AVIATION RESEARCH DIVISION STRATEGIC PLAN

8/20/2013

i EXECUTIVE SUMMARY

For the past half century the fundamental NAS architecture has not changed although the systems and equipment that comprise it have. Technology has provided faster computers, sophisticated surveillance systems, more accurate navigation aides, and greater numbers of aircraft that are faster and more agile. For the first time in our history that environment is changing. From a vast network of ground-based equipment and systems, to one that is principally resident on satellites; from one that is “controlled” from the ground, to one that shares responsibilities between pilots and controllers; from one that reflects many disparate data sets, to one that is network centric; from one that reflects a rather common set of aircraft, to one that highlights transport aircraft of many designs and compositions, that features a large number of UAS, and that has commercial spacecraft in its mix.

Although the end-state is relatively clear, transition from the current to the new environment is the challenge. Mixed aircraft types, equipage, and construction combined with an evolving set of supporting equipment and processes represent some of the challenges. Research to address these challenges is reflected in the National Aviation Research Plan (NARP) with programs, in addition to air traffic operations, that span Fire Safety, Propulsion and Fuel Systems, Advanced Materials/Structural Safety, Continued Airworthiness, Aircraft Catastrophic Failure Prevention, Safety Information Management and Analysis, Aircraft Icing, Terminal Area Safety, Human Factors and Aviation Software, Electronics and Digital Systems Assurance; the focus of the WJHTC Aviation Research Division.

The primary division goal is to ensure that current and projected research within its purview are focused and support the needs of the FAA, the direction that the industry is taking, and the flying public. While it is difficult to measure and quantify the effectiveness of safety research, since accident avoidance is difficult if not impossible to assess and classify, this plan presents several of the more significant division accomplishments, and current programs and their projected benefits; and projects the need and benefit for addressing the proposed longer-term research initiatives. Longer-term research initiatives (5 to 10 years) must be examined, assessed, and refined. Supporting infrastructure requirements and numbers and skills of personnel must also be assessed to ensure that the refined research needs can be achieved.

This Aviation Research Division Strategic Plan is borne from the desire to develop these initiatives and to stimulate other ideas and concepts in order to ensure that the longer- term research efforts are in consonance with the needs of the FAA and reflect the direction and goals of industry. An unconstrained view was taken to capture the research that the division believes is needed for the next 10 years with emphasis on the last 5 years. It is the expectation that what is presented herein, especially the proposed research initiatives, is provocative and would either be validated by our sponsors, industry and academia and/or be the stimulus for generating new and better, far-reaching ideas.

While much of the current research is reactive, driven largely by accidents and incidents, many of the ideas and concepts presented are proactive, driven by one or more of the following:

- Changes in technology,
- Implementation of NextGen,
- Environmental considerations,
- Introduction of future airships including UAS, and
- Predictions of aircraft vulnerabilities.

Chapter 2, Overview, presents a table that correlates and summarizes the research initiatives discussed in Chapter 3, by program area, to the drivers above.

Two cross-cutting functions are presented in the plan; one that is new and the other that will be used more universally in the division research. The proposed new functional area is Safety Information Management and Analysis. Its purpose is to support and make more efficient many of the research tasks in the division. Researchers lack access to comprehensive tools and data access methodologies to enhance their productivity. Therefore to support the research efforts, this functional element will provide rapid access to relevant information and appropriate tools to enable the efficient pinpointing and analyzing of relevant data; details of which are provided in Chapter 3, Section 3.6 and summarized in Chapter 2. It will also provide information security awareness and analysis as needed for the research efforts.

Similarly, human factors research while not a new division role is systemic to almost every aspect of division research. Several of the identified initiatives rely heavily on a human factors perspective. It is visualized therefore that human factors researchers will actively participate in many of the initiatives. These are described in Chapter 3, Section 3.9 and summarized in Chapter 2.

ii Strategic Plan

CHAPTER 1 INTRODUCTION

1.1 PURPOSE

To present a strategic view of the division research program and thereby elicit comments from sponsors, academia and industry on its focus.

1.2 BACKGROUND

The division is involved in many facets of safety research driven directly by headquarters sponsors and reflected in the National Aerospace Research Plan (NARP). The NARP addresses near, mid and longer term research efforts with a horizon of 5 years. However many unique changes are driving future systems, equipments and processes and include:

- Changes in technology,
- Implementation of NextGen,
- Environmental considerations,
- Introduction of future airships including UAS, and
- Predictions of aircraft vulnerabilities.

Longer term research, 5 to 10 years, must be focused on and address their impact on aviation safety. In addition, supporting infrastructure requirements and numbers and skills of personnel must be identified and assessed to ensure that research needs can be met. As a result, this plan was developed to ensure all needed research is addressed and is in consonance with the needs of the agency and the direction of the industry. It presents an unconstrained view of the proposed research initiatives that should be undertaken to prepare for the anticipated changes and their impact.

1.3 SCOPE

The plan is organized into 3 Chapters, Introduction, Overview and Strategic Research Initiatives. The body of the plan addresses the proposed initiatives reflecting the safety research focus for each of the division 10 program areas. The Overview, Chapter 2, presents a table that correlates the proposed initiatives by program area to the unique changes (systemic research drivers) listed above. Chapter 3 provides detailed descriptions of these initiatives, organized by program area.

There are 3 Appendices; Appendix A, Division Accomplishments Summary; Appendix B, Current Programs and Projected Benefits Summary, and Appendix C, Aviation Research Division Strategic Plan.

The complete Strategic Plan is subdivided into 4 parts; Overview, Current Program Summary, Strategic Research Direction, and Transition. The Overview summarizes the current and expected program direction and accomplishments; while the Current Program Summary reflects the key research initiatives being pursued. The Strategic Research Direction repeats Chapter 3, where researchers present an unconstrained view of future proposed initiatives based on their understanding of where the agency and industry are, and their expectation of the direction both are predicted to go.

Lastly, the Transition portion summarizes the potential needs for people and facilities based on the current and projected programs. Although cursory, it attempts to leverage identified needs by using either in-house personnel where appropriate, partnerships, or procurement vehicles to achieve the predicted results.

CHAPTER 2 OVERVIEW

The following table relates the identified 5 Systemic Drivers to the 10 Division Program areas and the Strategic Research Drivers to the proposed Strategic Research Initiatives. For example, Changes in Technology for the Fire Research and Safety Program Area is expected to lead to the introduction of new materials which in turn leads to the proposed Material Flammability initiative shown on the first row of the table.

Each of the initiatives is discussed in detail by program area in Chapter 3.

SYSTEMIC DRIVERS	PROGRAM AREA	STRATEGIC RESEARCH DRIVERS	STRATEGIC RESEARCH INITIATIVES
Changes in Technology	Fire Research & Safety	Introduction of New Materials	Material Flammability
		Hazards of Fuel Cells	Hazardous Materials
		Persistent Incidence of In-Flight Smoke and Odor Events of Unknown Origin in Passenger Airplanes	Systems Fire Protection
	Propulsion and Fuels	Use of fuel cell technology to power auxiliary power units	Fuel Cell Technology
		Potential replacement of 100LL fuel with an alternative unleaded fuel	Future Engine Component Capability
	Advanced Materials/Structural Safety	Introduction of new and advanced metallic, composite materials and hybrid structures	Hybrid Structures, Advanced Composite Materials
		Increased use of bonded structures replacing mechanically fastened structures	Bonded Structures
		Potential use of additive and other advanced manufacturing to fabricate complex parts that can't be formed by conventional techniques	Additive Manufacturing
		Introduction of new innovative aircraft designs	Advanced Structural Configurations
		New advanced manufacturing techniques	Additive Manufacturing, Nano-material Technology

SYSTEMIC DRIVERS	PROGRAM AREA	STRATEGIC RESEARCH DRIVERS	STRATEGIC RESEARCH INITIATIVES
Changes in Technology (continued)	Continued Airworthiness	Introduction of new and advanced metallic, composite materials and hybrid structures	Advanced Metallic Alloys and Processes, Advanced Hybrid Construction
		Increased use of bonded structures replacing mechanically fastened structures	Advanced Welding and Joining Processes
		Potential use of additive and other advanced manufacturing to fabricate complex parts that can't be formed by conventional techniques	Additive Manufacturing
		Introduction of new innovative aircraft designs	Advanced Hybrid Construction
		New advanced manufacturing techniques	Advanced Hybrid Construction
	Safety Information Management and Analysis	Increasing capabilities in handling Big Data, Data Mining, Risk Models/Analysis, Intelligent searches, and migration to Cloud-based service environment	Embedded analytics, complex event processing, natural language processing, and modeling and simulation
	Aircraft Icing	New technologies to reduce or eliminate glycol-based fluids	Ground Icing
		Terminal Area Icing Weather Information System (TAIWIS)	Icing Weather in the Cockpit and Down-linking of Data from Ice Detectors
		Introduction of new atmospheric icing instrumentation and ice detection technology	Smart Icing Systems
	Terminal Area Safety	Increasing operational complexity due to traffic growth, new vehicles, shared communications	Developing representative stall models for more aircraft type
			Enhancing flight simulator capabilities for upset recovery training
			Improving safety of helicopter operations
	Human Factors	Introduction of new emerging sensor and display technologies	Information Requirements and Display/User Interaction Research
			System Acquisition
			Human Factors Design Standard (HFDS)
		Increasing operational complexity due to traffic growth, new vehicles, shared communications	Workload and performance
			Concept Evaluation
			Research Metrics
			Cognitive Models
			Modeling and Simulation
	Aviation Software, Electronics and Digital Systems	Impact of introduction of new technologies for more "electric aircraft"	More Electronic Aircraft
			Real-Time Adaptive Digital Systems
		Introduction of e-enabled aircraft, Electronic Flight Bags, and wireless LAN for flight crew communications	e-Enabled Aircraft
			Radio Frequency Identification Device Sensor Development
			Integrated Modular Electronics

SYSTEMIC DRIVERS	PROGRAM AREA	STRATEGIC RESEARCH DRIVERS	STRATEGIC RESEARCH INITIATIVES
Implementation of NextGen	Safety Information Management and Analysis	Introducing more capable mobile presentation platforms and continuous access to enterprise information	Advanced data visualization , dash- boarding
		Introducing Net-Centric operations, System-level Safety Services/Concepts, Risk Models/Analyses, and Enterprise Data Accessibility	Connectivity, safety information access, Map reduced and elasticity
	Terminal Area Safety	Adapting to a variety of NextGen improvements that involve low visibility operations, optimized profile descents, time-based metering and enhanced surface movement operations.	Evaluation of technologies and procedures to increase terminal efficiency
			Identifying risks associated with mixed equipage operations
			Developing solutions to manage increasing operational complexity
	Human Factors	Introduction of increased automation, controller/pilot information sharing	Humans and Automation
			Concept Evaluation
			Workload and Performance
			Fatigue Measurement Tool
		Human performance measurement, performance prediction, and decision making behavior	Workload and Performance
			Fatigue Measurement Tool
			Research Metrics
			Data Management and Visualization
			Cognitive Models
		Information integration and presentation	Information Requirements and Display/User Interaction Research
			Human Factors Design Standard (HFDS)
			System Acquisition
			Data Management and Visualization
		Introduction of new concepts	Concept Evaluation
			Cognitive Models
			Modeling and Simulation
			Workload and Performance
			Research Metrics
	Aviation Software, Electronics and Digital Systems	Introduction of new air to ground communications and the impact on aircraft communication and navigation systems	NextGen
			Qualification of Data Used for Electronic Flight Bags and Maintenance Tablets

SYSTEMIC DRIVERS	PROGRAM AREA	STRATEGIC RESEARCH DRIVERS	STRATEGIC RESEARCH INITIATIVES
Environmental Considerations	Propulsion and Fuels	Standardized tests to measure major particulate and greenhouse gas emissions	Turbine Engine Emissions
	Advanced Materials/Structural Safety	Continued emphasis on the use of environmentally responsible materials	Changes Driven by Environmental Considerations
Introduction of New Airships	Fire Research & Safety	Introduction of Blended Wing Body Aircraft	Fire safety impact of possible new cabin ceiling
		Commercial Space Transportation	Fire safety impact of new operational and environmental conditions
	Advanced Materials/Structural Safety	Introduction of structural concepts for aircraft	Advanced Structural Configurations
		Commercial space transportation	Advanced Structural Configurations
Predictions of Aircraft Vulnerabilities	Propulsion and Fuels	Life-limited and critical engine components	Rotor Integrity
		Industry standard for inspecting engine fan blades	Non-Destructive Evaluation (NDI) on Critical Engine Components
		Preclude deleterious manufacturing induced anomalies, characterize them, and enhance process and inspection methods	Machining Process monitoring on Engine Disks
		Damage and service life reduction, and mitigations for engines operated in stratified ash	Volcanic Ash Exposure
	Advanced Materials/Structural Safety	Impact of new structural materials on continued operational safety of aircraft fuselages, wings and other primary structures	Advanced Structural Configurations
		Effect of configuration and materials changes on crash impact of structures and resulting survivability	Crash Conditions Definitions, Crash Model Validation Process
	Continued Airworthiness	Impact of active flutter suppression on fatigue life	Active Flutter Suppression
		Impact on maintenance and inspection for ensuring continued airworthiness of advanced structural materials	Maintenance and Inspection
	Aircraft Catastrophic Failure Prevention	Impact of materials having different properties in different directions	Advanced Analysis of Composite Materials
		Introduction of new aircraft types including blended wing body and UAS, commercial space vehicles	New Aircraft Design Concepts

SYSTEMIC DRIVERS	PROGRAM AREA	STRATEGIC RESEARCH DRIVERS	STRATEGIC RESEARCH INITIATIVES
Predictions of Aircraft Vulnerabilities (continued)	Safety Information Management and Analysis	Introducing enhanced data search, anomaly detection, complex analysis, pattern recognition, and intelligent search capabilities	Embedded analytics, complex event processing, natural language processing, modeling and simulation
	Aircraft Icing	Introduction of new aircraft types including blended wing body and UAS, commercial space vehicles.	New Challenges in In-flight icing
	Human Factors	Introduction of new aircraft types including blended wing body and UAS, commercial space vehicles.	Modeling and Simulation
			Concept Evaluation
			Workload and Performance
			Human Factors Design Standard (HFDS)
	Aviation Software, Electronics and Digital Systems	Potential security risk to onboard aircraft networks and communications on non-hardened servers	Internet Protocol (IP) Access to Aircraft
		Potential damage from higher voltage sources on the more electronic aircraft +/- 270 VDC and 230VAC wide frequency	Higher Voltage Damage Effects
			Sensory Prognostic Management Systems
		Impact to on-board systems on e-Enabled Aircraft with data driven from outside sources (weather ,Maps, NOTAMS), that must be standardized and verified to maintain current safety margins	System Complexity Effects on Aircraft Safety

CHAPTER 3 STRATEGIC RESEARCH INITIATIVES

This chapter contains detailed descriptions of each of the research initiatives outlined in Chapter 2. They are organized by program area as follows:

3.1 Fire Research and Safety

3.2 Propulsion and Fuel Systems

3.3 Advanced Materials/Structural Safety

3.4 Continued Airworthiness

3.5 Aircraft Catastrophic Failure Prevention

3.6 Safety Information Management and Analysis

3.7 Aircraft Icing

3.8 Terminal Area Safety

3.9 Human Factors

3.10 Aviation Software, Electronics and Digital Systems Assurance

3.1 FIRE RESEARCH AND SAFETY PROGRAM

Strategic fire safety research will be driven by the persistently large number of in-flight smoke and odor events that most often cause the pilots to return or land at the nearest airport. These events are particularly alarming because the crew often cannot differentiate between fire and non-fire sources and cannot identify the source or location of the problem. Also, the introduction of fuel cells into aviation in many different forms is a major concern, since the fuel source will likely be stored hydrogen. The consequences of a catastrophic hydrogen fire will instantly evoke recall of the Hindenburg airship tragedy in 1937. As with the current program, research will be required to support the safe introduction of new materials into aircraft. Future aviation vehicles that deviate significantly in configuration and operation will present unusual fire safety concerns. The impact of the striking large ceiling of a blended wing body aircraft, presented large surface area for significant fire spread from a buoyant fire, on post crash fire survivability is a major concern. Similarly, space transportation vehicles will operate under conditions that depart widely from conventional aircraft, including reduced gravity, elevated or reduced pressure and oxygen concentration, and hypersonic reentry velocity. To ensure fire safety in commercial space transportation will most likely become the greatest future fire safety research challenge.

