility, dry wind shear, icy/wet runway conditions, in-flight icing conditions, and runway/taxiway mis-alignment. This work would largely be a part of sensor/detection studies (IIFD.SS.1), but also continuously monitor SOA capability as compared with NextGen requirements (vis-à-vis the Level 3 RAHS and DDS concepts).	Q4/FY10 Q4/FY11 Q4/FY12	Assessment of baseline external hazard detection and intensity algorithms for hazards in the terminal area; Includes multiple assessments that are part of sensor technology studies (see SS.1), visual-awareness investigations (see SS.2), and icing investigations (see SS.4) that are associated with specific hazards, and conducted and reported under milestones in these areas (see specifically, SS.1.2, SS.1.3, SS.1.5, SS.1.7, SS.2.1, SS.2.3, SS.2.4, SS.4.1, SS.4.4, and SS.4.5); Assessments are based on the predicted ability to detect hazards and quantify intensity and will be compared to flight data, ground measurements, and/or independent remote measurements relative to the accuracy needed to enable the Level 3 concepts, and in support of the IAN investigation under IIFD.EA; Results documented as described in the referenced milestones; Additional research may be identified as a result of these assessments and tracking state-of-the-art.
IIFD.SS.4 (Subtopic)	Icing Remote Sensing and Characterization		
IIFD.SS.4.1	Pre-flight assessment of the Multi-Frequency Radar (MFR) for characterization of atmospheric icing conditions, including ground operation and comparison with NIRSS radar performance	Q3/FY09	The established MFR is modified to ensure the stabilization of emission frequencies with active thermal control of critical components, replace significant portions of the data acquisition hardware, revise the data acquisition software, and calibrate the three frequency's subsystems; Ground testing of the modified MFR will be used to verify performance given these changes; Evaluation of the utility of the radar for characterization of atmospheric icing conditions will be accomplished through the comparison of the MFR's X-, Ka-, and W-band measurements (reflectivities) to ground-based X- and Ka-band radar systems with proven field test histories; A minimum success of the comparisons would be matching reflectivities at similar frequencies and matching cloud boundaries.

IIFD.SS.4.2	Assessment of the feasibility and benefit of a scanning, narrow-beam radiometer for the detection and classification of icing hazards Explanation: This objective of this milestone is to advance the current experimental radiometer capability into a 3-D scanning system that works in concert with meteorological radar and to test the detection capability versus other collocated instruments	Q3/FY10	NASA TM, contractor report, or journal article submitted documenting comparison of measured boundaries and intensities of regions of liquid water to values derived from co-located instrumentation and forecast models; a positive comparison would be the matching of cell boundaries and average liquid water content (LWC); The feasibility and benefit of operation of the radiometer based upon comparison criteria, along with synoptic weather analysis will also be documented.
IIFD.SS.4.3	Assess instrumentation performance and flight operation procedures for High Ice Water Content (HIWC) flight research Explanation: Flight testing to measure cloud properties that lead to engine icing and to develop methods for detecting the hazard is required to meet IIFD.SS.4.5 below, and to evaluate in flight performance of sensors previously described for the remote sensing of hazards (e.g. IIFD.SS.4.1).	Q1FY11	Both instrumentation effectiveness and operational procedures will be evaluated with respect to achieving the science objectives for characterizing the microphysical properties of core, or near-core, regions of deep convective clouds, determining small ice particle formation mechanisms, and testing ground- and satellite-based remote sensing methods of determining cloud properties in high-IWC regions in deep convection; A baseline science plan and requirements matrix will document objectives in FY09; this assessment will compare actual performance against those described in these documents; NASA TM or conference paper submitted documenting assessment results.
IIFD.SS.4.4	Measure and record cloud properties that lead to engine icing for the purposes of developing models or databases that can be used to replicate such conditions in controlled environments, and to predict effects of mitigation methods	Q3/FY11	Collect sufficient data from flight-, ground-, and satellite-based instruments to 1) develop a statistical database of microphysical cloud properties sufficient for engine icing modeling, engine testing and development, and engine certification; 2) develop means of detecting engine icing threats using remote sensing and or onboard measurement systems; and 3) to develop a knowledge-base of ice crystal environments to enable weather modeling and forecast/nowcast tools to predict regions where engine icing is a threat or hazard; Success requirements include gathering in-situ measurements that can yield 99 percentile statistics on ice water contents at three altitude levels; for validation purposes, correlated measurements from remote sensing via flight, ground, and satellite instruments will be obtained.
IIFD.SS.4.5	Methods for detection, prediction, and avoidance of atmospheric conditions that are conducive to HIWC engine icing based on	Q1/FY13	Analyze flight-, ground- and satellite-based data collected previously (see IIFD.SS.1.6 and IIFD.SS.3.2); Provide methods for, and assessment and

	analysis and characterization/ modeling of the hazard environment		evaluation of, remote-sensing to detect high ice water content environments; Deliver statistics on ice water content levels and hydrometeor characteristics; Technologies examined for the remote detection of HIWC conditions shall include, at a minimum, satellite-based optical methods, airborne radar, and ground radar methods; Results documented in NASA TP and collaborative journal articles, and presented in a HIWC workshop with published proceedings.
IIFD.SS.5 (Subtopic)	Operator state sensing and signal processing		
	Determine critical needs and technical gaps for operator state sensing Explanation: Leverages work being conducted under IIFD.OC.3, “Characterize the functional state of operators” where important aspects of operator state are identified and COTS sensors for measuring these states are applied and evaluated. In the event that adequate sensing capability is not available, the sensor need and known requirements are reported here. An investigation may be initiated to determine what measurables can be associated with the operator state and what sensor technologies can be associated with the measurable. Following, a sensor technology investigation may be initiated (see IIFD.SS.5.2 below).	Q4/FY10 Q4/FY12	Identify operator state sensing needs that cannot be met by COTS devices; Recommend follow-on feasibility study or technology development with respect to these needs; This deliverable is contingent on IIFD.OC.3 research outcomes; i.e. when a sensor need is perceived in IIFD.OC.3, it is documented as a part of that milestone and serves as a catalyst for work here to determine whether there is a promising technology avenue to pursue either as a feasibility study or as technology development (see IIFD.SS.5.2 below). (Decision Point)
IIFD.SS.5.2	Conduct operator state sensor investigation to attack key technical barriers identified in previous work (see IIFD.SS.54.1) Explanation: This investigation may take the form of a feasibility study or technology development. Feasibility assessment will include model development and analyses of detection and measurement capability as related to operator state. Technology development is warranted when specific technology barriers must be overcome to make a sensor solution effective. Technology development expects	Q4/FY11 Q4/FY13	Evaluate sensor performance against requirements delivered from Level 1 (OC), Level 2 (OP and EA), and Level 3 (RAHS and DDS) with respect to operator state sensing technology; NASA TM, journal article, or contractor report submitted documenting results including, for example, experiment descriptions and results, model verification, performance predictions, and recommendations and objectives for further investigation or development.

	clearly defined requirements for sensing capability in order to provide a measure of the success of the development (i.e. performance will be evaluated versus the requirements).		