<u>Mid-Term Research (4-7 years)</u>

Mid-term research will focus on material flammability, systems fire protection, hazardous materials, modeling, and aviation bio fuels as described in the following paragraphs.

Material Flammability- Research will be required to ensure the fire safety of new materials being proposed for aircraft interior applications. In general, full-scale fire tests are initially required to determine if fire safety is impacted. If there is no impact, a small-scale flammability test method and criteria will be developed for approving the new materials and/or applications. For example, with the introduction of magnesium alloys into seat structure, the next likely application would be air conditioning ducting. Aluminum/lithium alloys are also being developed for fuselage skin and structure. Since lithium is a combustible metal, fire safety is a paramount concern. During a post-crash fire the effect on burn-through resistance is the main concern. In the event of a hidden in-flight fire it must be clear that the aluminum/lithium fuselage skin and structure will not ignite.

Systems Fire Protection- Fatal in-flight fires are rare events of great consequence. On September 2, 1998 a Swiss Air MD-11 flight from JFK International Airport experienced a hidden in-flight fire and crashed off the coast of Nova Scotia, killing all 229 occupants. Although fire safety improvements driven by this accident have been developed and implemented in the intervening years, in the United States there are over 900 unknown smoke and odor incidents each year. Most of the incidents are unrelated to an on-board fire; nevertheless they result in a significant number of returns and diversions, and, on some occasions, emergency evacuations which often result in injuries to the passengers. Also, questions have been raised about the adequacy of airline operational procedures to prevent the accumulation of smoke in the flight deck. Thus, the focus of systems fire protection research in the mid-term will be in-flight fire detection and extinguishment, technology to discriminate between fire and non-fire smoke/odor events, and flight deck protection against smoke accumulation from an in-flight fire.

Research will be conducted to develop operational methods and systems for the detection and extinguishment of hidden in-flight fires. The initial focus will be on rapid and reliable fire/smoke detection, since it may be argued that is imperative that the crew be immediately aware of the occurrence and location of a fire anywhere in the airplane. Advantage will be taken of new, miniaturized sensors, and digitized technology for analyzing and transmitting data at relatively low cost. Concurrently, a detailed study will be undertaken to determine the nature of the smoke and odor events, for example, that differentiates between engine and hydraulic leaks that migrate into the air conditioning system versus actual fire/smoke events. This will be followed by research to develop cost-effective detection systems that discriminate between fire and non-fire smoke and odor events. The obvious benefit of this technology would be to improve crew decision-making regarding the best course of action to take when smoke/odor is detected in the airplane.

Research on fire extinguishment will separately address standard and wide body aircraft. In a standard aircraft the volume of hidden space, particularly in the overhead or attic, is sufficiently small to allow for fire extinguishment with hand-held extinguishers. However, the cabin crew needs access to the hidden area and require some knowledge of the location of the fire. Access can be in the form of a fire port, or opening compatible with the extinguisher nozzle, or other means to effectively deliver the agent into a hidden area. Spacing of the fire ports would need to be determined as well, preferably by validated analytical modeling (see earlier discussion), since there is a finite effective extinguishment range. In addition, a detection system would be required to determine the location of the fire and the closest means of access (i.e., fire port). Conversely, in a wide body aircraft, because of the large volume of the attic or hidden space, a fixed fire extinguishment system is required. The agent must be safe for human exposure and discharge should not introduce harmful quantities of the agent/combustion products into the cabin/flight deck nor dislodge ceiling panels. A simple approach would be to use the agent from the cargo compartment fire suppression system. The culmination of the mid-term research would be the development of an integrated fire detection and extinguishment system that would incorporate (1) the advancements from the above research on fire detection and extinguishment, and (2) the availability of nitrogen enriched air

(NEA) from an on-board inert gas generating system (OBIGGS) to prevent fuel tank explosions. The integrated system would tie together and support (1) existing requirements for fire detection and extinguishment in cargo compartments and engines, (2) fire extinguishment in hidden areas which are difficult to access and pinpoint the fire location, and (3) expanded protection in areas such as wheel wells and electrical bays. This research will culminate in a cost benefit analysis to determine the feasibility of an integrated fire detection and extinguishment system.

Significant smoke in the cockpit and very poor visibility was reported by the crew in the fatal 747-400 freighter fires in Dubai (9/3/10) and Korea (7/28/11). The earliest effect of fire is smoke at levels that impair the visibility of the pilots. Current FAA-approved procedures are to adjust the Environmental Control System (ECS) air flow rates and pressures in a manner that prevents the migration of smoke into the cockpit. FAA requires that the effectiveness of this procedure be demonstrated during aircraft flight tests, usually employing artificial smoke generators. A study will be undertaken to determine the limitations of this approach, including the use of artificial smoke generators and their ability to simulate the effects of buoyancy and pressure of a real fire. Also, a second study will attempt to determine if the smoke conditions under which the current procedures are ineffective are associated with an uncontrollable fire. The findings will dictate the need for and nature of additional work; e.g., practical enhancements of the current approach or more novel methods of mitigating cockpit smoke build-up. For example, fuselage openings at appropriate locations, that take advantage of the lower outside ambient pressure distribution, can draw smoke out of the cockpit. However, the effect of this enhanced ventilation on the characteristics of the fire would need to be factored into any emergency ventilation procedure.

Hazardous Materials- Oxygen system failures have caused accidents (Valujet, 1996, 110 fatalities), contributed to post-crash fire fatalities (USAir, LAX, 1991, 22 fatalities), and caused numerous serious fire incidents, resulting in the destruction of the aircraft in many cases. In a unique event, an exploding oxygen cylinder ripped a gaping hole in a Qantas 747-400 carrying 365 people, causing a rapid depressurization of the airplane which the crew was fortunately able to land (7/25/08). It is very clear that the replacement of emergency oxygen systems in aircraft, including chemical oxygen generators for passengers and stored pressurized oxygen for the flight deck crew, would result in a significant improvement in aircraft safety. A study will be conducted to document the occurrences and consequences of oxygen system failures/malfunctions, and to identify technology that exists or could be developed to replace stored oxygen with a system that generates oxygen on demand. Particular attention will be given to an On-board Oxygen Generating System (OBOGS), which would employ hollow fiber membranes, molecular sieves or similar functioning materials to separate oxygen in air for emergency applications. Oxygen systems employed by NASA for manned spacecraft and by the Department of Defense

(DOD) will be examined for possible application to civil aviation. Fire tests will be conducted on promising new systems to demonstrate the fire safety benefit and for comparison with existing systems. The final task will be a cost benefit analysis, which will need to include the effect of the numerous fire incidents which have occurred in the past (it will be a challenge to obtain this important data).

Fuel cells are expected to become the next generation source of electric power, both for on board electrical needs, as well as for portable devices utilized by passengers. . Unlike a battery, which stores electricity, a fuel cell utilizes a chemical reaction involving a base fuel with oxygen from the air to generate electricity. A fuel cell is recharged by simply replenishing or replacing the fuel storage container. A broad range of aircraft fuel cell applications are under consideration and development, with each employing compressed hydrogen gas as a fuel source, which is a major fire safety concern. Fuel cell auxiliary power units (APU's) are currently under development and evaluation by industry because of the potential benefit to airplane efficiency and reduced gas emissions. Examples of other applications include power supplies for equipment in aeromedical aircraft and as a replacement for ram air turbine generators. For an installed fuel cell the introduction of a flammable fuel into an area of electrical power generation presents novel issues. At the very least a fixed extinguishing system will be required, which will differ in design from the current Halon 1301 extinguishing system for jet fuel-burning APU's. For passenger portable electronic devices, , various fuel sources are being examined and utilized in prototype fuel cells, for example, methanol, formic acid, butane, hydrogen gas, and borohydrides. The potential flammability of the base fuels is a concern when brought onboard an aircraft. Thus, research will be required to ensure the safety of small fuel cells used by passengers.. Briefly, research on consumer fuel cells could result in restrictions placed on certain fuels or fuel cell cartridge quantities, with different restrictions in passenger carry-ons versus checked luggage.

Modeling- In a number of past investigations of aircraft fire incidents, fires originating in a lower area of the aircraft spread upward, causing the greatest fire damage in the upper area. For example, a fire started behind a cargo compartment liner in a 747 spread upward and gutted the upper first class cabin behind the flight deck. The cargo compartment had virtually no fire damage. The effect of buoyancy on the spread of fire in an upward direction will be more pronounced in large aircraft because of this "chimney effect". Research will be undertaken to develop a CFD model to predict the upward transport of fire gases in a double deck large transport aircraft such as the A380. This capability will be applied to the spread of a post-crash fire upward through an open stairwell in a double-deck aircraft, and to a hidden fire spreading upward in either a single or double-decked aircraft. A double-decked full-scale fire test fuselage is available in the FAA's Full-Scale Fire Test Facility to support the development and validation of the model. The modeling output will be directed to addressing the possible need for more stringent material fire test criteria on the upper deck of very large transport aircraft or for “Fire Stops” in hidden areas to contain and prevent upward fire spread.

Aviation Bio Fuels- Aviation bio fuels (e.g., 50/50 Jet A/bio fuel blends) are being developed and flight tested by the aircraft manufacturers and airlines. The goal is to reduce engine exhaust emissions into the atmosphere and the consumption of petroleum-based fuel. Although the combustion characteristics must be nearly identical to Jet A in order to allow their use in unmodified engines, the behavior of bio fuels in a fire must be examined to determine the possible impact on fire safety. For example, most FAA-required material flammability test conditions were derived from full-scale fire tests with burning jet fuel. Small changes in the fuel fire characteristics could impact the fire test conditions employed in FAA flammability test methods. Another potential impact is the FAA Fuel Tank Flammability Reduction Rule, which protects against fuel tank explosions. Basically, an operator utilizes an FAA Monte Carlo model, which employs a representative flash point distribution curve for Jet A fuel, to determine the fuel tank flammability envelope for all the aircraft that they operate and the need for fuel tank flammability reduction; i.e., a fuel tank inerting system. The flash point distributions for various bio fuels will be determined to determine the impact on Monte Carlo modeling results and the need for flammability reduction, which could have safety implications and a major economic impact on a carrier.

Far-Term Research (8-10 years)

Far-term fire safety research will focus on revolutionary air transport vehicles that are a significant departure from the conventional cylindrical fuselage design flying at subsonic speeds. The blended wing body aircraft (BWBA) unites the passenger cabin and the wing, making the cabin almost as wide as it is long. In one particular design configuration, the BWBA is comprised of eight aisles and 20 exits, with a seating capacity for 1000 passengers. Rapid evacuation to meet the current 90-second certification requirement will be a tremendous challenge as will the fire safety design, because the characteristics of a cabin fire in a BWBA are unknown at this time. In the future, the viability of commercial space transportation will depend on many factors, but certainly safety and, in particular, fire safety will be paramount. Operational and environmental conditions that differ significantly from current commercial aircraft, including supersonic and hypersonic speeds (during re-entry), low gravity, and departures in ambient pressure and oxygen concentration, will be the primary drivers for determining fire safety requirements.

Fire safety research on BWBA will initially utilize CFD modeling. Based on current trends it is expected that CFD capabilities in the future will be far more predictive. Moreover, CFD modeling will be a more cost-effective and timely approach for analysis of the impact of different designs – which are expected to remain fluidic for a long period of time - than full-scale fire tests. A most striking feature about the layout of a BWBA cabin is the very large ceiling, which will provide for a significant area for fire spread. We can only speculate at this time about the impact of the large ceiling area, but it is likely that there may be a need for more stringent fire test criteria for ceiling and upper cabin materials. For conventional transport aircraft, post-crash fire survivability is dictated by when flashover occurs in the cabin, and flammability test criteria for large surface area materials are based on a heat release rate requirement which is the most germane test parameter to the occurrence of flashover. A major question will be whether flashover will also drive survivability in the large cabin volume of a BWBA or will fire/flame spread or some other enclosure fire characteristic predominate. These are only a few of the questions that will need to be addressed to ensure fire safety in BWBA.

The fire safety needs for commercial space transportation will require a far greater departure from current research capabilities. Initially, research undertaken and supported by NASA will be a good source of data to begin understanding the nature of the problem. That information will be supplemented by small-scale fire tests under conditions that simulate a space transportation environment. What seems clear at this time is that the main focus on fire safety will be on materials that are highly ignition resistance, rapid and reliable fire detection and, fire extinguishing agents that are effective and safe when exposed to humans, and each of these needs will be dependent upon the environmental conditions. For example, the absence of buoyancy in a low gravity environment will impact the fire resistance of materials by reducing convective cooling (less fire resistance than at normal gravity) and effect the optimal placement of detectors (less/no directional flow of combustion products). During re-entry, frictional heating of the walls of the space transportation vehicle will create higher than ambient temperatures, which will have a bearing on the ignition resistance of those materials experiencing elevated temperatures. These are just a few of the examples of the fire safety challenges in commercial space transportation.

3.2 PROPULSION AND FUEL SYSTEMS

While it is difficult to predict, it is probable that research in the areas described in the following paragraphs will provide the most benefit.

Probabilistic Damage Tolerance Analysis for Components other than Rotors

The FAA Aviation Research Division (ARD) has made a large investment in the development of a Probabilistic Damage Tolerance Analysis (PDTA) that is becoming an industry practice for risk assessment of high-energy rotating components in aircraft gas turbine engines. This approach can address both inherent and induced anomalies associated with the manufacturing process that can lead to rare but potentially catastrophic failures. The PDTA process is summarized in several recent FAA Advisory Circulars that address specific types of inherent and induced anomalies (AC 33.14-1 and AC 33.70-2, respectively) and to establish a general framework for all life-limited engine parts (AC 33.70-1). The associated risk of fracture can be predicted using the DARWIN® code.
This investment will be leveraged to address other life-limited and critical components. Blades (including the blades on blisks/integrally-bladed rotors), shafts, casings, and mounts will be included in this Probabilistic Damage Tolerance Analysis process. While many of the probabilistic integrity methods developed for rotors are applicable, additional work will address the unique characteristics of these components, including 3D geometries, materials, and temperature regimes and the DARWIN® code will be enhanced to address each of these components.

Rotor Integrity

In order to continue to ensure the structural integrity and durability of critical rotating engine parts in turbine engines additional areas of research will be conducted to address:

- Fretting Fatigue and Edge-of-Contact Problems
- Increasing Engine Temperatures
- Powder Metallurgy Nickel-Based Super-alloys
- Damage Tolerance of Advanced Engine Materials

The damage tolerance methods, tools and data developed through this research will provide the basis for new/revised engine certification standards and Advisory Circulars.

Non-Destructive Evaluation (NDI) on Critical Engine Components
Inspection plays a critical role in commercial engine life management philosophy as described in Advisory Circular 33.14-1 – "Damage Tolerance for High Energy Turbine Engine Rotors". The damage tolerance approach recognizes that the potential exists for anomalous conditions that could result from inherent design,

manufacture or use of a component. The anomalies are accounted for in the life management calculations using expected defect distributions coupled with fracture mechanics calculations. Inspection is used for each component to assure that disks that contain defects that could result in catastrophic failure of the engine do not enter service.

Today, we look at new and emerging NDI techniques which can detect much smaller defect sizes. For example, the division is working with Siemens and industry partners, to develop a surface inspection technique called Sonic I/R. The basic premise of this methodology is the use of an external energy source, using an ultrasonic horn, to excite the component. The external energy source causes an increase in local heating which is detectable with infrared cameras. As a result of this research, the USAF is now conducting a feasibility study to implement this technology to inspect engine fan blades at their depot level. The FAA, USAF and industry partners are in process to develop an industry standard for this technique.

Machining Process Monitoring on Engine Disks

During new part production of engine rotors undetected manufacturing induced anomalies may be inadvertently introduced and if undetected can result in catastrophic failures. These anomalies result from the unintended application of machining parameters outside of frozen specified limits, application of a non-robust process or mismanagement of tool life. Often these excursions are undetected and the product is released into service.

On July 6, 1996 a Delta Airlines MD-88 experienced an uncontained engine failure. The engine was a Pratt and Whitney JT8D-200 series engine that experienced a failure of the Titanium fan hub. The resultant lack of containment compromised the fuselage and caused fatal injury to two passengers. The cause of the fan disk rupture was attributed to a severely worked material surface layer (i.e. a manufacturing induced anomaly) in one of several tie-rod bolt-holes introduced during machining of the disk.

According to a 1997 summary of disk fracture root cause from the Aerospace Industries Association (AIA) Rotor Integrity Sub-Committee, post-forging Manufacturing Induced Anomalies (MIA) accounted for about 25% of rotor cracks/events. A further analysis of this data for in service disks shows that manufacturing anomalies, caused by machining abuse, were rising and in the 1990s had become the primary cause of disk cracking. There are multiple manufacturing induced anomalies that could have a deleterious effect on material properties. Examples of these anomalies include, imbedded carbides, distorted microstructure, plucking, material redeposit, smearing, chatter marks, excessive surface roughness, overheating due to dull cutting tools or poor coolant delivery, chip congestion, etc.

In response to this and other accidents and incidents caused by manufacturing induced anomalies in critical rotating parts, the FAA and industry partners have conducted ongoing research to develop advanced process monitoring systems for drilling and broaching process that would preclude the onset of deleterious manufacturing induced anomalies, characterize of those anomalies, and enhance process and inspection methodologies. As a result of our research, many manufacturers have introduced the machining process monitoring technology into their production system, parting order to be able to monitor and detect the onset of damaging processes. Additional research will expand on the successes previously achieved while continuing to reduce anomalies, increasing the level of aviation safety.

Adaptive Machining Process Monitoring on Engine Disks

As the Industry gained new knowledge from the development of machining process monitoring technology and correlation of its thresholds to material integrity, it was discovered that this process can be utilized for both process qualification and intelligent manufacturing. A snapshot of long term research for advanced manufacturing that the FAA and industry partners are planning to do in the next ten years includes: developing process monitoring controls; optimizing each individual process output by introducing adaptive process control; and considering adaptive control at the system level.

The onset of adaptive system level process control will provide an opportunity to qualify a highly robust manufacturing process. FAA and Industry partners will utilize this rich knowledge of the process in a standardized manner (i.e. an Industry standard) to substantiate many critical manufacturing processes. Such methods would provide almost absolute certainty of the process outcome and could provide for significant return on investment in terms of remedial actions, escapes and a much less laborious/iterative approach to manufacturing process qualification.

The division is in process of partnering with USAF in this effort. The outcome of this project is a development of an Industry standard for qualification of manufacturing process monitoring methodologies. This standard would help to define which monitoring technology is appropriate, how to calibrate the process and how to establish process thresholds beyond which material anomalies would occur.

Volcanic Ash Exposure

Volcanic eruptions and their impact on aviation have been known for some three decades or so, but interest in the last 5 years has grown acute in the seemingly odd interaction of gas turbine engines (GTE) and volcanoes. This is probably due to two emerging trends: the first is that modern GTE, to improve fuel efficiency, operate at increasingly higher pressure ratio, and therefore temperature, which makes them more susceptible to hot-section attack from the airborne volcanic ash. Ingested ash literally melts and accumulates within the engine combustion chamber, inner turbine nozzles, and rotor sections. The second trend is that some of the more recent eruptions have ejected sizable quantities of ash that have drifted into major air-routes. Most notable of these incidents are 2010's Eyjafjallajökull eruption in Iceland which shutdown the North Atlantic great circle route and 2011's Chilean Puyehue which disrupted aviation across the south Pacific Ocean as far away as Australia. Commercial flights in 2010 were largely shutdown over the North Atlantic, the largest such impact since World War II. The impact on military aviation was also extreme as well; a high priority med-vac flight was diverted to a route far south and many sorties not canceled (over 600) were flown three quarters of the way around the planet on the eastern route to avoid the Atlantic great circle route closed by Eyjafjallajökull's volcanic ash plume.

It must be emphasized that volcanic ash does not resemble the fluffy product of wood burning stoves and fireplaces; this material is a glassy form of silica quartz, hard, highly-vescularized and angular from the release of great gas pressures when ejected from volcanic vents, it makes a great abrasive media for erosion in cold sections of turbine engines (compressors, fans, and nacelles) and airframes, while it easily melts and adheres within hot-sections (combustors and turbines). The latter effect can trigger dramatic in-flight failures. The lofted particles that are problematic, typically ranging in size from about 5 to 50μm in diameter, are easily lofted into the stratosphere from the combination of vented gas thrust and the convective lofting of the hot ash column. Once they encounter high altitude winds they often disburse widely and are there encountered by jet transport aircraft. Silica in the ash is often mixed with other constituents that not only depress the melting temperature of the silica, but also can trigger chemical attack, and thermal spallation attack on ceramic thermal isolation coatings. Additionally, it can carry high electrostatic charge with potential disruptive effects on control electronics. Commonly dubbed “CMAS”, for calcium-magnesium-alumina-silica, other contaminants in CMAS can include iron, sulfates, and crystalline quartz among other volcanic minerals. Similar mechanisms of attack result from the ingestion of fine desert sand, another aggressively abrasive CMAS that also melts in the hot sections; this source is becoming of concern with increasing desertification in many regions.

Hot-section attack mechanisms can have a rapid onset to dramatic in-flight incidents, including total multiple engine failures. Two better-known historic incidents are 1982's British Airways flight 9 and 1989's KLM flight 867 which encountered ash from Mt. Galunggung in Indonesia and Mt. Redoubt in Alaska, respectively. Both Boeings’ 747 experienced four engine failures with dramatic loss of altitude before engine restarts were accomplished.

The lack of knowledge includes: the rate of damage accumulation and service-life reduction with cumulative ash exposure, the probability and severity of incidents in flight, the evolution of engine operating parameters as the exposure proceeds, and short term remediation techniques. Compounding the problem is that various engine systems have different levels of susceptibility to ash damage and critical failure paths. One GTE might have a critical failure path from boundary cooling layer disruption in the nozzles triggered by CMAS accumulation around the cooling pores, while another suffers heat distress from thermal barrier coating (TBC) spallation from CMAS thermo-chemical attack. Future research will address the rate of damage accumulation, service-life reduction and develop mitigation techniques for engines operated in stratified ash conditions.

Turbine Engine Emissions

There are many major particulate and greenhouse gas regulations based on turbine engine emissions being developed or debated worldwide. It is anticipated that this will continue over the next decade. The impact of these initiatives on commercial aviation can be significant. Development and maintenance of standardized test practices to reliably measure these emissions will be needed. Further, standardized practices will require modification to align with engine, airframe, and instrumentation technology advancements.

Research products will support development and maintenance of these standard measurement technologies. Specifically, particulate and soot emissions from commercial aircraft are increasingly being looked at for regulatory action worldwide. Techniques and technologies to measure particulate dispersion, particulate size density, and particulate count from actual aircraft are under investigation with the results being highly impacted by the variation in measurement methods and procedures. Research conducted by the division will assist in the development of standardized testing protocols with guidance on standardized measurement technologies for both test cell and in-flight particulate turbine emissions measurements.

Fuel Cell Technology

It is envisioned that the aircraft industry will move to fuel cell technology to power Auxiliary Power Units (APU) in an effort to reduce fossil fuel consumption. As a result, the division is proposing to conduct research on the supporting systems required to use this technology. Research will address safety and airworthiness issues related to use of fuel cells and will support the EPD and EPD sponsors in the development and application of regulatory guidance material and Federal Aviation Regulations. By way of example, specific research areas will address systems monitoring and conditioning research, and failure mode analyses, among other research areas.

Future Engine Component Capability

It is anticipated that an alternative unleaded fuel, developed to replace the current 100LL fuel, may not safely operate in all piston aircraft. As such, the program expects to conduct research relating to engine or fuel component modifications to safely accommodate the replacement fuel. This may involve research in combustion chamber design, ignition timing, electronic ignition systems, or Full Authority Digital Engine Control (FADEC) technology.

Future Alternative Jet Fuel Capability

We are currently expanding our capability to perform full spectrum testing of any and all aircraft fuels. This includes, but is not limited to: Jet Fuel, Diesel Fuel, and Alternative Jet Fuels, derived from coal, liquid natural gas, and biomass (both liquid and solid). This capability includes laboratory, rig, engine performance and engine emissions testing.

3.3 ADVANCED MATERIALS/STRUCTURAL SAFETY

Future research is largely based on the aircraft certification application process. Applications are not entirely predictable as most of the major airframe manufacturers' research spans a wide variety of technologies with only a few ever gaining the status of accepted innovation. This results in the FAA having to stay in close contact with the manufacturers to understand the probability of particular technology being part of a civil aircraft Type Certification (TC) submission. Additional direction will accrue as a result of events in the civil aviation industry such as major design flaw discoveries, service difficulties and operational events. The planned research initiatives are depicted in Figure 1.

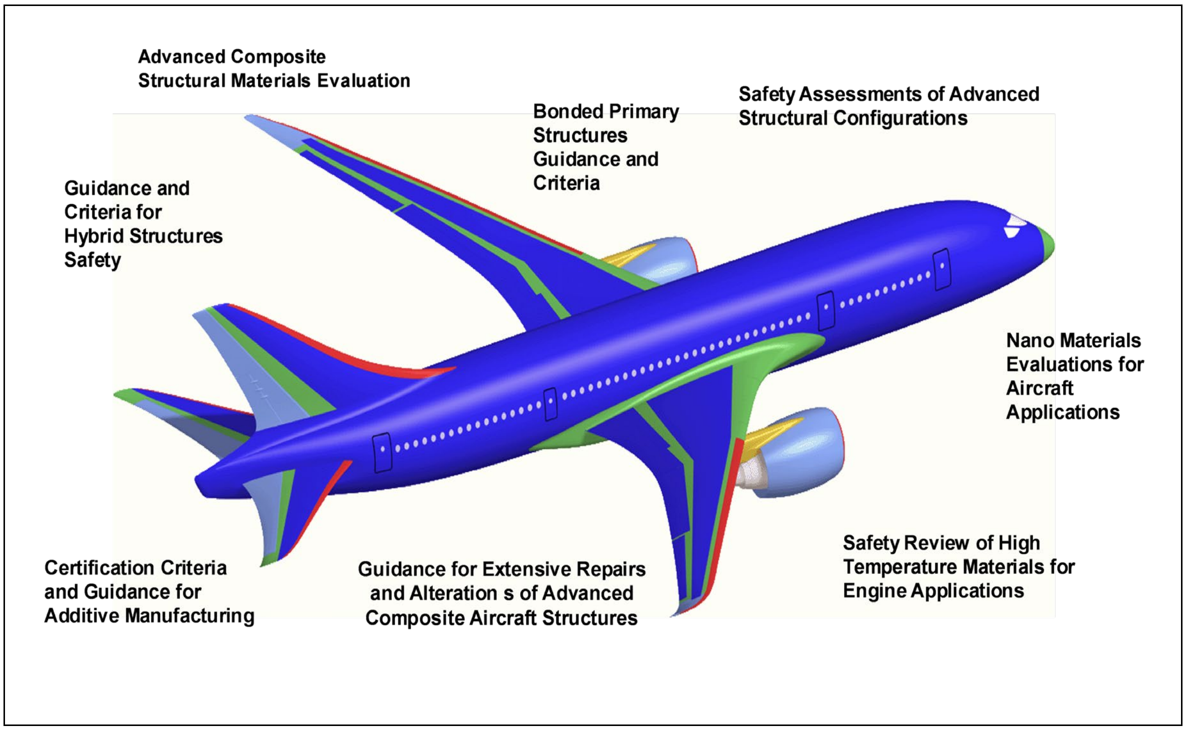

Figure 1: Future Research Initiatives

The advanced materials and structures area will see additional applications for composites including high temperature ceramics and metal matrix, as well as a focus on hybrid structures. New processes to manufacture materials will also require the FAA to understand the differences between them and standard practices. In the structural safety area, a significant shift from testing to analysis will drive the research for the next 10 to 15 years.

The future research program is divided into two time components; 5 to 7 years and 7 to10 years. The following paragraphs describe the activities which are vital to the research.

Mid Term Research (5-7 Years)

Research will address Advanced Composite Materials, Bonded Structures, Hybrid Structures, Changes Driven by Environmental Considerations, High Temperature Applications, Additive Manufacturing, and Crash Conditions Definition as described below.

Advanced Composite Materials- Advanced composite materials will be used extensively in many new aircraft. Alternate processing techniques, such as Out of Autoclave Curing (OAC), Vacuum Assisted Resin Transfer Molding (VARTM), and new materials will be introduced in the next few years. The advances in the understanding of the characteristics of these changes will continue to drive research in the composites arena. The areas most likely to require focus are the reactions to damage, durability and operational concerns. Continuing interest is expected in understanding the nature of operational threats to structures and their response to these threats. Additional work will be done in understanding the hydrothermal effects on the durability capabilities of composite structures, specifically the effect on fatigue resistance.

Bonded Structures- The use of bonded structures will increase due to the economic and performance advantages over current mechanically fastened concepts. There will be a large effort to establish the reliability and durability of these bonded structures. Currently there is an effort to find an NDI testing protocol to assess and assure the durability of bonded structures; however the practical implementation of this type of inspection is years away. When introduced in the civil aviation fleet, the FAA will need a strategic plan for using this technology on certified structures. The safe use for both initial designs and repairs covering both certification and continued operational safety will need research.

After developing standards over the next two years for the use of bonded repair, limiting the potential size for repairs, additional work will focus on the development of background information for the use of bonded structure for Transport Category Aircraft. This research will establish limits and controls for the use of bonded structures in both production and repair applications based on the ability to assure durability of the bonded joint. This work will build on the surface assessment work currently underway under the direction of the advanced materials and structural safety program. This will support the development of a policy memo from AVS on the use of bonded structure in critical load paths for transport aircraft.

Hybrid Structures- Another major area of focus will be hybrid structures. They are a refinement of the current introduction of new materials into structural applications. They utilize the strengths of each material in specific structural configurations to achieve a structure which performs better than either material could separately. This leads to interface issues and leads to mismatches not seen in a single material including load transfer, thermal expansion, and corrosion. The transition from one material to another in hybrid structures will need to be researched to understand the critical factors which affect the safety and contribute to reduction in operational capabilities.

Research will be required to understand hybrid structures and the unusual loadings that results from the interaction of different materials. Additionally, research will characterize fatigue reactions of hybrid structures that will lead to the establishment of design criteria and test protocols. Research will be needed in the area of damage tolerance to understand the threats to these structures and their reactions to impacts and other damage sources.

The establishment of methodologies to determine the Limits of Validity (LOV) for hybrid structures will also be researched. This information will be the basis for Advisory Circulars (AC) which will be released by both the Small Airplane Directorate (SAD) and the Transport Airplane Directorate (TAD).

Changes Driven by Environmental Considerations- The continuing drive to use environmental responsible materials in manufacturing and service operations will create changes in materials used in aviation. These changes will impact existing systems and require substantiation of compatibility with the current structures. A current example of this is the move to alternate fuels in GA fleets. This has led to questions of compatibility with fuel tank structures and other materials in the fuel delivery system. The FAA has initiated a fact-finding program to address the possible consequences of the change, resulting in research requirements to investigate compatibility of the fuels with structural and fuel system components.

High Temperature Applications- The continuing drive for development of higher efficiency turbine engines will require materials that can sustain higher temperatures. This, along with a renewed interest in decreasing the weight of engine components, will require the use of Ceramic Matrix Composites (CMC). There will also be an increase in the use of high temperature Polymer Matrix Composites (PMC) which will need to be characterized for civil applications. The use of these materials is currently under development and plans are that they will be used in the next five years for civil aircraft applications. Research will create standards and detailed understanding of the criteria for safe use in engines and other high temperature applications.