Multi-Modal Interfaces (MM) – Level 1			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.MM.1	Develop and evaluate improved visual interface capabilities	Q3/FY09	(IIFD.MM.1.1) Conference paper submitted that documents results of initial lab assessment of prototype head-slaved stereoscopic device for improved 3D perspective information display; This formative assessment will investigate the impact of this technology on spatial situation awareness, tunneled attention, and navigational decision making; as well as how behavior differs from a baseline configuration.
		Q3/FY10	(IIFD.MM.1.2) NASA TM, conference paper, or journal article submitted documenting results of human-in-the-loop evaluation of the new perspective display in full mission simulation to assess impact on spatial situation awareness and potential deleterious effects on monitoring other systems. (IIFD.MM.1.3) NASA TM or conference paper submitted summarizing results of a laboratory study evaluating methods for improving the ability to obtain information from displays adjacent to that which is foveal, and characterizing the limitations for presenting peripheral information on distributed displays; Prior research has focused on perceptual threshold limits for peripheral targets; This document reports extending such research to determine new methods for improving the use of the periphery, and for modeling the probability of detection with these new methods at various eccentricities.
IIFD.MM.2	Develop and evaluate improved aural/speech interface capabilities	Q3/FY09	(IIFD.MM.2.1) Conference paper or journal article submitted documenting a laboratory-based evaluation of speech quality and comprehension effort for parameters of prosody and rate-synthesized voice messages to use in a real-time speech display for future flight deck systems; This document reports the interaction among the independent variables characterizing speech that are

			hypothesized to affect intelligibility, comprehension, and discriminability; Metrics will include performance and subjective measures associated with these three constructs, with a threshold of 95% for objective data and "high" ratings on subjective data initially set as the criteria for successful information conveyance. (IIFD.MM.2.2) NASA TM or conference paper submitted documenting results of a part-task simulation study completed using a representative user population and initial audio display technology integrated with data link, weather, and traffic merging & spacing display concepts; Report will include initial guidelines for use of auditory displays as part of Level 3 concepts and evaluations.
		Q1FY10	(IIFD.MM.2.3) NASA TM or journal article submitted that describes the method and outcome for designing a comprehensible set of aural stimuli for conveying NextGen alerting conditions; This report will consider aural parameters (including those for speech and non-speech alerts) for detection, discriminability, and intelligibility in isolation and as part of an integrated auditory display and based on differences in communication requirements for future displays as compared to state-of-the-art; The report will be based on a combination of literature review, evaluation of current technology, and laboratory evaluation of new technologies; Simulation studies are not included here, but may be considered as part of a Level 3 DDS concept evaluation.
		Q3FY10	(IIFD.MM.2.4) NASA TM or journal article submitted that evaluates theoretically-indicated applications of aural indicators to NextGen IAN requirements (see OC.2) for detection, intelligibility, distinguishability, perceptual grouping, and as supportive of response effectiveness (speed and accuracy); Initial investigations will be laboratory studies with aims to incorporate into future Level 3 DDS integrated simulation studies.
IIFD.MM.3	Develop and evaluate novel and multi-modal interface capabilities	Q4/FY09	(IIFD.MM.3.1) Book Chapter submitted on the design and human performance considerations in the development of dynamic operating documents; Dynamic operating documents use sensed data, or

			operational context, to alter previously static checklists and documents in real-time to increase their applicability and utility for operators; This chapter will focus on design and development issues associated with this concept and will cover the full range of flight deck operational documents which might be made dynamic; The aspect of this effort that contributes to this research element is to determine how dynamic, potentially multi-modal information presentation devices can best support operator requirements.
		Q3/FY10	(IIFD.MM.3.2) NASA TM or journal article submitted that recommends parameters for effectively coding haptic interfaces for improved joint human/automation control; These recommendations will derive from a laboratory study that compares various configurations of haptic interface codings and baseline conditions for their effect on pilot workload, control efficacy, responses to off-nominal conditions (e.g. automation failures), and subjective measures of preference for comfort. (IIFD.MM.3.3) IIFD report submitted documenting state-of-the-art review of interface technologies that may permit more effective presentation of information to operators, or may permit more effective attention distribution among perceptual modalities to best maintain situation awareness; This review will canvas technologies under development and used in other application domains, and posit the utility for future flight deck systems; Such a review will be used as a decision point with respect to future research in this area; this interim report would be made publicly-available via the IIFDT website or alternate means subject to NASA's public-release approval process. (Decision Point)

Information Interaction Modeling (IM) – Level 1			
ID	**Title**	**Date**	**Exit Criteria**
IIFD.IM.1 (Subtopic)	Theoretical approaches for presenting large volumes of data in limited display space		
IIFD.IM.1.1	Development and validation of general theory and executable model for data extraction, integration, and abstraction against	Q4/FY09	(IIFD.IM.1.1.1) Demonstrate application of the theoretical approach to information abstraction and presentation using representative recorded flight data and

	baseline practices and Level 3 application		indicating performance deviations from expected norms; NASA TM or TP submitted documenting generalized approach to information abstraction for analog signals.
		Q4/FY11	(IIFD.IM.1.1.2) Verification of the approach and performance against design requirements utilizing an operationally-relevant number of sensor/data streams and considering three main criteria: failure sensitivity to a single data stream change, preservation of individual stream identification capability, and detection of deviations from expected signatures; NASA TM or TP submitted documenting revised approach and verification results.
		Q4/FY13	(IIFD.IM.1.1.3) Validate the approach as instantiated within the IAN function (see IIFD.EA) and using data from at least one Level 3 concept evaluation (IIFD.RAHS.1.2 or IIFD.DDS.1.2) by confirming that operators are able to maintain awareness of single data stream changes, identify the source of the changes, and detect deviations from expected signatures as predicted by the model; NASA TP or journal article submitted documenting design and validation results.
IIFD.IM.2 (Subtopic)	Predictive modeling of human interaction performance		
IIFD.IM.2.1	Development and validation of integrated model of automation and operator performance defined for Level 3 conceptual designs	Q4/FY10	(IIFD.IM.2.1.1) Demonstration of initial task performance prediction model using at least one NextGen-based scenario (see IIFD.FDS.1.1).
		Q4/FY13	(IIFD.IM.2.1.2) Validation of task performance model predictions for at least one NextGen-based scenario; Empirical data obtained from the Level 3 evaluations (IIFD.RAHS.1.2 and IIFD.DDS.1.2) will be compared against modeled predictions of automation and operator performance to assess the extent to which the model provides insights valuable to automation design; NASA Technical Paper or journal article submitted documenting model design, assumptions/limitations, and validation results.
IIFD.IM.3 (Subtopic)	Formal models of fault-tolerant systems that include human elements		

IIFD.IM.3.1	Development and validation of representative fault, error, and communication analysis models for both human and automation system components	Q4/FY10	(IIFD.IM.3.1.1) Framework defined for designing machine-checkable formal models sufficient for capturing relevant aspects of human error persistence and effect; Framework reviewed by subject matter experts for completeness and sufficiency either via workshop process or journal article peer review.
		Q4/FY11	(IIFD.IM.3.1.2) Models developed and verified against design requirements for at least one Level 3 concept.
		Q4/FY13	(IIFD.IM.3.1.3) Validation of representative set of failure/error predictions in relevant environment; Empirical data obtained from the Level 3 evaluations (see IIFD.RAHS.1.2 and IIFD.DDS.1.2) will be compared against modeled predictions for human and machine error and resulting effects to assess the extent to which the model provides insights valuable to automation design; NASA TM, TP, or journal article submitted documenting model design, assumptions/ limitations, and validation results.