Additive Manufacturing- Currently there is a large effort within the military to utilize a group of processes know as additive manufacturing. This area is sure to develop a civil aviation following because of the many advantageous and unique capabilities of the technique. The additive manufacturing process promises to allow fabrication of complex parts that cannot be formed by conventional machining and fabrication processes. Several areas are currently being pursued for military applications including complex heat exchangers, intricate shapes, one-off replacement parts and repairs. These all have different validation and certification processes. This will require research to understand the critical parameters that affect the reliability and repeatability of the additive manufacturing process used and its implication on safety of air vehicles.

Crash Conditions Definition- The development of crashworthiness aircraft certification criteria should be based on representative crash scenarios. These scenarios should include hard, soft and water impact surfaces and take in to account the conditions at the time of impact. This should include information on the aircraft (e.g. configuration, attitude etc.), the terrain (e.g. sloped, hilly, wave heights in the case of water impacts) and environmental conditions. Current certification testing is limited to vertical drop tests of aircraft fuselage sections. The use of unique designs or materials may result in unexpected impact scenarios. The FAA needs to develop a better understanding of actual impact conditions in order to develop representative crashworthiness criteria.

Long Term Research (7-10 Years)

Longer term research will focus on_Advanced Structural Configurations, Nanomaterial Technology, and Crash Model Validation Process as described in the following paragraphs.

Advanced Structural Configurations- There will be an effort to capture new methodologies and procedures that are developed for the emerging concepts of advanced structures. The blended wing-body concept is one of a number of possible configuration changes which are proposed. Also the entry into the commercial space market will require guidance and certification criteria establishment. These will require review and documentation to address the information needed for substantiating use on civil aviation applications. These developments and additional structural concepts will be incorporated into existing guidance materials, e.g., AC 20-107.

Nano-material Technology- Nano-material development has not impacted civil aviation structures as originally predicted ten years ago. These materials are expected to deliver high specific strength and stiffness structures. This will create concerns with integration with current structural materials and unique characteristics to be addressed during certification. In the interim, scale-up issues with developing usable quantities at a reasonable cost have resulted in fewer capabilities for these materials than predicted. Attaining expected capabilities is still an issue as well.

Some development efforts for specific property enhancements like transparent EMI shielding and high conductivity materials have seen application. It can be expected that some progress in realizing the potential of nanotechnology will be made in the next ten years and the FAA will need to understand the implications of these radically different materials from a structural reliability and durability perspective. The program will monitor civil airframe producers to determine expected uses of these materials and respond to initiatives to introduce them in certified aircraft.

Crash Model Validation Process- The current emphasis in industry is to develop analytical models to design and evaluate the crashworthiness response of an aircraft. The current method, certification by analysis supported by test, relies on a building block approach. This methodology compares the analysis results with the experimental test results, and increases in structural size and complexity up to and including large-scale/ full-scale tests.

This is a complex, time consuming and expensive process for industry and the FAA. The FAA must be confident that the results of using analytical models produce representative data. This includes results with experimental data as well as the predicted results of full-scale test scenarios that are not tested. A standardized crash model verification and validation process will assure proposed analytic processes provide safe structures. The research will need to focus on providing information for developing rulemaking, policy and guidance.

3.4 CONTINUED AIRWORTHINESS

Strategic research is focused on Airframe Structures and Aircraft Systems. Airframe Structures includes Structural Integrity, Active Flutter Suppression, and Maintenance and Inspection. Aircraft Systems includes Flight Controls and Mechanical systems, and Rotorcraft Systems. These are discussed below.

Airframe Structures

Structural Integrity - New and emerging metallic structural technology (EMST) will be implemented into transport category aircraft as industry continually strives to reduce weight and reduce the cost of manufacturing and operation. These technologies consist of advances in materials and processing, new fabrication and construction methods, and novel designs. Often such new technology does not initially have data available to assess the longer-term safety impact. Research is needed to assess the compliance of structures using these technologies. Then, to insure that the regulations and guidance stay current, continuing research is needed to assess potential EMST applications as industry introduces advances in materials and new fabrication and construction methods. Data will be required to assess the continued relevance of existing regulations, impose additional safety standards (via Special Conditions/rulemaking), and provide additional regulatory guidance (advisory materials/policy memoranda). Future research efforts will span wide areas of metallics, metallic hybrids, metallic construction and processing, and inspection/monitoring methods. To achieve that end, multidisciplinary coordination is required with composite, maintenance and inspection communities. EMST on the horizon includes:

- *Advanced Metallic Alloys and Processes:* Since the announcement of the B787, there has been industry resurgence on developing new metallic materials and processes that can compete with composite structures. Aluminum manufacturers are investing heavily in several key areas including the development of light weight alloys like aluminum-lithium (Al-Li) and processes like forgings that reduce costs and improve buy-to-fly ratios. Industry projects increasing demand for Al-Li in narrow body aircraft applications, and as a result has invested heavily in their production facilities. ALCOA alone is investing 90 million dollars to increase Al-Li production capabilities.

- *Advanced Welding and Joining Processes:* Advances in welding and joining are providing many opportunities for improved structural performance, buy-to-fly ratios, and reduced manufacturing costs. In particular, the friction welding process allows joining many combinations of metallic alloys and building damage-tolerant hybrid structures. Considerable investments have been made in trade studies to demonstrate the feasibility of applying friction welding methods to join pressurized fuselage structures. Laser beam welding is being used in the construction of skin-stringer panels for the Airbus A319, A340, and A380, which improves corrosion resistance and reduces manufacturing cost and weight by

20% and 10%, respectively. However, there is a lack of published data on strength and durability of welded joints.

- *Additive Manufacturing*: New advancements in additive manufacturing (AM) have demonstrated the ability to produce complex components, which are attractive for structural applications. Lockheed is investigating the application of AM to fabricate titanium parts for the F-35. In addition, AM has wide appeal in the Department of Defense (DoD) for replacement of older parts. Issues with process control, surface conditions, and porosity may have dramatic implications on fracture and fatigue properties. Standardization efforts to develop material properties may be elusive, resulting in many special design certifications.

- *Advanced Hybrid Construction*: Hybrid advanced structures have the most potential in producing a significant leap in structural efficiency. Technology demonstrations have already shown that significant improvements are possible. In proposed hybrid assemblies, thin aluminum sheets are tailored in shape and span to align with structural loadings. Sandwiched between these aluminum laminates are cores made from fiber-metal laminate materials like Glass Laminate Aluminum Reinforced Epoxy (GLARE). These materials will be used in various manufacturing techniques to produce seamless unitized structures. Future research will advance the scientific knowledge of these structures and characterize their structural integrity.

- *Thick Structure Bonded Repair Technology:* Current research is focused on fuselage structure applications. These are relatively thin and are subjected primarily to in-plane loads. In partnership with Boeing, additional efforts are needed for bonded repairs of thicker structures such as wing components which are subjected to much more complex loads.

- *Structural Health Monitoring (SHM):* Industry is promoting SHM technologies to reduce the long-term maintenance cost and improve operational safety. With the increased use of advanced materials (both metal and composites), methods for real-time health monitoring are being pursued and demonstrated. SHM systems have the potential to identify and react to structural damage or fatigue while recording and communicating the precursors for maintenance review, and to allow time to take preventive action. SHM systems could also provide valuable information to flight crews in emergency situations, reducing reaction time in time-critical situations.

As part of the longer term research, resources will be leveraged through partnerships with industry and other government agencies. A primary focus will be programs that address the above mentioned EMST. In particular, a full-scale test of an advanced metallic fuselage structure concept using the FASTER laboratory will be used to assess durability and damage tolerance of multiple

EMST including unitized welded structures, new metallic alloys (Al-Li), and hybrid bonded construction. Data will be generated to validate new analytical tools and to support certification, and continued airworthiness of these emerging materials, structures and fabrication methods. Applicable inspection methods will be explored including integrated Structural Health Monitoring (SHM). Research will be conducted to assess EMST for: Multiple load paths (concern with reduced damage tolerance); Crack arresting features (concern with reduced fatigue performance); Damage containment features; Selective reinforcements with fatigue-insensitive materials; and Applicable NDI and SHM.

Active Flutter Suppression (AFS) – Additional research will address the impact of fatigue life in the presence of an AFS system. Fly-By-Wire (FBW) flight control systems provide significant maneuver & gust load alleviation, and envelope protection / limiting, which results in large structural weight reductions in the airframe. As structural weight is reduced, the requirement to prevent control surface flutter will result in an undesirable stiffing of the control system by adding weight to the control system. This negative weight impact will be overcome with the use of AFS. The next generation of transports will utilize advanced FBW technology that take more advantage of the weight reduction features mentioned above and will be capable of providing AFS to reduce the impact of flutter on the airplane design. In addition, future airplane configurations (other than tubes with wings) and supersonic designs may be more susceptible to flutter. The introduction of AFS systems requires research to address relevant technical challenges and provide basis for certification requirements.

Maintenance and Inspection - Over the next ten years, maintenance and inspection research efforts will focus on ensuring the continued airworthiness of advanced structural materials as they gain wide spread industry usage. Advanced materials will largely include composites fabricated from carbon fiber, and epoxy and non-traditional metallic structures, created from new alloys and advanced processing methods.

Transport aircraft fabricated predominantly with composite primary structures, such as the B-787, are just now entering commercial service in the US. As more composite aircraft accumulate flight experience, it is possible that unique, unanticipated maintenance and inspection challenges may arise. These challenges are different due to the construction of composite aircraft and the different structural responses to in-service damage as compared to those fabricated from traditional aluminum. The longer term maintenance and inspection challenges include ensuring adhesive bond integrity and incorporating remote damage detection sensors. Each of these challenges is described in more detail below.

- *Inspection of Weak Bonds and Quantification of Bond Strength:* The use of bonded joints continues to increase in the manufacture and repair of aircraft structures in small airplanes, transport airplanes, and rotorcraft.

Development of appropriate inspections is a high priority to maintain the required level of aviation safety both for initial and continued airworthiness. In general, bonded structures may include composite-to-composite, composite-to-metal, and metal-to-metal assemblies. The purpose of this research is to address concerns over long-term durability and an inability to quantify bond strength (i.e., identify weak bonds) in adhesive joints. Bond deterioration in aging structures and bond strength in original construction are critical issues that require more than a simple disbond detection capability. Additionally, as composite primary structures gain in-service experience, it is possible that unforeseen damage scenarios will be discovered that would need to be addressed. Research in the area of bond quality characterization by NDT will require development of a repeatable methodology to create realistic adhesively bonded aircraft joints of reduced strength levels. Innovative inspection technologies will be developed that can characterize the strength of an adhesive bond. Research will be required to develop and then validate new technology prior to field inspection use.

- *Sensors for Remote NDT*: Remote sensing technologies are on the verge of being utilized for several aluminum aircraft applications. These include eddy current sensors, piezoelectric, vacuum, and optical strain gauges. The sensors are designed to be mounted in a location which has a well-documented history of cracking and which is difficult to access. When these areas are viewed, the sensors can be permanently mounted and its data remotely queried. For composite structures, similar remote sensing technologies will likely be proposed to detect impacts, delaminations, loss of bond integrity water ingression, etc. The most promising technologies will be studied to determine their performance, installation, long term durability, and detection reliability.

- *Inspection of Advanced-Manufactured Metallic Structures*: More efficient manufacturing processes and new alloys are constantly being explored for aerospace applications. Processes such as friction stir welding and advanced casting technology offer the potential to greatly reduce the number of structural elements and mechanical fasteners required in aircraft construction. Although the part counts of these monolithic structures may be reduced, there is concern that increased part complexity may challenge the current inspection methods. Similarly, metallic alloys such as aluminum-lithium, which offer improved damage tolerance properties, will be evaluated to determine the capability of current inspection methods to find critical flaws.

<u>**Aircraft Systems**</u>

Flight Controls and Mechanical Systems- This research is supporting and updating certification standards to improve rules, guidance, and policies in promoting safety. It is anticipated that the future research in the next 5 – 10 years will be focusing on studies to prepare the FAA for the new and emerging technologies to meet NextGen challenges and requirements. The research will help in the transition to NextGen by ensuring the FAA has the appropriate equipment standards and has adequate functionality to support NextGen operational objectives.

Far term research requires developing functional, safety and certification requirements for Advanced Flight Displays to meet NextGen trajectory management needs, such as flight path angle, and vertical/lateral trajectory deviation. Additionally, a FCMS research project will investigate detailed stall characteristics that can be easily modeled The Terminal Area Safety (TAS) initiative (Section 8) will investigate their use in improved training programs. Subsequently the models and improved programs will be incorporated into training curriculums to enhance safety of flight by ensuring correct that pilots recognize stalls and use correct stall recovery techniques.

Rotorcraft Systems- Rotorcraft safety is receiving greater focus as the accident rate continues to rise. Leveraging advancements in radar development will allow for future research exploring the use of such systems to avoid birds and prevent controlled flight into terrain (i.e. trees, power lines and towers). This research will target mitigation of currently problematic accident causal factors in the EMS environment and other low level operations. Pilots often suffer from poor visibility while flying at night, in bad weather or in brown outs as the rotor wash kicks up dust/dirt from a landing zone. Research to improve situational awareness with the use of night vision goggles, better terrain radar and object avoidance sensors will be pursued as accident prevention technology. This future research will leverage previous work done by the military. Other areas to be explored include:

- Active rotor systems for advanced aerodynamic performance: high-lift, low drag, low vibration, low noise rotors.
- Flight dynamics and control research on handling qualities for large rotorcraft.
- Materials and structures research focused on rotorcraft-specific issues in crashworthiness, advanced materials for airframes, engines, drive-trains, durability and damage tolerance.

Integrated Vehicle Health Monitoring (IVHM) has the potential to affect every area of continued airworthiness research. IVHM includes all of the following: complex systems; materials awareness; structural monitoring, systems (mechanical and electrical); and sensors on transport, rotorcraft and general aviation aircraft. Far term research should provide the capability to address many potential, expected requirements.

Integration of propulsion and subsystems health management technologies, flight operational data, usage data for life limited components for “on-condition” maintenance of all aircraft systems. These technologies will inform the operators and maintenance personnel of the health state of all the vehicle systems, predict remaining useful life, and required maintenance action to be performed.

3.5 AIRCRAFT CATASTROPHIC FAILURE PREVENTION

Strategic research in this program builds upon the successful completion of work identified by the ACO's, performed under a partnership with Academia, Industry, and other Government Agencies, and guided by the industry working group. This work continues to evolve the analytical capability by developing advanced computational models and the test methods and data to validate them. By means of generic examples, civil aviation manufacturers can follow industry recommended processes to develop predictive analysis capabilities for their proprietary materials.

<u>Mid-Term Research (5-7 years)</u>

Mid-term research will focus on Engine Containment Certification by Analysis, Nonlinear Material Models for Impact Analysis of Composite Materials, Design Strategies for Protecting Aircraft from Uncontained Open Rotor Blades, and Aircraft Vulnerability Analysis.

Engine Containment Certification by Analysis Research- In addition to the current model development research, certification by analysis has an important technical problem to tackle, material anisotropy; i.e., materials that have different material properties in different directions. This work will be applicable to aircraft and engine use of composites as well as to directionally manufactured metals. It is evident that composites, which are being used in more and more aircraft and engine components, need to be modeled accurately and that a predictive model is needed for them. The problem is significantly harder than metals because the material has very different properties in each principal direction and in some cases may have almost no strength in one direction while being very strong in another. This research is being conducted with NASA Glenn Research Center and coordinated with advanced materials program at the FAA William J Hughes Technical Center. The ACFPP work compliments the advanced materials work and is specifically focused upon failure from impact of the composite during the unique engine failure event conditions. Initial work will focus on a homogenous material with anisotropic properties, and in this formulation will apply to many materials in addition to composite like wood and directionally manufactured metals.

Nonlinear Material Models for Impact Analysis of Composite Materials- In the mid-term, the homogeneous orthotropic composite models developed during the first 4 years will be expanded to include initial development of modeling different composite configurations that require more than a homogeneous model. Designers need to be able to evaluate how many layers are needed and also which directions of the fibers provide the lightest weight design. In a homogeneous model, the layers and directions are averaged into a model of the final product. To accurately develop design of composite materials, a method to model the directional material and how layers are oriented is needed and is a long term goal. A significant analytical effort is required to develop the interaction between the principal directions as stress accumulates, and actual material data in the principal directions is envisioned as the material model input.

Design Strategies for Protecting Aircraft from Uncontained Open Rotor Blades - A real world application and certification challenge that is currently in Preliminary Design at the air-framers and engine manufacturers, and in preliminary rule making assessment, is the open rotor engine design. The FAA desires that the unducted fan applications achieve an equivalent level of safety when compared to current ducted fan designs. The major challenge is accommodating the consequences of a fan blade failure. In ducted engines the blade must be contained. In open rotor designs the blade is free and can impact the aircraft.

In the 1980's, the open rotor engine design was pioneered because it offered improved fuel consumption, see Figure 5.5. This design uses two rows of counter-rotating blades without an outer case around the fan. The dual row open rotor achieved efficiency improvements up to 20% relative to competing ducted fan designs. However, problems with excessive noise and blade containment, among other issues, caused this design to be put on hold. Recently however, interest in reducing noise, fuel burn and emissions has revived interest in open rotor. The FAA Environment and Energy Division has funded further research on the open rotor engine. However, no funding has been allocated to assess aircraft vulnerability for this engine design. Since the unducted design does not provide the fan blade containment historically required for ducted fan engines, any fan blade failure, such as may occur from a bird strike, other FOD, or mechanical failure, will no longer be contained within the engine. Engine and airframe manufacturers are now considering open rotor engines on future aircraft designs and the FAA Transport Airplane Directorate has requested research to help evaluate whether the new open rotor designs with composite material blades can achieve an equivalent level of safety relative to current engine designs. As designs are developed to increase the impact resistance of the airframe to uncontained composite fan blades, Research will analyze the shielding capability to assess whether the designs can achieve an equivalent level of safety to a contained engine aircraft and make recommendations to AVS.

Aircraft Vulnerability Analysis- Research will be required to assess the various open rotor engine and aircraft configurations to assure adequate protection against a catastrophic failure. The UEDDAM analysis will be expanded to add these configurations and any new materials to update aircraft configurations to new designs. If weight and structural practicable shielding designs cannot be developed, the UEDDAM model can be used to assess the vulnerability of open rotor engine designs. As open rotor certification progresses, it is envisioned that the vulnerability code will need to be updated for use in evaluating design layout of the advanced open rotor aircraft.

Far-Term Research (8-10 years)

Further research will focus on New Aircraft Designs and Advanced Analysis of Composite Materials.

New Aircraft Design Concepts- Far-term Aircraft Catastrophic Failure Prevention Program will focus on revolutionary air transport vehicles that are a significant departure from conventional cylindrical fuselage design flying at subsonic speeds. For example, the blended wing body aircraft unites the passenger cabin with the wing. This type of aircraft will require new vulnerability modeling based on changes to engine location and attachment along with changes to location and functionality of aircraft critical systems. Other new design concepts will be evaluated as required.

Advanced Analysis of Composite Materials- Initial composite analysis will focus on homogeneous orthotropic material models. To accurately develop composite materials design, a method to model the individual composite layers is needed. This is an order of magnitude increase in complexity. It is expected that increased computing power through better parallel processing and cloud memory allocation will enable accomplishing these more complicated geometric modeling challenges. There are program plans to enable modeling failure in a complex composite design in the next 8 to 10 years.

3.6 SAFETY INFORMATION MANAGEMENT AND ANALYSIS

Rapid access to relevant data is the key element for safety information research. Currently, analysts within the division and throughout the aviation industry lack access to comprehensive safety information to effectively and efficiently perform needed research. The issue within the aviation safety organizations is similar to that of "Big Data" within the commercial sectors. Big data is typically defined by three key characteristics; volume, variety and velocity. The volume of data being produced today within the aviation community is enormous. Several on-going efforts such as ASIAS, NAS data repository, Aeronautical Information Network, and weather programs are producing Terabytes of data daily and storing Petabytes of historical data. The variety of data is huge as well. NAS operation produces digital information from hundreds of different operational systems. The SMS and safety reporting mechanisms within the FAA and industry produce varying levels of accident, incident, and safety data in textual formats often not standardized and therefore difficult to process. Finally the velocity of data is immense with NAS providing safety operations 24x7.

The division and the WJHTC are well positioned to be a portal for aviation safety organizations. The facilities at the WJHTC connect to nearly all NAS operational systems. The alliances with ASIAS and ATO safety provide access to both digital and non-digital sources of information. The division will deploy new technology in the areas of analytics, information sharing and data visualization that provide safety analysts access to relevant safety information and tools. Analysts will have access to structured and non-structured data that support safety research. Data analysis tools, such as SPSS, Business Objects, Matlab, and others will be customized and readily available to sort through larger data sets and pinpoint information that is relevant to a specific research effort. Figure 1 provides an overview of the information collaboration visualized.
In support of the volume, velocity, and variety of data available the division will enhance its competencies in information analytics, data visualization, and safety information sharing/cloud integration. These are discussed in the following paragraphs.

Information Analytics
The field of information analytics has grown immensely over that past few years. Public and private organizations are finding that effective analysis of operational data can be of great benefit in increasing productivity and effectiveness. Most companies collect vast amounts of data during normal operations. The FAA, in this respect, is no different. It collects vast amounts of data from multiple, diverse systems that routinely operate on a 24 hours per day/7 days per week schedule. However, in most cases, collected data is underutilized.

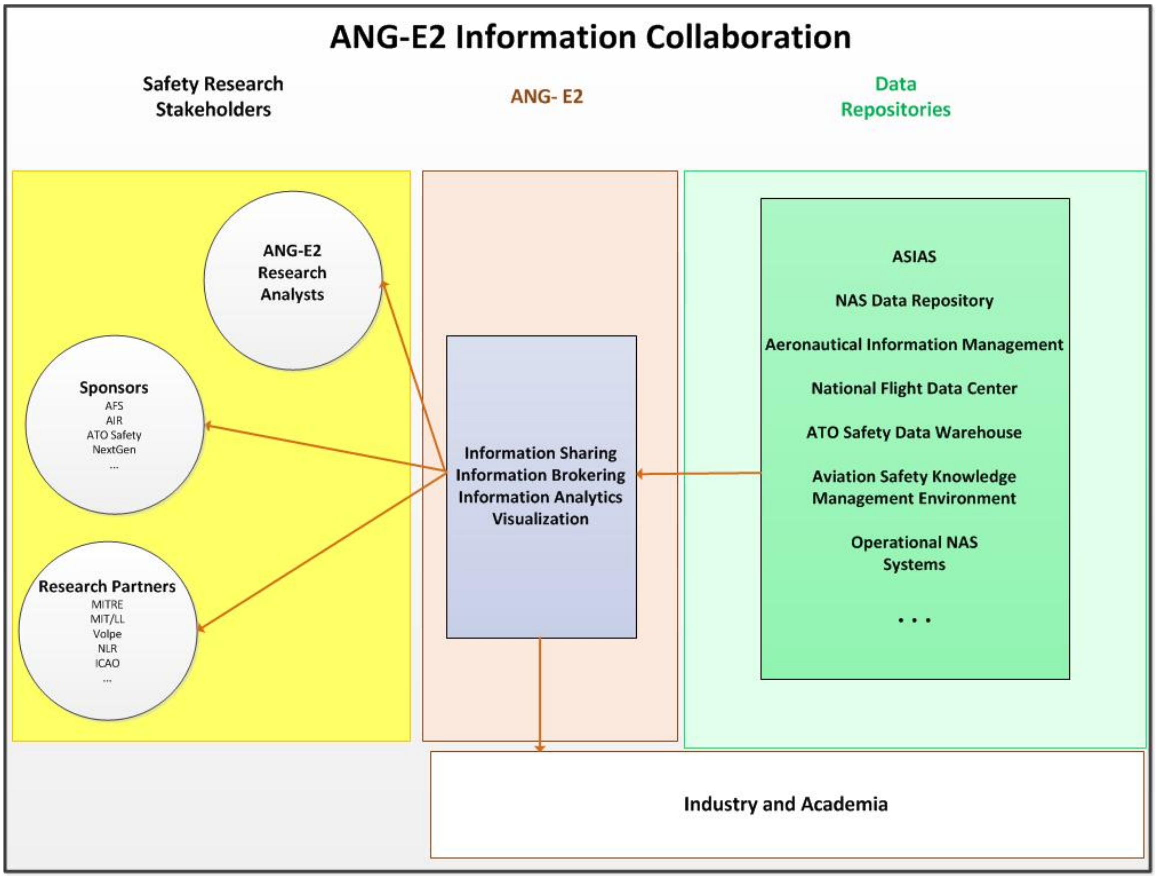

Figure 1: Vision for Aviation Research Division Information Collaboration

Often, it is used only for testing or monitoring operational system performance and not for proactive safety analyses. Commercial tools in the areas of embedded analytics, complex event processing, and human data analysis can help to narrow this gap by using existing data and information in new and novel ways in order to provide FAA stakeholders with capabilities that increase the productivity and effectiveness of aviation safety research.

Embedded Analytics- There is a need to sift through large amounts of textual and non-textual data. The incorporation of embedded analytical tools will allow researchers to set up logical queries that run continuously, providing results that may be of interest on a particular research effort. Analysts improve productivity by narrowing data searches that, while gaining access to information, they would not likely easily discover. Researchers from the Aviation Research Division will utilize embedded analytics to solve problems in their respective domains. An example of this is a general aviation researcher analyzing the causal factors that may contribute to an accident. Rather than spending time looking up the requisite data, creating hundreds of tables, and building statistical models that examine past databases (i.e. NTSB, ASRS, etc.), embedded analytics will allow the researcher to control specific parameters within these datasets and fine-tune the results; allowing for a study of “what-if” scenarios.

Complex Event Processing- By developing triggering mechanisms, analysts will be able to view information relevant to anomalies surrounding NAS operations and oversight activities. An example of one of these mechanisms is a loss-of-separation event in the airport surface environment (i.e. runway incursion, runway excursion, taxiway deviation, etc.). This type of event is readily captured in today's NAS using existing systems. However, these systems only examine these incidents after they occur and fail to consider normal operations, rather making a determination based on set criteria defining an event. By comparison, a triggering mechanism can provide alerts based on anomalies related to off-nominal conditions, while retrieving data reflecting the event. Thereby, a "trigger" allows an analyst to look at data surrounding any type of event, not just those associated with actual event, in order to uncover safety risks. These mechanisms allow analysts to structure research questions and produce reports quickly including the relevant data and contributing factors that surround incidents, accidents and events.

Natural Language Processing (NLP) and Artificial Intelligence (AI)- Organizations rely primarily on structured SQL queries which often lack the contextual basis, leading to results that contain large amounts of unusable data. By incorporating NLP and AI research capabilities, analysts will be able to produce results that are relevant to the area they are researching. For example, ASIAS has conducted some initial research on auto classification tools that alleviate the need to read through large volumes of safety reports. The voluminous safety reports within the ATO and AVS organizations require tools that can logically parse textual information and relate the information to on-going NAS operations. Relationships between diverse, large sets of data are needed to automate the process of selecting appropriate information for analysis. AI techniques will be developed to assist analysts in identifying anomalies and recommending mitigation activities. Text mining, data analytics and statistical analysis tools will provide the foundation for transforming raw data into formats that can be extended to NLP and AI. In addition, real-world safety modeling and simulation capabilities will be developed to assist in the prediction of incidents and accidents as well as assessing impacts to safety of off-nominal operating conditions.

Modeling & Simulation-. Both the NextGen Integration & Evaluation Capability (NIEC) Laboratory and the Human Factors Laboratory at the WJHTC are examples of facilities used by the Human Factors and Software and Systems Branches for Human-In-The-Loop simulations. However, these and other branches also make use of non-real-time models and fast-time simulations. While the application of these models tend to be very focused (i.e. a flame propagation model for fire research or an icing model), they do share several characteristics, including a demand for processing power, a need for real-world data, and in some cases, a modeling/simulation platform. These are the areas where a division-wide modeling and simulation capability can reduce costs to individual programs by providing a common, core infrastructure in which to develop, run, and refine models and simulation activities. In addition, these capabilities will assist analysts in predicting incidents and accidents as well as assessing impacts to safety from off-nominal operating conditions. They may also be used to assist other FAA organizations with applications such as Safety Risk Management Decisions (SRMDs), Safety Management Systems (SMS), and other risk-based systems.

Data Visualization

Much of the on-going research in data visualization has focused on air traffic controller visualization. Little work has been conducted in the human factors associated with safety data analysis. Data analysis tools are developed by software engineers resulting in tools that are complex and difficult to use. With the evolution of mobile devices, individuals are becoming accustomed to user friendly applications (apps) that present information in a simple and ergonomic fashion. The need for such functionality for safety analysts is no different.

Advanced Data Visualization- The current analysis methodologies for developing queries, sorting through results, and producing reports will not suffice in the future. New methodologies for visualizing data for presentation is key to the productivity and decision making process. Software design guides and tools (e.g. visual replays, graphical data presentation) will be developed specific to aviation safety and NAS data that allow analysts to efficiently select and view safety related information.

Field oversight personnel (e.g. Aviation Safety Inspectors, Designated Engineering Representatives, Runway Safety Action Team members) are in need of hands-on tools that provide access to information relevant to their day-to-day operations and job functions. To that end, software methodologies will be explored to ensure that information and tools for visualizing data are efficiently presented to enhance productivity and effectiveness.

Dash-boarding- The ultimate goal for data visualization is to provide decision-makers, researchers, and stakeholders access to safety information to proactively support decisions, research, and safety oversight. Dash-boarding is a way of graphically presenting important information updated regularly. It provides decision makers access to information for long term planning as well as immediate decisions that affect NAS safety. In general, data analytics and safety information sharing is useless unless the results are presented in a meaningful, efficient and accurate manner, which dash-boarding allows.

Safety Information Sharing/Cloud Integration

Technologies related to connectivity and Service Oriented Architectures (SOA) are advancing rapidly. The NextGen program has identified the System Wide Information Management (SWIM) as a key enabler. SWIM provides a framework for accessing data internal and external to the operational NAS. Similarly, the ASIAS program and aviation industry are looking toward Cloud computing as a resource for not only effectively sharing information, but providing analysis capabilities at an enterprise-level. The program will capitalize on the investment made within SWIM and Cloud technologies to work more effectively with research partners and to provide analysts access to the tools required to most effectively perform research.

Connectivity- The program will develop the infrastructure to support full integration with ASIAS and on-going Cloud initiatives within the FAA and industry. In its infancy, the ATO is developing an FAA Cloud that will allow applications to reside in centralized service oriented architecture. The main focus of the cloud initiatives are administrative, e.g. mail & documentations services; and is expected to expand to allow use by operational programs throughout the FAA. The program will continue to support ASIAS in their Cloud initiatives as well as develop prototype safety services for use by internal researchers and collaboratively with research partners. The use of Cloud services will reduce the in-house hardware, software, operations and maintenance costs.

Safety Information Access- There are many safety data collection efforts throughout the FAA. Safety related information retrieval and storage is not limited to research. The ASIAS program stores large amounts of NAS operational and safety related data. The newly formed NAS data distribution organization is in the process of creating a NAS data repository with the goal of storing and making available historical NAS data. Programs such as Aeronautical Information Network (AIN), Aviation Safety Knowledge Management Environment (ASKME), National Flight Data Center (NFDC) and many others are collecting and storing safety-related information for long-term trending and analysis. By integrating capabilities within the WJHTC's R&D enclave, the program will provide common point access and service oriented capabilities to share and broker safety information for internal research projects and research partners. It will explore the use of new technologies such as NoSQL (not only SQL) to minimize the time required to integrate large amounts of data for research projects.

Map Reduce & Elasticity- Integration with both FAA and industry Cloud initiatives provides access to a wealth of on-demand computing power. Rather than procuring, installing and maintaining servers, common technologies of map reduce and elasticity will be used to allow analysts access to thousands of CPUs running in parallel to quickly and efficiently process data. Researchers will be able to provision as little or as much computing power as needed to process safety related information.