COORDINATION AND COLLABORATION

The IIFDT project partners across a broad spectrum of organizations to achieve the defined objectives. Leveraging talents and capabilities across the nation in this way creates a virtual team aligned with a common vision of improving flight deck system safety and capability. Coordination and collaborative activities involve industry, other government agencies, other projects/programs within NASA, and academia.

NASA's approach to industry partnerships is a shift from near-term evolutionary procurements to long-term intellectual collaborations. As required, collaboration with industry partners may be formalized through non-reimbursable Space Act Agreements (SAAs) targeting research in specific areas. Similarly, formal partnerships with Other Government Agencies (OGAs) can be executed through Inter-agency Agreements (IAs), Memoranda of Agreement (MoAs) or other agreements as appropriate. Universities, small businesses, and industry conduct some of the foundational research and development necessary for the IIFDT project to succeed. Research at the foundational Levels provides input to the more integrated research efforts involving broader collaboration with others in government, industry, and academia. The vehicle intended to solicit these collaborations is a NASA Research Announcement (NRA). The resulting agreements are, in most instances, cooperative agreements. However, in some cases, they may be contracts or grants depending on NASA procurement regulations.

The following sections list partnerships in place as of the approval of this technical plan. These will be updated as part of the revision process for this plan.

Space Act Agreements and Industry Coordination

The AvSafe Program conducted an "Industry Days" workshop in September 2006. Industry representatives attended who expressed interest in participating in non-reimbursable pre-competitive collaboration with NASA. The group consensus was to form an Industry/NASA Flight Deck Research Working Group (FDR WG). The FDR WG meets periodically to discuss research results, technology trends, emerging needs, and potential collaborations. This activity supports and complements the project's internal activities (particularly at Level 3/4). This forum can also serve as a catalyst for developing formal Space Act Agreements (SAAs) as appropriate. FDR WG terms of reference were written and approved by the group and are available at www.aeronautics.nasa.gov/avsafe/iifd.

Currently, IIFDT participates in a collaborative SAA with the Boeing Company (SAA2-401315) for Requirements Definition, Design, Analysis, and Evaluation of Flight Deck Concepts.

Interagency Agreements

IIFDT has negotiated an Inter-agency Agreement (IA) with the Air Force Research Lab at Wright-Patterson Air Force Base to conduct collaborative research in the area of improved crew-vehicle interfaces for low visibility operations. Additionally, an IA is in place with the FAA to support the management and maintenance of the ASRS.

NASA Research Announcements

Since the initial release of the 2006 ARMD NRA "Research Opportunities in Aeronautics" IIFDT has conducted four solicitation/review/award processes. These have resulted in eighteen awards, negotiated as contracts or cooperative research agreements, to contribute to project objectives (see Table D-1). Throughout the term of the project, IIFDT will continue to use the NRA process to fund novel research in selected topical areas to fill gaps in the in-house research portfolio.

Table B-1. NRA-Based Contracts and Cooperative Research Agreements

Title	Lead Org.	End Date	Research Topic Contribution
Methodology to Support Dynamic Function Allocation Policies Between Humans and Flight Deck Automation	Ga. Tech	Sep-09	IIFD.RAHS IIFD.OP IIFD.DT
Operator State Sensor Investigations, State Classification, and Feedback Algorithms	Univ. of Iowa	Nov-11	IIFD.OP IIFD.EA IIFD.SS
Control of Attention: Modeling the Effects of Stimulus Characteristics, Task Demands, and Indiv. Differences	Univ. of Illinois	Dec-08	IIFD.OP IIFD.IM
A Novel Non-intrusive Multi-modal System for Real-time Operator State Assessment	Intelligent Automation	Nov-08	IIFD.OP IIFD.EA IIFD.SS
Designing Human-Automation Interaction Through Computational Modeling of Cognition and the Dynamic Flight Environment	Ga. Tech	Jul-10	IIFD.RAHS IIFD.DT IIFD.IM
Automation Interaction Design and Evaluation Methods	George Mason Univ.	Jul-10	IIFD.RAHS IIFD.DT IIFD.IM
Proactive System Design and Evaluation: Supporting Pilot-Automation Interaction thru Empirical and Modeling Analyses	Univ. of Mich.	Sep-10	IIFD.RAHS IIFD.DT IIFD.IM
Advanced Computational Models for the Design of Automated Systems	Aptima	Aug-10	IIFD.RAHS IIFD.DT IIFD.IM
Testing and Validation of a Psychophysically Defined Metric of Display Clutter	NC State Univ.	Sep-09	IIFD.DDS IIFD.OP IIFD.DT
Head-Worn Display Systems	Honeywell	Sep-08	IIFD.MM
Characterization of Airborne Runway Incursion Sensors	RTI	Dec-09	IIFD.SS
Airborne Phased Array Radar for Microphysics-Based Hazard Detection and Monitoring	Univ. of Ok.	Sep-08	IIFD.SS
Sensor Technology Model Development and Evaluation for an External Hazard Monitor	Ohio Univ.	Sep-08	IIFD.EA IIFD.SS
Hazard Analysis for a Forward-Looking Interferometer	Ga. Tech	Oct-08	IIFD.SS
Airborne Bistatic Radar for Wind Hazard Detection and Avoidance	Old Dominion Univ.	Jul-08	IIFD.SS
Smart Sensor Processing for Automatic Runway Hazard Detection	Old Dominion Univ.	Dec-09	IIFD.SS
Design, Development, Verification and Validation of an Integrated Alerting and Notification Function for an Integrated Intelligent Flight Deck	Ohio Univ.	Aug-11	IIFD.OP IIFD.EA IIFD.DT
ALARMS: Alerting and Reasoning Management System	Aptima	Jun-10	IIFD.OP IIFD.EA IIFD.DT

Small Business Innovative Research (SBIR) Program

The NASA SBIR program provides an opportunity for small advanced technology companies and research institutions to participate in Federal Government-sponsored research and development (R&D) efforts, such as IIFDT. SBIR sub-topics currently posted and supported by IIFDT include: Aviation External Hazard Sensor Technologies (A1.04), Crew Systems Technologies for Improved Aviation Safety (A1.05), and Technologies for Improvement Design and Analysis of Flight Deck Systems (A1.06). Since the project's inception, IIFDT has collaborated with multiple research efforts via SBIR Phase I/II/III awards (see below). For more information, see www.sbir.nasa.gov .