3.7 AIRCRAFT ICING

The FAA Aircraft Icing Research Program plans to initiate new research efforts in the following areas over the next ten years: New Technologies that can Reduce or Eliminate the Use of Glycol-based Deicing and Anti-icing Fluids; Self-deicing Aircraft Vertical Surfaces; Engineering Tools for Supercooled Large Drop (SLD) Conditions; Smart Icing Systems; Icing Challenges for Unmanned Aircraft; Assessment of a New Generation of Atmospheric Icing Instrumentation; and Icing Weather in the Cockpit and Down-linking of Data from Aircraft Ice Detectors The first two will be new efforts in Ground Icing research, and the second two will be new efforts in Structural In-Flight Icing. The final three pertain to New Challenges in In-flight Icing.

Ground Icing

The Icing Research Program will continue and complete research described in Section 8.2. Additional research areas will also be addressed to include New Technologies that can Reduce or Eliminate the Use of Glycol-based Deicing and Anti-icing Fluids and Self-Deicing Aircraft Vertical Surfaces. These are described below.

New Technologies that can Reduce or Eliminate the Use of Glycol-based Deicing and Anti-icing Fluids- Glycol based anti-icing fluids are used throughout the airline industry. Although effective in providing protection, they have raised environmental concerns and there are requirements, now and in the future depending on the locality, for either reduction in their use or more effective collection of the used fluid. Thus the introduction of nano-structured surfaces on aircraft to eliminate or reduce the use of anti-icing fluid, the use of super hydrophobic coatings to reduce the need for anti-icing fluid, or their replacement with non-glycol based fluids are all worthy of research. A nano-structured surface can be applied to aircraft surfaces. Oil or some other hydrophobic liquid is applied to and held within the structure of the coating. This surface inhibits ice formation in many conditions, and prevents ice that may form in certain conditions from adhering. This approach is applicable to ground and in-flight anti-icing applications.

Super hydrophobic coatings prevent water from adhering to surfaces treated with these materials, and therefore reduce ice formation and adherence. These coatings typically consist of a single active layer as opposed to item #1 above in which a layer is applied to the aircraft surface then “charged” with a hydrophobic substance which is held within the nanostructure of the initial coating. This approach also offers potential benefits for both ground and in-flight anti-icing applications.

Although there has been activity in the development of non-glycol based deicing and anti-icing fluids, none has yet been developed which has been shown to provide the protection of glycol based fluids. The effectiveness of such fluids, and operational issues related to their use, must be investigated by the FAA before they can enter operational use.

Technology development is mainly the role of industry, however the FAA can provide some initial support for the development of potentially effective approaches, and also must evaluate the effectiveness of the operational use of new technologies, including their possible impact on holdover and allowance times. The program will assess the potential of nano-structured surfaces, super hydrophobic coatings, and non-glycol fluids, and pursue those which are judged to have significant prospects for success.

Self-Deicing Aircraft Vertical Surfaces- Aircraft vertical surfaces such as winglets and vertical stabilizers do not significantly retain anti-icing fluid and, as a result, can become re-contaminated more quickly than the wings and horizontal stabilizers. These areas are considered critical aircraft surfaces and need to be aerodynamically clean at takeoff. Winglets may provide as much as five percent of total lift and the vertical stabilizer is critical to aircraft control in engine-out takeoff situations.

These surfaces may be candidates for heating via energized carbon fibers impregnated in the surface coating, or some similar process. This type of heating system would need to run on existing electrical power available on the aircraft without major alterations to the onboard generating system. These areas are much larger than leading edges which, on some aircraft, are protected from icing during flight. Although there has been some activity in developing heater blankets for use on certain wing areas subject to cold soaked fuel on susceptible aircraft, these units are too thick to adapt to non-wing surfaces. The FAA would be involved directly in or sponsor research to help get a concept moving towards a production solution, but would not fund the mid and final development stages.

Structural In-Flight Icing

As noted in Section 8.2.2, the research on 3D Ice Shapes and their Aerodynamic Effects on Swept Wings, culminating in a high quality, bench mark database, is projected to continue through 2018. In addition, research will be undertaken in Engineering Tools for Supercooled Large Drop (SLD) Conditions and Smart Icing Systems as described below.

Engineering Tools for Supercooled Large Drop (SLD) Conditions- A certification rule for flight in supercooled large drop (SLD) icing conditions, which include freezing drizzle and freezing rain, for Part 25 aircraft under 60,000 pounds and with unpowered controls is expected to be published in 2013. Engineering tools to support means of compliance for these conditions need additional improvements and new capabilities, particularly for supporting new experimental and simulation methods to address freezing rain. The aerospace industry has provided substantial comments to both the FAA and the European Aviation Safety Agency (EASA) that the new SLD proposed rules need additional means of compliance capabilities to support future certifications.

The FAA in collaboration with NASA will support research to develop and evaluate new test capabilities and test methods for means of certification compliance, as well as data and information for guidance on the use of the capabilities and methods. In addition to working with NASA Glenn in defining SLD test capabilities in the Icing Research Tunnel, the FAA anticipates working with the Army on the use of its new Objective Helicopter Icing Spray System (OHISS) to simulated SLD conditions for certification for smaller, slower aircraft.

Smart Icing Systems- The focus is to manage environmental icing condition threats to aircraft through the development of advanced ice protection concepts and on-board assessment of icing conditions by:

- Developing concepts and means of detecting, diagnosing, and assessing icing conditions and their respective threat level, and the availability of validated means and guidance for complying with linked regulations for those devices and systems.
- Supporting development and evaluation of new ice protection technologies including performance and utility of advanced thermal protection for composites and more-electric aircraft applications, and ice management systems that provide aircraft state information, reactive detection, and flight deck updating to allow better decision-making support for the flight crew.
- Examining state-of-the-capabilities for ground and airborne remote means of detecting and diagnosing icing conditions, and support the development of methods to provide a comprehensive in-situ icing weather evaluation that provides the flight crew with current and expected icing conditions and the attendant threat level to their respective aircraft.

<u>New Challenges in In-flight Icing</u>

Icing Challenges for Unmanned Aircraft (UA)- Unmanned aircraft (UA) must meet challenges to operate in civilian airspace with flight missions in icing conditions that are different than current piloted fleet operations. In order for UAs to fly in icing weather, the aircraft has to be able to provide in-situ information to the ground pilot-operator that defines its current performance, control authority margin (aircraft state information) and local icing rate. This aircraft state information and the rate of accumulation are required to determine if the UA is operating within its performance and handling qualities (HQ) margins and if there is a threat for continued exposure to the icing conditions. The National Airspace System (NAS) also needs to supply current, highly resolved regional weather information for both tactical routing and avoidance decision-making.

The current capabilities of aircraft state sensors and HQ evaluation technologies need further developmental research to deliver these capabilities and validate their use for operations in icing weather information. The FAA also has to determine where icing operations and the threats associated with these conditions to unmanned aircraft fit in the current FAA development of new regulations for the UAS.

The threat level for operations in icing with UAs is more complicated to manage than for current manned aircraft operations and needs a substantial investment of energy by an experienced, diverse team to provide guidance for new rulemaking in hardware and operations and to identify where research investments need to be made.

Assessment of a New Generation of Atmospheric Icing Instrumentation- A new generation of instrumentation for icing research and atmospheric characterization is becoming available. As was the case with the previous generation, there is a very limited market for these instruments, and consequently a need for government agencies to assess the capabilities of the instruments and develop corrections that might be needed to obtain accurate water contents and drop distributions, especially in certain special conditions. For example, substantial corrections were needed for the existing instrumentation when research flights were undertaken to obtain data in supercooled large drop (SLD) conditions. A similar situation will exist with respect to some of the instrumentation for the HIWC flights. Research on the capabilities, limitations, and necessary corrections to atmospheric icing instrumentation can be conducted much more efficiently with in-house expertise, so this research area would benefit greatly from the addition of a research meteorologist or cloud physicist with instrumentation experience to the program's staff.

Since the new generation of instrumentation will increasingly be used in certification flights, this area is important not only for assessing research data but also to certification specialists who are called upon to approve certification flight data. Pertinent Information of the instrumentation, and especially the availability of an FAA expert for consultation, can be very valuable to them.

Icing Weather in the Cockpit and Down-linking of Data from Ice Detectors- Icing information is currently available during the preflight when the pilot receives a weather brief. Once in flight, no in-cockpit icing information is available and the only method of detecting and avoiding icing conditions is for the pilot to immediately exit icing conditions, or to rely on pilot reports in the area of flight. In-flight icing information is needed in the cockpit to:

- Provide pilots of non-icing certified aircraft the needed tools to help avoid icing conditions, and

- Provide pilots of icing certified aircraft the needed tools to reduce the duration or severity of any icing encounter.

Work can be done to include in flight icing information to the weather portion of the ADS-B data stream. ADS-B weather is becoming more commonplace in the cockpit through either aircraft mounted hardware or through tablet style computers that are paired with small portable ADS-B receivers. The icing data displayed in the cockpit could consist of a combination of the latest Current Icing Potential (CIP) graphic diagnoses, graphic and textural pilot reports, and information received from ice detectors on nearby aircraft.

To create better icing condition data for sharing with other aircraft, the program can develop and implement a method to downlink in-flight icing information from ice detectors and hardware that is already installed on aircraft. Methods could include using existing on-board ACARS or ADS-B equipment. This icing information could be shared as electronic pilot reports with other ADS-B equipped aircraft and could also provide data to weather models such as the CIP.

3.8 TERMINAL AIRCRAFT SAFETY

Mid-Term Research (5 to 7 years)

In the next 5-7 years, the program will continue to bridge the gap between the identified risks in terminal area operations and effective solutions. Specifically, the mid-term research will focus on Developing Representative Stall Models for More Aircraft Types, Enhancing the Capabilities of Flight Simulators for Upset Recovery Training, and Improving Safety of Helicopter Operations in Terminal Area. Scope of these studies is described in the following paragraphs.

Developing Representative Stall Models for More Aircraft Types- Representative mathematical models of full aerodynamic stall and post-stall are crucial for effective simulator training. Such models will help expand the usable training envelope in ground-based simulators in order to meet the Congressional mandate that all commercial transport operators must provide full stall recovery training. The development of stall models is part of an evaluation project to inform the FAA and the aeronautical community on the most appropriate approach to take for teaching proper stall avoidance, recognition, and recovery techniques. Subsequent to the completion of an aerodynamic model for the Boeing 737NG, the TAS team will develop more representative stall models for additional aircraft types. Examples include:

- Envelope protected aircraft
- T-tail jet
- Turboprop

Enhancing Flight Simulator Capabilities for Upset Recovery Training- The most recent *Boeing Statistical Summary of Commercial Jet Airplane Accidents* shows that loss-of-control remains the leading cause of fatalities in worldwide jet fleet. In addition to the development of novel mathematical stall models, research will also be carried out to ensure that the training objectives can be satisfactorily accomplished. The research will focus on the following:

- Pilot-in-the-loop evaluations will determine the fidelity requirements of simulator models to satisfactorily train pilots for airplane-upset recoveries.
- A key component in many of loss-of-control events is pilot spatial disorientation. Improved pilot training in these abnormal flight conditions, including the ability of training simulators to replicate spatial disorientation, is needed to reduce loss of control accidents. The research aims to determine what types and levels of spatial disorientation can be simulated in simulators with widely varying capabilities.
- With the availability of novel models that are aiming at improving the simulator fidelity in the stall and post-stall regimes, adequate training

scenarios will be developed to enable realistic pilot training for stall recognition and recovery.

Improving Safety of Helicopter Operations- This TAS research will address the safety of helicopter operations in terminal areas. Helicopter pilots lack sufficient cues for low altitude en-route operations and maneuvering and landing in degraded visibility environments. The helicopter instrument procedure approach minimums have reached their limits with the current suite of visual aids available to pilots (displays, lighting, & marking). Although lower minimums can be achieved using Global Positioning System (GPS) Wide Area Augmentation System, lower visibility minima can only be achieved with improved visual cues. Recent developments in sensor and display technologies make it possible to achieve visual cues equivalent to those provided by conventional lighting and marking. This program will conduct research to verify and quantify the benefits of using the newly developed technologies before they can be implemented in either new standards or products. The successful implementation of these technologies will provide helicopter crews with the necessary elements for increased day or night situational awareness, minimizing the potential occurrence for both controlled-flight-into-terrain and collision with unknown obstacles.

<u>Far-term Research (8 to 10 years)</u>

Future terminal area operations will adapt to a variety of anticipated Next Generation Air Transportation System (NextGen) Operational Improvements (OI) that involve low visibility operations, optimized profile descents, time-based metering, and enhanced surface movement operations, among others. These are listed in Appendix B, Table B.1 for reference.

The improvements introduce an unprecedented level of complexity that is exacerbated by the likelihood of a mixed equipage environment. The challenge is to assure that safety is not compromised as the OI are implemented. Critical directions for far-term research include (1) evaluation of novel technologies and procedures that aim to increase the terminal efficiency, (2) identification of risks associated with mixed equipage operations, and (3) development of solutions to manage the increasing operation complexity in terminal environment. The research challenges associated with the planned operational improvement are addressed below.

Evaluation of Technologies and Procedures to Increase Terminal Efficiency- The introduction of novel technology in the cockpit and the integration of new systems will continue promoting better safety and efficiency in the terminal area operations. For example, the ability to land in low visibility/ceiling conditions will be improved for aircraft equipped with some combination of technologies like Ground Based Augmentation System, Enhanced or Synthetic Vision Systems, ADS-B and Head-Up Displays. Integration of these systems into the cockpit is proposed to improve aircraft safety and airport capacity by making it possible for pilots to see in low visibility weather conditions, or at night, on both head-up and head-down displays. It is crucial for the FAA to evaluate the benefits and limitations of the emerging technologies in terms of their symbology, flight operations and pilot interfaces. Research will be necessary to quantify how much the landing minima and visibility can be lowered and the level of operations improved using the new technologies.

Identification of Risks Associated with Mixed Equipage Operations- Navigation, as well as merging and spacing responsibilities, will move from ground infrastructure and air traffic control onto the aircraft flight deck. The goal is to apply new procedures such as RNAV, RNP, and time-based metering to enable more efficient use of runways and airspace at high-density airports. The planned evolution requires a high level of accuracy for operation within a defined airspace, and therefore includes the capability of the entire available infrastructure, navigation aids, and the aircraft. As transition into NextGen continues, mixed operations, where legacy aircraft will operate along with aircraft equipped with the latest technologies, will be commonplace. Multiple procedures and separation standards will continue to demand increased understanding and implementation. In the meantime, not all new aircraft will be capable of performing to the same navigation precision as other air carrier aircraft. New challenges will be encountered in the mixed surveillance environment, compared to segregated operations. Research to identify these limitations and constraints will ensure efficiency and safety in terminal operations.

Develop Solutions to Manage Increasing Operational Complexity- The expected increase in operation complexity associated with the growth in air traffic, introduction of new vehicle concepts, continued operation of legacy vehicles, and greater reliance on automation and data communication, will present significant challenges to the terminal area safety. To cope with these new challenges, the program will conduct research to provide the knowledge, concepts and methods to manage the increasing complexity in the design and operation of vehicles and air transportation systems, including advanced approaches to enable improved and cost-effective verification and validation of flight-critical systems. Remedial action, including flight simulator training solutions, necessary to maintain agreed safety performance will be investigated and developed. For example, new procedures such as an Optimized Profile Descent (OPD), which aims to improve the fuel efficiency, will allow an aircraft to reduce the number of level flight segments between cruise and landing. Research will be necessary to understand the impact of OPDs on stabilized approaches through improved flight simulator capabilities and training. Enhancements to surface traffic management will incorporate taxi instructions, surface movement information, and aircraft wake category to enhance departure flow operations. The airport surface will present a landscape of complexity where research into situation awareness and human decision-making will be essential to assuring that NextGen enjoys the highest level of safety, efficiency, and environmental responsibility possible.

3.9 HUMAN FACTORS

The next ten years are likely to be a transformational era for aviation, making human factors even more critical. The FAA will be modernizing the aviation system while facing increasing budget constraints, growing globalization, changing demographics of personnel and passengers, and rapid technological changes. The introduction and integration of unmanned aerial systems (UASs) in the airspace will further increase complexity. The FAA modernization of the National Airspace System (NAS) known as NextGen, proposes a transformation of many of the core systems and procedures within the NAS and a fundamental change to the way the United States will control air traffic. This transformation can revolutionize air transportation, however, with it comes uncertainty and risk. These transformational changes can critically impact the people that operate the NAS.

Over the next ten years, research will continue to reduce the risks related to mismatches between the users and the systems that they interact with and enhance the benefits of the systems. This risk reduction may take the form of identifying more efficient or usable ways of interaction or eliminating concepts or concept manifestations that could negatively impact safety or efficiency. The program will follow the same four broad areas outlined above; Fundamental Research, Translational Research, Standards and Guidelines, and Advanced Tools and Technologies. Some key expected results from these research areas are shown in Figure 1.

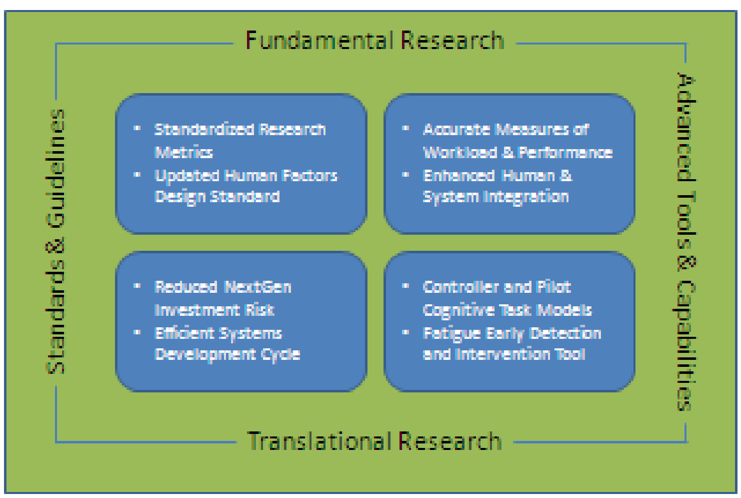

Figure 1: Key Expected Research Results

Fundamental Research

The Human Factors Program will continue to perform research that captures the physical, psychological and human performance data essential to the sound design of systems and for determining the operational performance and safety of systems.

Humans and Automation- One of the core changes throughout NextGen and the modernization of the Air Traffic Control system is the trend toward increased automation. The Human Factors Program will examine the implications of a highly automated system on the controllers, including issues such as vigilance, cognitive engagement, situational awareness, trust in automation, and overreliance. It is critical to determine the level of automation that can be realistically and safely achieved for controllers and to resolve issues related to the degradation of basic skills with the associated performance implications should automation fail. Therefore, the program will investigate how users are impacted by automation, examine the impact of alternative models for the division of responsibility, research alternate modes of failure recovery, and evaluate situational awareness under differing levels of automation.

Workload and Performance- Human performance is a key component for safe operations. Performance can vary from day to day due to many different factors; the influence of these factors is not fully understood. Accurate measurement of performance provides valuable insight on how to reduce performance variability and predict performance decrements, leading to the development of guidance materials for operational environments. The Human Factors Program will conduct research on human performance measurement, performance prediction, and behavior in decision making. In the next 10 years, the program will develop and validate improved ways of measuring user workload and performance. This research will be used to develop models of human performance for predicting the effects of various display concepts, fatigue, mental state, and work/rest cycle on performance, and will enable the development of tools for enhancing performance and balancing workload.

Information Requirements and Display/User Interaction Research- With the increasing number of new systems and equipment and the simultaneous increase in data, it is critical that the information presentation is optimized for the intended users. It is also critical that new systems are integrated effectively into the overall system. Information requirements and display research and user interaction research conducted by the Human Factors Program will facilitate system integration, improve user-system interaction, and optimize information presentation.

Data Management and Visualization- As NAS information requirements evolve, there will be a need to develop new approaches to the display of and navigation through large amounts of complex data in a way that will make it meaningful to the users. With the implementation of the NextGen concepts, there is a burgeoning need to manage the availability and efficient use of data. The White

House Digital Government Strategy[1] report calls for an "Information-Centric" approach for delivering digital services to the public, including more information available through web APIs. As more Federal Agencies are involved with the Digital Services outlined by the White House, the Human Factors Program will, as both a provider and consumer of information, identify ways to make the most of the data available, maximizing reuse without duplicating efforts.

Translational Research

Translational research requires applying the knowledge gained from foundational research to specific systems or concepts, generally in the mission analysis and investment analysis stage of the FAA lifecycle management process.

System Acquisition- The Human Factors Program will continue to provide technical, analytical and scientific guidance to support system development and acquisition of programs. According to research estimates, every $10 spent on human factors early in the systems development cycle saves an estimated $100 in later redesign. In addition, involving human factors early in the acquisition process can benefit the system usability, leading to efficiency gains as well as cost savings. Usable systems are also less likely to result in user error, a leading cause of accidents.

Concept Evaluation- The Human Factors Program will continue to evaluate NextGen concepts applying foundational research techniques to reduce end risk. These techniques will allow the program offices to identify risk before significant investment is made, saving money and development time. The evaluations can also identify and help ameliorate potential safety risks, leading to safer systems.

Standards and Guidelines

The Human Factors Program will work on updating Human Factors Standards and evaluating and validating research metrics as described below.

Human Factors Standards- Human Factors Standards have a significant influence in acquisition programs as a major source of system requirements. With increasing globalization, it is critical to update these standards to be consistent with international standards. Therefore the Human Factors Program will update Human Factors standards with efforts to harmonize them with national and international standards. To this end, a number of small scale research projects will be conducted to address the gaps in current standards and working agreements will be initiated with international standardization bodies.

Research Metrics- The US Department of Transportation Inspector General stated that "Leveraging other agencies' research is key to achieving the

[1] http://www.whitehouse.gov/sites/default/files/omb/egov/digital-government/digital-government-strategy.pdf

capabilities envisioned for NextGen." In order to leverage the research of other agencies or for them to leverage FAA research, it is critical to ensure that the research is comparable. If research metrics used in different studies or by different organizations result in different outcomes, it is nearly impossible to leverage the associated research. As a result, the Human Factors Program will evaluate and validate research metrics used in simulations in order to make justifiable comparisons of results and will develop and refine additional research metrics to ensure data validity across simulations.

Advanced Tools and Capabilities

Advanced tools and capabilities include any tool or procedure that is used to collect human-centric data, perform human factors measurements, or model human capabilities. The Human Factors Program will develop tools and techniques to increase the fidelity and effectiveness of data gathering techniques.

Cognitive Models- The Human Factors Program will pursue the use of software agents as human behavioral representations to be used as synthetic simulation pilots and air traffic controllers. The use of synthetic simulation pilots in high fidelity air traffic control simulations will directly reduce the cost of HITL experiments, enhance the fidelity of the simulation and increase the flexibility of the simulation techniques. The use of cognitive agents will provide a research device to investigate how new tools and procedures will impact ATC task models. Through the use of synthetic air traffic controllers, the program will be able to explore, evaluate and compare various design alternatives for NextGen. While models have been created in the past by other organizations, limitations have prevented wide-spread use of them in HITL simulation as suitable replacements for human actors. The program will seek to update models or create new ones to overcome these limitations.

Fatigue Measurement Tool- One of the human limitations in continuous operation and maintenance of mission critical systems is that of sleep and fatigue. As the systems become more complex, the need for fully alert operators becomes paramount. Historically, it has been difficult to measure fatigue until the effects are made evident through natural observation. Current technology and research, however, have advanced to a point where it is possible to develop tools that may detect fatigue in a timeframe that would allow for early intervention. The Human Factors Program will build on expertise gained in previous studies of fatigue using a sleep motion logger and reaction time task. Through collaboration with others both within and external to the FAA, new technologies such as EEG will be applied to data collection efforts, resulting in new tools, including a fatigue measurement tool. The resulting toolset will bring the latest advances in laboratory settings to an applied operational environment and will help the FAA address fatigue-related risk.

Modeling and Simulation- The NextGen system will bring about an evolution of the NAS from a collection of standalone systems into a complex integrated system of systems. To fully understand the implications of operational improvements, systems can no longer be tested in isolation. As a result, the Human Factors Program must grow the simulation capabilities to match the need.

As the systems grow in complexity, so do the roles of the human actors in the systems. Just as the systems work in cooperation, the human actors must work in collaboration. The roles of controllers and pilots will change, as well as the team collaboration between controller and pilots and even between controllers. In order to understand and help define these roles, the Human Factors Program must develop the capability to simulate the complex systems of systems. To this end, the program will pursue the development of Air/Ground integration simulation capabilities.

3.10 DIGITAL AND ELECTRONICS SYSTEMS

Introduction

The strategic direction of the research for digital and electronics systems is depicted below in the Research Roadmap. This depiction clearly shows the traceability of the mid and far term research drivers that are planned for the current research

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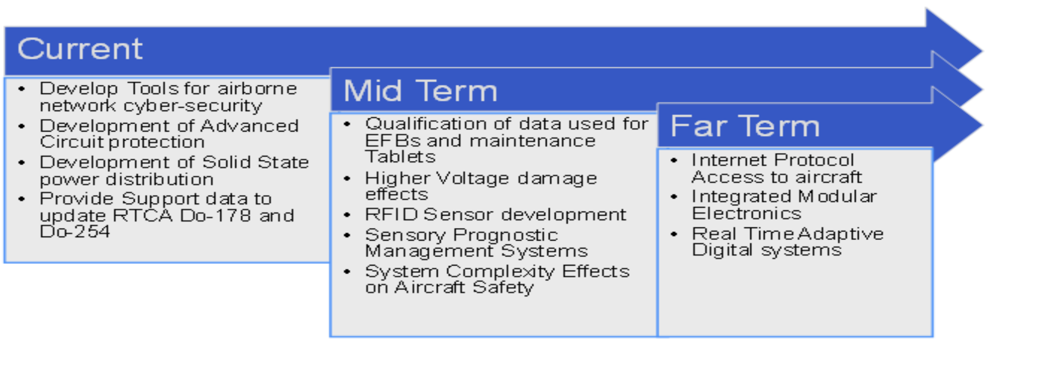


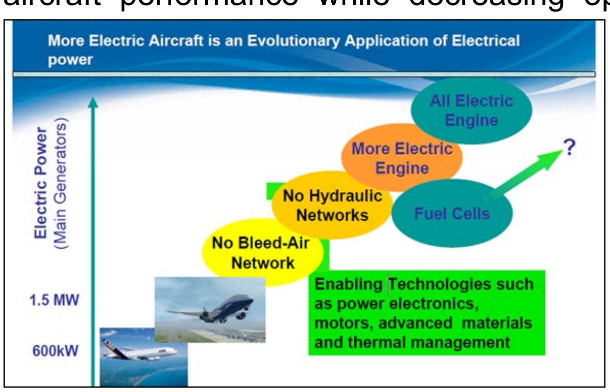
Strategic Research Roadmap - Current, Mid Term (5 to 7 years), Far Term (8 to 10-years)

Mid and far term research drivers will focus on assuring current safety levels are maintained or exceeded as the FAA transitions to newer electrical and digital technologies. Early research programs were driven by aircraft accidents and incidents and then by the introduction of new rule making. Using a more proactive approach the proposed mid and far term research is driven by industry trends and new technology. There are 3 major influential trends driving the mid and far term research; with all of these trends having a human factors component:

- More Electric Aircraft
- Introduction of NextGen, and;
- E-enabled Aircraft

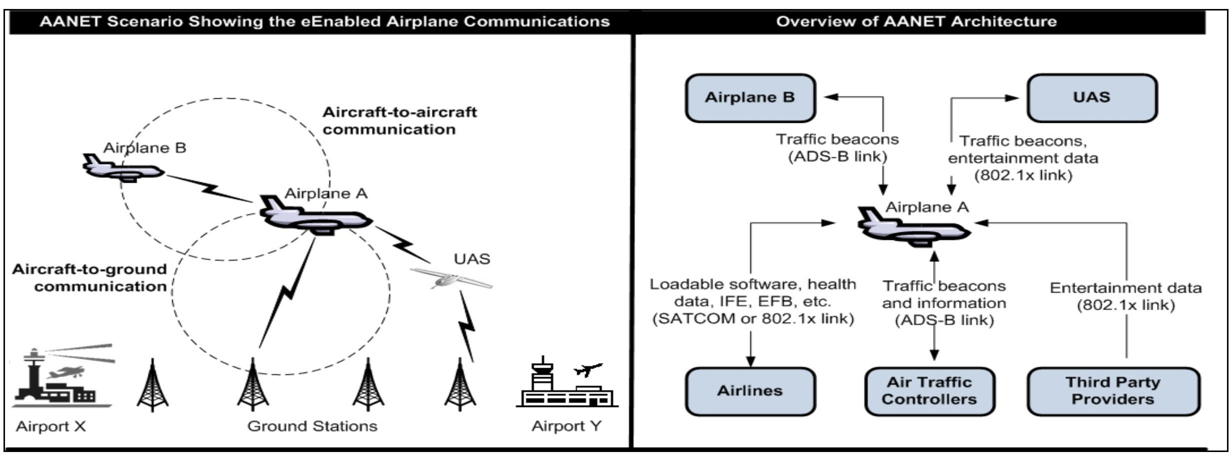
*Note: each trend is described below

More Electric Aircraft: Aircraft manufactures are always trying to optimize aircraft performance while decreasing operating and maintenance costs and reducing environmental impacts. This optimization has pushed the airline industry to break away from traditional systems and install more efficient electrical powered systems onboard their aircraft. The general trend in aircraft manufacturing has been a steady increase of electrical components and more complex



digital avionics. The amount of power generated on all transport aircraft has doubled with each new design from a median of 100KVA to 1.45MVA on the Boeing 787. As the electrical loads have increased, the amount of wire onboard the aircraft has proportionality increased and now measures hundreds of miles. The effects of this trend have been to break with traditional aircraft power and voltage designs and move towards power systems that have higher voltages and wider frequency ranges. The current design of the Boeing 787 has employed 230VAc wide frequency, +/- 270VAc along with traditional 400Hz 115VAc and 28VDc. These new potentials allow the use of smaller wire gauges by carrying smaller currents and thereby reducing wire weight which could save fuel costs. Additionally, the 787 has also eliminated several engine driven hydraulic systems and replaced them with electrical equivalents.

<u>Introduction of NextGen:</u> Over the next five to ten years NextGen will introduce several complicated safety critical digital systems on the aircraft for air to ground communications that will drive our research. Many of these will require access to onboard systems that were once isolated and may require onboard servers to be hardened for cyber security. The main effect of E-enabled NextGen airplane communications is predicted to be to the aircraft-to-aircraft, aircraft-to-ground and flight management systems and is depicted in the diagram below.



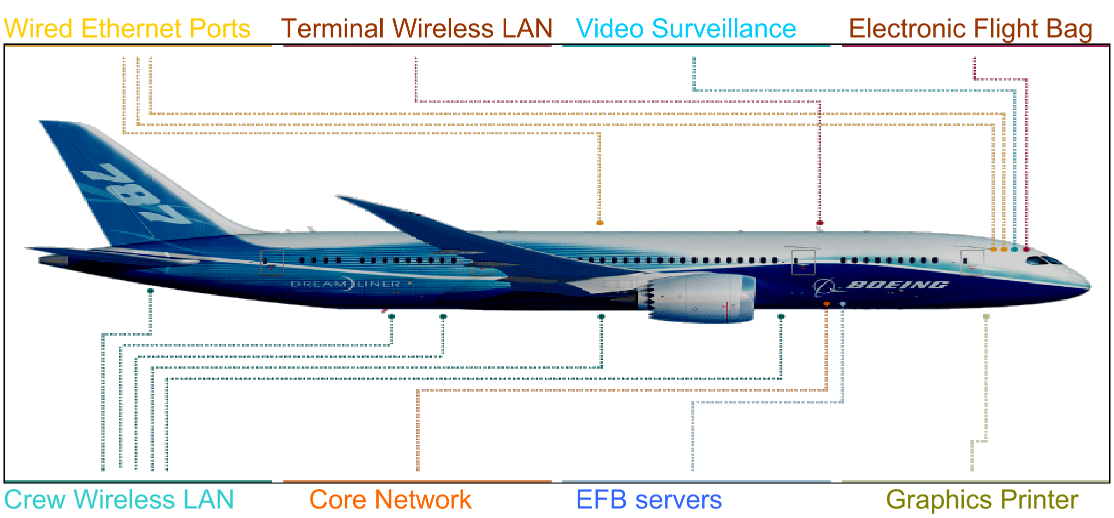
The Aviation Safety (AVS) NextGen work plan shows the following systems that are to be installed in the future on aircraft: Flight management systems with auto clearance acceptance, NextGen satellite communication systems and a revision to Flight Information Services-Broadcasts (FIS-B's).