Phase I

- Fiber Laser Coherent Lidar for Wake-Vortex Hazard Detection, Fibertek, Inc., January 2009 to July 2009 (see IIFD.SS)
- Low-Cost LIDAR for Wake Vortex Detection, Q-Peak, Inc., January 2009 to July 2009 (see IIFD.SS)
- Flight Crew State Monitoring Metrics, Emerald Sky Technologies, LLC, January 2009 to July 2009 (see IIFD.OP)
- Voice to Text Language Translation (VTLT), Ingenium Technologies Corporation, January 2009 to July 2009 (see IIFD.MM)
- Cognitive Modeling for Closed-Loop Task Mitigation, Intelligent Automation, Inc., January 2009 to July 2009 (see IIFD.OC)
- H/OZ: PFD and Collaborative Flight Control System, Emerald Sky Technologies, LLC, January 2008 to July 2008 (see IIFD.OP)
- A Low Cost, Electronically Scanned Array (ESA) Antenna Technology for Aviation Hazard Detection and Avoidance, ThinKom Solutions, Inc., January 2009 to July 2009 (see IIFD.SS)
- Computational Model and Measurement Tool for Evaluating the Design of Flight Deck Technology, Aptima, Inc., January 2009 to July 2009 (see IIFD.DT)

Phase II

- See and Avoid Collision Avoidance Using ADS-B Signal and Radar Sensing, Intelligent Automation, Inc., November 2006 to November 2008 (see IIFD.SS)
- Near Infrared Lidar for Hazard Sensing and Characterization, RL Associates, Inc., August 2007 to August 2009 (see IIFD.SS)
- Optical Liquid Water Content Probe, Innovative Dynamics, Inc., December 2006 to December 2008 (see IIFD.SS)

Phase III

- Head-Worn Displays to Enable Equivalent Visual Operations, Intersense, October 2007 to October 2008 (see IIFD.MM)
- Multi-Frequency Airborne Radar System for Aircraft Icing Avoidance, ProSensing, July 2006 to April 2008 (see IIFD.SS)

Participation in Technical Committees

IIFDT leaders and researchers participate on multiple government and industry technical committees. In these venues, relevant research results are presented describing advanced concepts and findings that may be useful in meeting TC objectives. In addition, these venues provide opportunities to gain insight into boundaries or barriers related to the introduction of new concepts; thereby, identifying areas of research. Lastly, these venues can serve as catalysts to the coordination, collaboration, and integration of research activities across the community. IIFDT actively participates in the following technical committees:

- RTCA/EUROCAE SC-206, Aeronautical Info. and Meteorological Services (AIS/MET)
- RTCA SC-213, Synthetic and Enhanced Vision Systems
- RTCA SC-186, SG-1, Surface Traffic Alerting
- FAA/Industry RNP-RNAV Task Force (a.k.a. the CNS Task Force)
- SAE Aerospace Behavioral Engineering Technology TC (G-10)
- NASA/Air Force Executive Research Committee
- IEA Human Factors Technical Committee
- Royal Aeronautical Society Flight Operations Group
- FAA/EUROCONTROL Action Plan 15 Committee on Safety Research
- FAA/EUROCONTROL Action Plan 21 Committee on Surface Operations Research

NASA Post-doctoral Program (NPP) and Graduate Student Research Program (GSRP)
For flight deck-related opportunities for post-doctoral research, search the NPP Web site for the topic: Integrated Intelligent Flight Deck Technologies. Visit http://nasa.orau.org/postdoc/ . For flight deck-related opportunities for Masters- and PhD-level graduate students, search the GSRP Web site for these topics: Crew vehicle interfaces; External hazard detection; Robust automation-human systems; Verification, validation, and predictive capability; Aircraft icing. Visit http://fellowships.hq.nasa.gov/gsrp/program/ .

NASA Collaborations
IIFDT collaborates with multiple projects, programs, and mission directorates across NASA. Activities include, for example, workshops and technical interchange meetings, joint experimental studies, and jointly-funded cooperative research agreements via the NRA process. Topics include:

- AvSafe/IVHM – Architecture analysis; data mining (see below)
- AvSafe/IRAC – Pilot decision support; Human-automation interaction design methods and tools (see below)
- ASP/Airspace – Trajectory-based operations; Human-system integration; ConOps and scenario development
- ASP/Airportal – Runway incursion prevention and surface routing; Surface CD&R; Human-system integration; ConOps and scenario development
- FAP/Supersonics – Synthetic Vision and External Vision (SV/XV)
- Aeronautics Research Mission Directorate – Experimental inter-discipline group
- Science Mission Directorate – Atmospheric modeling and remote sensing
- Exploration Systems Mission Directorate – Spacecraft handling qualities; human-automation interaction design evaluations

With respect to the responsibilities and interactions among the four AvSafe projects, IIFDT develops concepts to address human-, automation-, and external environment-induced hazards. IVHM contributes to IIFDT automated data mining methods to analyze relevant fleet-wide data to uncover potential safety risks and hazards. Specific areas of collaboration between IVHM and IIFDT include the display and annunciation of health state and remediation actions, data mining technologies, and flight critical architectures. Remote sensing information from IIFDT technologies is utilized by IRAC for flight management and intelligent flight planning and guidance. This capability assists in ensuring flight safety during upset recoveries and provides a final layer of resilience and safety in the event of external hazards. IRAC provides input to IIFDT with respect to appropriate function allocation strategies and operator information needs during complex, uncertain, and time-pressure situations (e.g. upset, damage, and icing conditions). This collaboration expands the application domain of the work being done in IIFDT operator characterization and interaction modeling as well as contributing to Level 3 activities.

IIFDT provides to IRAC adaptive interface substrates for information the operators need access to during upset conditions. The capability of IIFDT technologies to monitor and classify operator state facilitates IRAC's ability to classify situation awareness during tactical upsets and utilize this knowledge for function allocation – further optimizing the operator as an integral part of the flight control system. In summary, IRAC includes the operator as part of the *flight control system* whereas IIFDT characterizes the operator as an element of the *flight deck system*. These approaches define the operator as both an outer-loop and inner-loop controller in the *aircraft system*.

GLOSSARY OF TERMS

Application Domain

The region representing the design space for a system as constrained by a particular set of end-user requirements.

Note: For flight deck systems, IIFDT considers the application domain a multi-dimensional design space. The six dimensions chosen to represent flight deck system ADs are: Mission, Operating Environment, Target Level of Performance, Crew, Vehicle, and Equipage. Because IIFDT research targets safety issues associated with flight deck systems, a description of risk factors is also included in AD descriptions.

Automation

Generally refers to a machine capability to perform functions normally attributed to humans. IIFDT research addresses, more specifically, automated functions that control some aspect of vehicle dynamics and/or operation of vehicle sub-systems.

Better than Visual

The ability to improve upon the safety and operational tempos achieved while operating under Visual Flight Rules (VFR).

Concept of Operation

A description of how a system will operate. (JPDOc, 2007)

Diagnostic

Serving to identify a particular disease or characteristic. (Webster's)

Error

(1) Deviation from correct system state that may lead to a failure (Avizienis, 2004); (2) An occurrence arising as a result of an incorrect action or decision by personnel operating or maintaining a system (JAA AMJ 25.1309); (3) A mistake in specification, design, or implementation. (SAE ARP 4761)

Failure

(1) Delivered service deviates from correct service (Avizienis, 2004); (2) A loss of function or a malfunction of a system or a part thereof. (SAE ARP 4761)

Field of Regard

The area covered via a sensor.

Flight Deck

A volume of space designed to accommodate at least one human operator and the interfaces between the operator and the remainder of the flight deck system.

Flight Deck System

A system that includes (1) the entity(s) who have the authority and responsibility for directing the flight of an aircraft, (2) all sub-systems that directly interface to these entity(s), and (3) the interfaces between them. (see Flight Deck).

Formal Methods

Mathematically based techniques for the specification, development and verification of software and hardware systems (http://en.wikipedia.org/wiki/Formal_methods)

Hazard

A potentially unsafe condition resulting from failures, malfunctions, external events, errors, or a combination thereof. (SAE ARP 4761)

Human Factors

The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance (HFES, 2000)

Mitigation

A method, procedure, function, or technology that can reduce the risk of a hazard occurring.

Multi-modal Interface

An interface that employs more than one interface mode between crew and aircraft systems.

Operator

A person, organization, or enterprise engaged in or offering to engage in aircraft operation. (ICAO Annex 13)

Quality

Totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs. Note: entity is an element that can be individually described and considered. (ISO 8402) (ICAO Annex 15)

Risk

The frequency (probability) of occurrence and the associated level of hazard. (SAE ARP 4761)

Robust

Able to recover from unexpected conditions during operation.

Scenario

A description of an event or series of actions and events.

Note: In support of IIFDT research, scenarios are developed to test plausible situations within a defined operational environment where a system, or concept, requires either validation, or analyses with respect to performance/risk potential. Scenario descriptions include not only event/action sequences, but also metadata. Depending on the scope of a given scenario, event/action sequences may be required, for example, within aircraft, within ATM facilities, and within Airline Operations Centers (AOCs). Attributing the events within sequences may or may not be required, but timestamps, time delays, and temporal dependencies within and across event sequences are attributes to consider. Metadata provides information that is applicable to the entire scenario.

Situational Awareness

The perception of elements in the environment, the comprehension of their meaning, and the projection of their status into the near future. (Endsley, 1990) For example, for pilots, the elements of the environment include, but are not limited to, the crew, passengers, aircraft systems, time, position, weather, traffic, and ATC constraints.

Validation

Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled. (ISO 8402) (ICAO Annex 15)

"Solving the right equations." (Roache, 1998)

Verification

Confirmation by examination and provision of objective evidence that specified requirements have been fulfilled. Objective evidence is information that can be proved true, based on facts obtained through observation, measurement, test, or other means. (ISO8402) (ICAO Annex 15)

"Solving the equations right." (Roache, 1998)

ABBREVIATIONS AND ACRONYMS

AD	Application Domain
ADS-B	Automatic Dependent Surveillance - Broadcast
AFRL	Air Force Research Laboratory
AIAA	American Institute of Aeronautics & Astronautics
AIS	Aeronautical Information Services
ANSP	Air Navigation Service Provider
AOC	Airline Operations Center
APG	Annual Performance Goal
ARMD	NASA's Aeronautics Research Mission Directorate
ASP	NASA's Airspace Systems Program
ATC	Air Traffic Control
ATM	Air Traffic Management
AvSafe	NASA's Aviation Safety Program
BTV	Better than Visual
CD&R	Conflict Detection and Resolution
CDU	Control Display Unit
CNS	Communications, Navigation, Surveillance
CODA	Cognitive and Operational Demands Analysis
CONOPS	Concept of Operations
COTS	Commercial-off-the-Shelf
CWA	Caution Warning Alert
CWE	Collaborative Work Environment
DDS	Displays and Decision Support
DoD	Department of Defense
EA	Enabling Avionics
EFB	Electronic Flight Bag
EHM	External Hazard Monitor
EVO	Equivalent Visual Operations
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
FAP	Fundamental Aeronautics Program
FDRWG	Industry/NASA Flight Deck Research Working Group
FDS	Flight Deck System
FLI	Forward-Looking Interferometer
FLIR	Forward-Looking Infra Red
FMS	Flight Management System
fNIRS	Funtional Near-Infrared Spectroscopy
FY	Fiscal Year
GA	General Aviation
GSRP	Graduate Student Research Program
HAI	Human-Automation Interaction
HCI	Human-Computer Interaction

HIWC	High Ice Water Content
HSI	Human System Integration
HWD	Head-Worn Display
IA	Inter-agency Agreement
IAN	Integrated Alerting and Notification
ICAO	International Civil Aviation Organization
IIFDT	NASA's Integrated Intelligent Flight Deck Technologies Project (a.k.a. IIFD)
IMC	Instrument Meteorological Conditions
IMS	Information Management System
I/O	Input/Output
IR	Infrared
IRAC	NASA's Integrated Resilient Aircraft Control Project
IRT	Icing Research Tunnel
IVHM	NASA's Integrated Vehicle Health Management Project
JPDO	Joint Planning and Development Office
LiDAR	Light Detection and Ranging
MoA	Memorandum of Agreement
MET	Meteorological
MFR	Multi-Frequency Radar
MRI	Magnetic Resonance Imaging
MS	Milestone(s)
NAS	National Airspace System (current instantiation)
NASA	National Aeronautics & Space Administration
NextGen	Next Generation Air Transport System
NPP	NASA Post-doctural Program
NRA	NASA Research Announcement
NRC	National Research Council
NTSB	National Transportation Safety Board
OGA	Other Government Agencies
OSTP	Office of Science and Technology Policy
PICE	Preventing Inadvertent Commission Errors
RAHS	Robust Automation-Human Systems
RDT&E	Research, Development, Test, and Evaluation
RF	Radio Frequency
RNAV	Area Navigation
RNP	Required Navigation Performance
RTCA	RTCA, Incorporated (aka Requirements and Technical Concepts for Aviation)
SA	Situational Awareness
SAA	Space Act Agreement
SAGAT	Situation Awareness Global Assessment Technique
SARS	Situation Awareness Rating Scale
SART	Situation Assessment Rating Technique
SBIR	Small Business Innovation Research

SDO	Super Density Operations
SLDAST	System Level Design and Analysis Team
SO	Strategic Objective
SVS	Synthetic Vision Systems
SVT	Spatial Vision Tree
SWORD	Subjective Workload Dominance Technique
TAWS	Terrain Avoidance Warning System
TBD	To Be Determined
TBO	Trajectory-Based Operations
TCAS	Traffic Alerting and Collision Avoidance System
TIM	Technical Interchange Meeting
TM	NASA Technical Memorandum
TMA	Terminal Area
VMC	Visual Meteorological Conditions
WXR	Weather Radar
XVS	eXternal Vision System

REFERENCES

(Abbott, 1996) Abbott, K., et. al.: *The Interfaces Between Flight Crews and Modern Flight Deck Systems,* Federal Aviation Administration, 1996.

(Avizienis, 2004) Avizienis, A., J., et. al., Basic Concepts and Taxonomy of Dependable and Secure Computing, *IEEE Trans. Dependable and Secure Computing*, vol. 1, no. 1, pp. 11—33, 2004.

(AvSafe, 2008) Pritchett, A., “NASA Aviation Safety Program Overview,” 2nd Annual NASA Aviation Safety Technical Conference, Denver, CO, October 21 – 23, 2008.

(Barber, 1983) Barber, B., *The logic and limit of trust*. New Brunswick, NJ: Rutgers University Press, 1983.

(Boeing, 2005) "Statistical Summary of Commercial Jet Airplane Accidents. Worldwide Operations, 1959-2004." Aviation Safety, Boeing Commercial Airplanes. Seattle WA, May 2005.

(Boy, 1997) Boy, G. A., Optimization of automation in the civil flight deck. In *European Workshop to Develop Human Factors Guidelines for Flight Deck Certification*, London - March 25-26, 1997.

(Brezillion, 1997) Brezillion, P. & Pomerol, J., Joint Cognitive Systems, Cooperative Systems and Decision Support Systems: A Cooperation in context. In *Proceedings of the European Conference on Cognitive Science*, Manchester, UK, , pp. 129-139, 1997.

(Carter, 1998) Carter, C.S., Braver, T.S., Barch, D.M., Botvinick, M.M., Noll, D., & Cohen, J.D., ACC, error detection, and the online monitoring of performance, *Science, 280*, 747-749, 1998.

(Carter, 2000) Carter, C.S., Macdonald, A.M., Botvinick, M., Ross, L.L., Stenger, A., Noll, D., & Cohen, J.D., Parsing executive processes: Strategic vs. evaluative functions of the ACC, *Proceedings of the National Academy of Sciences of the United States of America, 97*, 1944-1948, 2000.

(DiNocera, 2007) Di Nocera, F., Camilli, M., Terenzi, M., A random glance at the flight deck: Pilots’ scanning strategies and the real-time assessment of mental workload. *Journal of Cognitive Engineering and Decision Making*, 1(3), 271-285, 2007.

(Endsley, 1995) Evaluation of situation awareness in flight operations employing synthetic vision systems, SA-TECH-00-11.

(FAAn, 2008) National Aviation Research Plan 2008, Federal Aviation Administration, February 2008.

(FAAo, 2008) NextGen Implementation Plan, Federal Aviation Administration, June 2008.

(FAA, 2006) Accident/Incident Data System, Federal Aviation Administration, 2006.

(Hancock, 1998) Hancock, P. A., & Scallen, S. F., Allocating functions in human-machine systems, *Viewing Psychology as a Whole.* (pp.509-540), American Psychological Association, Washington, DC, 1998.

(IBPD, 2009) NASA’s 2009 Integrated Budget and Performance Document, http://www.nasa.gov/news/budget/index.html

(IIFD, 2009) JPDO-Identified Operational Improvements, R&D Needs, and Enabling Technologies Supported by IIFD Research, draft, www.aeronautics.nasa.gov/avsafe/iifd

(JPDOc, 2007) Concept of Operations for the Next Generation Air Transportation System (Version 2.0), Joint Planning and Development Office, www.jpdo.gov, June 13, 2007.

(JPDOe, 2007) NextGen Enterprise Architecture, Version 2.0, Joint Planning and Development Office, www.jpdo.gov, July 3, 2007

(JPDOi, 2008) Integrated Work Plan for the Next Generation Air Transportation System, Version 1.0, Joint Planning and Development Office, www.jpdo.gov, September 30, 2008.

(JPDOr, 2007) Research and Development Plan for the Next Generation Air Transportation System (FY2009-FY2013), Joint Planning and Development Office, www.jpdo.gov, August 2007.

(Kerns, 2004) Kerns, J. G., Cohen, J. D., MacDonald III, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S., Anterior cingulate conflict monitoring and adjustments in control, *Science, 303*, 1023-1026, 2004.

(Lee, 1994) Lee, J.D. and Moray, N. (1994) Trust, self-confidence, and operators' adaption to automation. *International Journal of Human-Computer Studies,* Vol. 40, pp. 153-184, 1994.

(Leveson, 1997) Leveson, N.G. & Palmer, E., Designing automation to reduce operator errors. In *Proceedings of the IEEE Systems, Man, and Cybernetics Conference*, October 1997.

(NASA, 2007) Porter, L., "NASA's New Aeronautics Research Program," 45th AIAA Aerospace
Sciences Meeting & Exhibit, January 11, 2007.

(NASA, 2006) NASA 2006 Strategic Plan, www.aeronautics.nasa.gov, 2006.

(NASAn, 2007) NASA and the NextGen Air Transportation System, www.aeronautics.nasa.gov, 2007.

(NRC, 2006) "Decadal Survey of Civil Aeronautics – Foundation for the Future," National Research Council of the National Academies, National Academies Press, Washington, DC, 2006.

(Oberkampf, 2002) Oberkampf, W., et. al., "Verification, Validation, and Predictive Capability in Computational Engineering and Physics," Foundations for V&V in the 21st Century Workshop, Johns Hopkins University Applied Physics Laboratory, October, 2002.

(OSTP, 2006) U. S. National Aeronautics Research and Development Policy, President's Office of Science Technology and Policy, December 2006.

(OSTP, 2007) U. S. National Aeronautics Research and Development Plan, President's Office of Science Technology and Policy, December 2007.

(Pritchett, 2000)	Pritchett, A. & Hansman, R.J. (2000) Use of testable responses for performance-based measurement of situation awareness. In M. Endsley & D. Garland (Eds.) Situation Awareness Analysis and Measurement. Mahwah, N.J.: Lawrence Erlbaum Associates. (189-210).
(Proctor, 1998)	Proctor, P., "Integrated cockpit safety system certified," *Aviation Week and Space Technology,* p. 61, April 6, 1998.
(Sarter, 1995)	Sarter, N. & Woods, D. (1995). "How in the world did I ever get into that mode?": Mode error and awareness in supervisory control. Human Factors, 37, 5-19
(Roache, 1998)	Roache, P., *Verification and Validation in Computational Science and Engineering*, Hermosa Publishers, Albuquerque, NM, 1998.
(Song, 2003)	Song, L., & Kuchar, J. K., "Dissonance between multiple alerting systems. I. Modeling and analysis; and II. Avoidance and mitigation," *IEEE Transactions on Systems, Man and Cybernetics – Part A: Systems and Humans, 33,* 366-375(I) and 376-385 (II).
(Tenney, 1992)	Tenney, Y., Adams, M., Pew, R., Huggins, A., Rogers, W. (1992). A Principled Approach to the Measurement of Situation Awareness in Commercial Aviation. NASA-CR-4451. Langley, VA: National Aeronautics & Space Administration.
(Wilson, 2000)	Wilson, G. (2000) Strategies for psychophysiological assessment of situation awareness. In M. Endsley & D. Garland (Eds.) Situation Awareness Analysis and Measurement. Mahwah, N.J.: Lawrence Erlbaum Associates. (175-188).

IIFD Milestone Change-log					
Change	**Milestone ID**	**Title**	**Due Date**	**Exit Criteria**	**Rationale**
#1	IIFD.FDS.1.1	Specification of NextGen-based flight deck system application domain, concept of operations and reference scenarios	Q4/FY09	Development and application of a systematic method for exploring the trade-space, designing and evaluating application domains, concepts of operation and scenarios for safety, capacity and efficiency; at a minimum, shall include a technical interchange meeting and/or workshop with relevant contributors from ARMD and external projects and programs; Results documented as reference information for subsequent L1/2/3 activities and made publicly available; Specifications should address, at a minimum, NextGen terminal area operations assumptions for domain and scenario parameters such as aircraft class, fleet mix, crew, weather, traffic, and airport environment, and equipage, and assumptions about, and performance metrics for, relevant entities in the system. (Decision Point, revised bi-annually)	9/1/09 - These three exit criteria are being achieved in concert; multiple meetings and workshops have been held and draft material has been delivered to the project office. However, additional time is required for review/revision and thereby achieve all stated criteria. In addition, presentation at the AvSafe technical conference in Q1/FY10 provides for peer review and vetting across a larger community. No other milestones in the project will be affected.
	IIFD.RAHS.1.1.1	Hypothesized solution concept within specified application domain for flight deck system function allocation and human-automation interactions during 4-D trajectory-based operations (Decision point 1, revised bi-annually).	Q4/FY09	Operations and conceptual system designs for flight management tasks, role/responsibility assignments, technology/human functions for the NextGen terminal area environment described at L4, and documented performance metrics that the solution concept seeks to improve (see IIFD.FDS.1.1); (Decision point, revised bi-annually).	
	IIFD.DDS.1.1.1	Hypothesized solution concept within specified application domain for flight deck system displays and decision-support functions providing for better than visual operations, integrated alerting and notification, and collaborative environments (Decision point1).	Q4/FY09	Operations and system conceptual designs for information conveyance and avionics functional requirements for the NextGen terminal area environment described at L4, and documented performance metrics that the solution concept seeks to improve (see IIFD.FDS.1.1); (Decision point, revised bi-annually).	
	No change	No change	Q1/FY10	No change	
#2	IIFD.OP.1.2	Methods for conveying and assessing situation awareness (Decision Point 2).	Q3/FY09	Compare a haptic-multimodal interface concept for NextGen-based terminal area operations to a representative current-day interface by evaluating effects on operator performance and situation awareness (see also IIFD.MM.OC.3 and IIFD.MM.3).	8/3/09 - Apparatus problems delayed experiment completion.
	No change	No change	Q1/FY10	No change	
#3	IIFD.OP.2.2	Methods for fostering appropriate use of automation and complex information sources.	Q4/FY09	NASA TM or conference paper submitted that reviews methods and issues concerning the portrayal of uncertain information in support of pilot decision making; aspects of information uncertainty to be considered include aggregated information fused from multiple data sources, quality of information (QOI) estimates in general, and uncertainty in information portrayed by or about automated systems in particular; the review shall span best practices in portraying uncertain information and will highlight where further guidance and metrics are needed to support design and evaluation (at the level required for certification), and to support corresponding training on the appropriate interpretation of uncertainty.	7/31/09 - Due primarily to reassignment of WYE support personnel, and other-program work demands on lead researcher; has also been enhanced via collaboration with an FAA-sponsored datalink communications study.
	No change	No change	Q1/FY10	No change	

Change	Milestone ID	Title	Due Date	Exit Criteria	Rationale
#4	IIFD.OP.3.1	Methods for supporting communication and collaboration among multiple intelligent agents.	Q4/FY09	NASA TM or conference paper submitted documenting variables that characterize operator and adaptive controller interplay; This work is collaborative with efforts in the IRAC project to design adaptive controllers that reconfigure in response to aircraft malfunction (see IRAC technical plan milestones IRAC-IDFC-1.1.1.1 and 1.1.2.1); The IIFD aspect focuses on supporting the human operator serving as a monitor and as an agent for intervention if necessary.	9/25/09 - Personnel change-over affected ability to complete adaptive controller model in simulator; which led to problems with scenario generation.
	No change	No change	Q2FY/10	No change	
#5	IIFD.OP.3.2	Methods for supporting communication and collaboration among multiple intelligent agents.	Q4/FY09	Contractor report documenting results of a fast time simulation (continuous descent approach in the NextGen environment with a modified FMS looking at typical human error scenarios) evaluation of static function allocation policies. Metrics include: workload based on task load, human performance modeled resource loading, contiguity of function allocation over time, consistency with actor's role, disruption to procedures, appropriateness with respect to human cognitive control mode or to automation's designated functional boundaries, stability of human experience (i.e., minimizing interruptions and disruptions), and team robustness to systems distrubances.	8/17/09 - These two exit criteria are expected in a single report via research under cooperative research agreement #NNL06AA22A; results were delayed due to simulation issues and a no cost extension was granted to allow for completion of the work.
	IIFD.OP.3.3	Methods for supporting communication and collaboration among multiple intelligent agents.	Q4/FY09	Contractor report documenting results of a simulation evaluation comparing dynamic and static function allocation policies; Metrics include: workload based on task load, human performance modeled resource loading, contiguity of function allocation over time, consistency with actor's role, disruption to procedures, appropriateness with respect to human cognitive control mode or to automation's designated functional boundaries, stability of human experience (i.e., minimizing interruptions and disruptions), and team robustness to system disturbances.	
	No change	No change	Q3/FY10	No change	
#6	IIFD.OP.3.4	Methods for supporting communication and collaboration among multiple intelligent agents.	Q4/FY09	NASA TM or contractor report submitted documenting interviews with NextGen stakeholders and investigators discussing requirements for supporting multi-agent coordination, communication and decision-making in future terminal area TBO environments.	9/25/09 - Medical & family considerations kept responsible researcher from completing to original schedule.
	No change	No change	Q1/FY10	No change	
#7	IIFD.OP.4.2	Methods for supporting human decision-making and reducing the propensity for, or consequences of, human error.	Q4/FY09	NASA TM or conference paper submitted documenting the design and effectiveness of the PICE (Preventing Inadvertent Commission Errors) technology to mitigate inadvertent commission errors by employing confirmation-of-intent guard(s) that employ an EEG-based determination of engagement; This report documents results of an initial laboratory test of a prototype to assess mitigation of this form of error in a desktop human-computer interaction task; The report concludes with a discussion of further developments required for such a system to be fielded in a flight-deck.	9/25/09 - Re-developing tool on different platform for evaluation, initial platform not robust enough.
	No change	No change	Q2/FY10	No change	
#8	IIFD.OC.1.2	Identify the operationally-relevant characteristics of NextGen airspace operators.	Q4/FY09	Journal article or NASA TM submitted documenting errors in checklist use and monitoring and describing countermeasures to errors; The basis of this report will be data obtained from jumpseat observations and review of relevant studies; The report will describe forms of monitoring and checklist executions failures, the conditions under which they occur, and the reasons they occur; and will suggest countermeasures to reduce vulnerability to such errors; Findings will be extrapolated to the use of future checklist platform designs (e.g. dynamic checklist displays driven by context-aware intelligent avionics functions).	7/31/09 - Reduction in available procurement funding.
	No change	No change	Q3/FY10	No change	
#9	IIFD.OC.1.7	Identify the operationally-relevant characteristics of NextGen airspace operators.	Q4/FY10	Workload management is of paramount importance for single pilots who fly jets with advanced technology cockpits, such as very light jets. Workload demands come from three primary, often overlapping, sources: a) operational demands, such as lowering the flaps at the proper time, b) cognitive demands, such as remembering to contact the tower when passing over the outer marker as instructed by TRACON ATC, and demands imposed by the advanced technologies, such as entering waypoints in a flight plan correctly. A conference paper or journal article will be submitted that describes the workload management requirements related to managing these three types of demands in single-pilot jet operations; This information will be ascertained through a human-in-the-loop simulation study; Single jet pilot workload management best practices will be identified and countermeasures for workload management difficulties, such as training strategies and procedures, as well as suggestions for alternate automation and technology design approaches will be proposed; The implications for human operator performance will serve to inform higher level research in IIFD to improve safety of flight operations in NextGen.	6/17/09 - Error in publication; this milestone was mistakenly included from an early draft; aspects of this research can be found in IIFD.OC.2.1 & 2.3.
	Delete	Delete	Delete	Delete	
#10	IIFD.OC.2.1	Identify information requirements to support the roles of NextGen operators	Q4/FY10	The Cognitive and Operational Demands Analysis (CODA) is a qualitative analysis approach that has been developed to facilitate the identification, evaluation, and analysis of three types of workload demands encountered on advanced technology flight decks and cockpits: operational, cognitive, and technology driven (see IIFD.OC.1.8); Human factors experts with domain expertise will submit a conference paper or journal article that describes the CODA approach, which was developed to more comprehensively identify and evaluate the varied and competing demands placed upon operators during NextGen terminal area operations than is possible using current approaches to cognitive, task, or work analyses.	10/2/09 - Owners of simulator facility to be used for the research (FAA CAMI) have had several budget and procurement issues while upgrading of the simulator so it could emulate the type of aircraft needed for this study (a VLJ). After over a year of several different plans being attempted and then changed, for one reason or another, FAA CAMI has been given the permission and funds to purchase an entirely new simulator. Contracts are just now being sent through the FAA procurement process, but a significant delay in completing the study will result.

Change	Milestone ID	Title	Due Date	Exit Criteria	Rationale
	IIFD.OC.2.3	Identify information requirements to support the roles of NextGen operators	Q4/FY10	Journal article submitted describing a human-in-the-loop study conducted to validate the Cognitive and Operational Demands Analysis (CODA) predictions and explanations of workload bottlenecks in NextGen terminal area operations; Initially this methodology will be applied to Very Light Jet single-pilot operations; Extensive interchange with pilot populations and aircraft manufacturers is planned to substantiate the realism of this work.	
	No change	No change	Q4/FY11	No change	
#11	IIFD.OC.3.4	Characterize the functional state of operators	Q4/FY09	NASA TM or journal article submitted describing effects of fatigue on operator performance and ability to reliably and comfortably ascertain fatigue levels during actual airline operations; Long-haul operational data on operator physiological effects will be combined with performance data to ascertain operational indicators, and operational effects of fatigued pilots (depends on IVHM collaborative research with EasyJet and ONERA in support of IVHM milestones 1.3.1.1, 1.3.3.2, and 3.1.3).	7/31/09 - Delay in negotiating Space Act Agreement with EasyJet (by IVHM project and AvSafe program office); also, no procurement funding was provided by IVHM project; data collection began Sep-09.
	No change	No change	Q3/FY10	No change	
#12	IIFD.OC.3.5	Characterize the functional state of operators	Q4/FY09	NASA TM, conference paper, or journal article submitted that describes best practices for fNIRS instrumentation design and data collection for operator state detection that is reliable, sensitive, and relevant to the flightdeck operating environment.	9/25/09 - As a result of developing a reimbursable collaborative research agreement with the Air Force Research Lab (AFRL), deliverables for that effort are nearly coincidental allowing for a better product here if delayed by one quarter.
	No change	No change	Q1/FY10	No change	
#13	IIFD.MM.2.3	Develop and evaluate improved aural/speech interface capabilities	Q3/FY09	NASA TM or journal article submitted that describes the method and outcome for designing a comprehensible set of aural stimuli for conveying NextGen alerting conditions; This report will consider aural parameters (including those for speech and non-speech alerts) for detection, discriminability, and intelligibility in isolation and as part of an integrated auditory display and based on differences in communication requirements for future displays as compared to state-of-the-art; The report will be based on a combination of literature review, evaluation of current technology, and laboratory evaluation of new technologies; Simulation studies are not included here, but may be considered as part of a Level 3 DDS concept evaluation.	7/31/09 - Reduction in available procurement funding.
	No change	No change	Q2/FY10	No change	
#14	IIFD.MM.2.4	Develop and evaluate improved aural/speech interface capabilities	Q3/FY10	NASA TM or journal article submitted that evaluates theoretically-indicated applications of aural indicators to NextGen IAN requirements (see OC.2) for detection, intelligibility, distinguishability, perceptual grouping, and as supportive of response effectiveness (speed and accuracy); Initial investigations will be laboratory studies with aims to incorporate into future Level 3 DDS integrated simulation studies.	7/31/09 - Reduction in available procurement funding.
	No change	No change	Q4/FY10	No change	