Destination 2025 states that one of the outcomes is "air navigation infrastructure and associated systems that are flexible, reliable, cost effect and secure" and a strategy is to "implement automated NextGen architecture systems that provide secure, timely, and accurate information for all equipped system users." This trend will become a major driver in the FAA's future research efforts.

The e-Enabled Aircraft: The e-Enabled aircraft will allow more operational flight information such as weather, Notice to Airmen (NOTAMs) and conditions at destination airports to be up linked to aircraft. Pilots and flight crews will spend less time transcribing voice reports and more time managing the flight. The Original Equipment Manufacturers (OEMs) are supplying Internet protocol (IP) driven networks to:

- Minimize data entry (and eradicate re-entry/human induced error).
- Standardize processes for greater consistency
- Automate and integrate manual tasks

Using these secured IP networks, new aircraft functions will be automated for efficiency in the cockpit and in cabin and aircraft maintenance operations, thereby, facilitating many new on-board user applications. This open architecture will present many challenges to current FAA certification processes and therefore will require additional research. The B787 incorporates a number of e-Enabled systems, many of which are being implemented for the first time on a commercial airplane and are depicted in the diagram below.
These drivers provide the basis for the proposed mid and longer term research initiatives described in the following paragraphs.



Mid-term Research Initiatives (5 to 7 years)

Qualification of Data Used for EFBs and Maintenance Tablets- Flight Management Systems and the associated airplane flight systems are the primary navigation tools on board today's commercial airplanes. The evolution of these systems has led the way for performance-based navigation and the NextGen Implementation. Aircraft digital electronics (ADS-B, Electronic Flight Bags, Synthetic Vision and other automated systems) are major enablers for the FAA's planned implementation of NextGen. The NextGen System's and Europe's Single European Sky Air Traffic Management (ATM) Research (SESAR) advanced airspace environments, will transform the current ground-based Air Traffic Control (ATC) system to an aircraft centric satellite-based system. With NextGen, neural networks and cloud computing on the horizon, core research areas are rapidly changing, and are increasingly becoming more complex and pervasive. The accuracy and reliability of data will be the key to safe trajectory based operations for aircraft. This will require the aircraft systems to be further integrated and interdependent. This complexity will provide unique challenges to certification and validation of these systems. Research will be required to ensure that the addition of various new data sources to interface into the weather, mapping and trafficking systems is properly validated, verified and secured.

Higher Voltage Damage Effects- As electrical systems have replaced some traditional hydraulic and pneumatic systems on the aircraft the Original Equipment Manufacturers (OEMs) are requesting to install higher voltage potentials to reduce overall wiring weight and improve efficacy. The existing potentials on aircraft have traditionally been 115VAc 400Hz and 28VDc, and, while these are still being utilized, the potential need on-board now requires 270VDc, 540VDc and 230VAc. Our research has recently characterized standard potentials for arcing and other potential damage regarding this increase. These new potentials in the mid-term require research on their long term use and interaction with the other potentials in the power distribution system. The Advanced Free electron Laser (AFEL) will be upgraded to be able to perform destructive testing on the higher voltage potentials. Our mid-term research will also be collaborated with the Department of Defense (DOD), NASA and the Society of Automotive Engineers (SAE) to ensure the component testing for wire and connectors are adequate for long term exposure to the higher voltages. The AFEL is also envisioned as being utilized to explore the different protections technology these unique systems require.

Sensory Prognostic Management Systems (SPMS)- The FAA's research into the existing on-board solid state power distribution system recognized that the computing power was being under-utilized. These solid state systems were designed to meet aircraft safety Level A certification redundancy requirements. Level A certifications require a great deal of redundancy, which created a lot of idle computing power on-board that could be utilized, while not compromising safety. The OEM's and operators determined they could run SPMSs on the idle computing power and utilize this application to capture real time data to improve on their designs and increase maintenance efficiency. Over the next five years our research will address how this real time data can be used to identify hard landings, improve on Full Authority Digital Engine Control (FADEC) trouble shooting, and provide common interfaces to reduce cost of implementation of SPMSs and similar systems to generate the prognostics. The output of this research will affect the way data can be utilized for life limited parts and reduction of unscheduled maintenance. Our research will also explore the certification issues associated with using SPMS data to modify life limited part replacement and maintenance intervals to be more cost efficient without compromising safety.

Radio Frequency Identification (RFIDs) Sensor Development- As the demand for more data to monitor the status of the aircraft's structural and system's health increases there are many situations that require a sensor for an intermittent issue or a safety inspection. RFIDs are currently utilized in industry to provide an inexpensive low power sensor for this type of monitoring. There are generally two types of RFID tags: active RFID tags, which contain a battery and can transmit signals continuously without exterior prompting, and passive RFID tags, which have no battery and require an external source (an interrogator/reader) to activate the tag and read the stored information. The main advantage of the active RFID tags compared to passive tags is their longer read range capability. However, the requirement of a battery (even printed batteries or energy-scavenging systems such as those from Cymbet, Elk River, MN) increases the weight, cost and complexity of the tag modified for use in the RFID sensors. This research will explore the use of RFID sensors for structural health monitoring, power system integrity, and the utilization of RFIDs as monitors for fire, chemicals, or corrosion in hidden areas of aircraft.

System Complexity Effects on Aircraft Safety- As the electronic content on aircraft increases, on-board systems will be more interdependent and require more interaction. This interaction will exponentially increase the difficultly to isolate effects utilized by the FAA for risk analysis. In-flight critical systems, redundancy and segregation are two of the most important factors in risk mitigation. The tools utilized by the FAA that model these systems have to adapt and simulate these increased interactions to identify problems early in the design to truly verify these complex systems behaviors. The proposed plan will require the research to fully understand the advantages and limitations of these advanced modeling tools.

This research program will additionally explore the development of standards for durable systems and building block components for aircraft systems. Durable systems are stronger and are designed to last longer than previous versions. Manufacturers will be developing these more durable systems and improved building-block components to enhance the safety, capability, and sales of their equipment. The FAA needs to keep pace with the improvements for proper oversight. Newer methods of development by the manufacturers will require the research to provide proper and accurate oversight for these new methods and systems.

Far term - Research Initiatives (8 to 10 years)

Internet Protocol (IP) Access to Aircraft- The greatest advancement in aircraft avionics will be the ease of access to real time data and the associated increase in bandwidth in the digital aircraft of the future. Utilizing these new IP based applications, it is projected that the digital aircraft will be integrated with ground systems for operations, air traffic control and maintenance. The cockpit will be fully integrated with ground systems to provide the flight crew with up to the minute weather, air traffic and NOTAMS. One of the challenges is that many of today's software development environments include bloatware of unused libraries and subroutines that could be exploited, another challenge is that as the demand for on-board information increases allocated bandwidth may reach a saturation point. These are just two examples of theoretical problems that could have an impact. Our proposed research will be conducted to ensure this digital aircraft of the future is implemented with the same or better level of safety that is implemented today. Research will be conducted to provide methodologies to ensure the data feeding these systems is secured and partitioned and is via a qualified and identifiable source. It is very important that data driving these systems becomes standardized so the system can be evaluated for accuracy. It is also important that the processes and procedures for addressing issues when a data conflict arises is standardized so as to act in a predetermined manor for safety assessment.

It is conceivable in the far term that the FAA will have certification software that will exercise and validate this software as part of the certification process. Our vision is that the aircraft will have a digital twin that various software and embedded systems can be tested and verified prior to being certified. The increased complexity of digital devices requires machine generated code to fully exercise the circuits to search for anomalies. Once the digital twin is verified the FAA can use this modeling tool as a basis to verify system performance and validate hardware and system modifications prior to certification.

Integrated Modular Electronics- The common core model B787 has a "Common Core System" that was developed by General Electric (GE). This movement towards a common core of integrated modular electronics will increase in future years. Several of the embedded systems that contain micro controllers will be used as functions to the common core system and both software and hardware partitions will isolate functions for safety. This will allow a new aircraft function to be added with just a software application. This integrated modular electronics design will present a challenge for FAA certification since a new aircraft function can be initiated with only a software change. Industry currently has specifications for the deployment of software configurable parts (ARINC 665-3, ARINC 667, DO254-ED/80 and others). Our vision is to perform research to assess the impact of current designs (Boeing 777, 787, AIRBUS A-380, A350) and to provide guidance for certification of future configurable designs.

Real Time Adaptive Digital Systems- With the addition of real time data and the redundancy to make systems meet acceptable reliability requirements, it is very conceivable to have systems on board aircraft that can identify a problem and self adapt to the current fault mode. NASA has been working for several years on adaptive flight controls and it is conceivable that the FAA will need to follow suit. These adaptive flight control systems require the full integration of the engine automatic controls as well as adjusting the fly-by-wire flight control system. The system, when it recognizes a fault, will utilize all the aircraft systems that are at its disposal to provide the pilot a way to control the aircraft by normal operator input, but will stress the aircraft in an unknown way. These systems will provide the FAA with many unique certification challenges that will require many research initiatives. Our vision is to perform research on these systems and recommend a major re-write of the current rules for FAA critical systems design. As of today the utilization of these adaptive flight controls would violate most of the current rules for FAA critical systems design certification. In addition research would address the effects of these systems on the continued airworthiness of the aircraft.

APPENDIX A
SIGNIFICANT ACCOMPLISHMENTS SUMMARY

PROGRAM AREA	SIGNIFICANT ACCOMPLISHMENTS
FIRE RESEARCH	• Reduced the risk of in-flight fires by developing hidden fire detection and extinguishment systems and firefighting methods • Facilitated the introduction of fuel cell technology by developing fire protection means for stored hydrogen • Developed fire safety design criteria for blended wing body aircraft and commercial space transportation vehicles that significantly reduced the risk of fire
PROPULSION AND FUEL SYSTEMS	• Developed process to predict and detect material defects in turbine engines • Instituted new flammability standards for aircraft seats
ADVANCED MATERIALS AND STRUCTURAL SAFETY	• Supported the development of policies, guidance and advisory materials for aircraft structures fabricated from composite materials • Established Internationally recognized standards for composite material testing; materials qualification and shared property databases • Developed Training Requirements for large scale use of composite materials in aircraft structure
CONTINUED AIRWORTHINESS	• Supported the development of rulemaking including: o Aging Aircraft Safety o Damage Tolerance for Repairs and Alterations o Responsibilities and Requirements for Implementing Part 26 Safety Initiatives
CATASTROPHIC FAILURE PREVENTION	• Developed the aircraft vulnerability assessment process • Using "Certification by Analysis" for engine certification: o Developed new material modeling capability for *failure* prediction o Developed new engine fabric containment material models
SAFETY INFORMATION MANAGEMENT AND ANALYSIS	• Supported development of ASIAS infrastructure • Deployed NAS Enhanced Repository Server • Developed System Performance Analysis System (SPAS) Performance Measures and Risk Indicators • Developed ATO Safety Future Concepts and Shortfalls • Created an Airport Complexity Risk Index Prototype • Developed causal and risk models for Flight Standards' System Approach for Safety Oversight (SASO)
AIRCRAFT ICING	• Developed extensive test data and analysis of aerodynamic effects of ice on airfoils • Characterized icing conditions in super-cooled large drop conditions within and below clouds • Identified the effect of anti-icing fluid, uncontaminated and contaminated, on aerodynamic performance
TERMINAL AREA SAFETY	• Improved stall and upset recovery training • Improved safety in low visibility operations • Reduced risk caused by inappropriate simulator training • Improved operations on slippery runways
HUMAN FACTORS	• Developed Human Factors Design Standard • Developed high fidelity human-in-the-loop ATC simulation capability with integrated workload and performance measurement tools • Identified needs to go into integrated Concept of Operations for NextGen Systems • Identified shortfalls in current TFM systems that need to be addressed in new NextGen systems through human factors shortfall analysis • Facilitated the integration of new features in operational systems in a way the enhances system usability • Evaluated new NextGen concepts for risks • Developed human factors requirements for NextGen Systems
DIGITAL ELECTRONICS AND ELECTRICAL SYSTEMS	▪ Supported the development of rulemaking for Enhanced Airworthiness Program for Airplane Systems (EAPAS) with 12 Advisory circulars • Developed Handbooks for o Selection and Evaluation of Micro-processor in airborne Systems, and; o Data Network Criteria

APPENDIX B
CURRENT PROGRAMS AND EXPECTED BENEFITS

PROGRAM AREA	CURRENT PROGRAM	EXPECTED BENEFIT
FIRE RESEARCH AND SAFETY	Unprecedented planned rulemaking to completely revamp the FAA flammability regulations for interior materials	New flammability test standards for hidden area materials and new material applications
	Growing incidence of lithium battery fires in aviation, primarily in cargo shipments	Fire resistant lithium battery packaging
	Recent two fatal freighter fire accidents and predicted risk of even more fire accidents over the next ten years	Cost effective fire suppression systems for freighter aircraft
PROPULSION AND FUEL SYSTEMS	Damage Tolerance	Ensure structural integrity of critical rotation engine parts in turbine engines throughout their service life.
	Unleaded AVGAS	Safely transition the General Aviation aircraft fleet to an unleaded fuel.
	Non-Destructive Evaluation of critical engine components	Ensure the structural integrity of critical engine parts throughout their operating life.
ADVANCED MATERIALS AND STRUCTURAL SAFETY	Assessment of fatigue and damage tolerant characteristics of composite aircraft structures	Methodology, protocols and general information on the design, manufacture and operational safety of composite structures providing equivalent safety to traditional airframe construction.
	Characterization of bonded structures for aircraft manufacture and repair	Criteria for the repeatable and reliable manufacture and repair of aircraft structure
	Development of a body of knowledge on composite materials use in aircraft structures	Provide information to existing engineering, manufacturing and maintenance infrastructure on differences in composite airframe structure from traditional ones.
CONTINUED AIRWORTHINESS	Flight Controls and Mechanical Systems	Develop Stall Characteristics for multiple transport category aircraft leading to enhanced pilot training Enhance Flight Displays for Stall Warnings
	Rotorcraft Systems	Revise AC 29-2C, MG-15, Airworthiness Approval of Rotorcraft Health Usage Monitoring Systems (HUMS) Technical data for use in developing guidance in the use of advanced flight control systems
	Structural Health Monitoring (SHM)	Develop SAE ARP for the use of SHM on transport category airplanes
	Structural Integrity of Emerging Metallic Technologies	Ensure the safe and efficient implementation of emerging metallic technologies (e.g. new metallic alloys, advanced joining techniques, hybrid construction) in airplane products
	Maintenance and Inspection Technology	Inspection methods to ensure the continued airworthiness of adhesively bonded structures. Improve inspection procedures, guidance, and training to detect and characterize composite laminate impact damage. Develop guidance on using inspection methods to characterize and repair thermal damage of composite structures.

PROGRAM AREA	CURRENT PROGRAM	EXPECTED BENEFIT
AIRCRAFT CATASTROPHIC FAILURE PREVENTION	Advanced Analysis Methods for Rotorburst and Fan Blade Out	Ability to predict test results across a wide range of failure conditions with a single material model
	Develop and demonstrate material test procedures necessary to populate new material models	Demonstrate test program required to use new tabular material models effectively.
	Develop quality assurance processes and user guidelines for analysis of aerospace impact problems	Standardize a set of problems that demonstrate modeling capability to establish a baseline for certification by analysis
SAFETY INFORMATION MANAGEMENT AND ANALYSIS	NextGen SWIM on-ramping and safety services development	Secure access to enterprise safety information within and external to FAA
	Enhanced Repository Service	Integration with current and future ASIAS capabilities
	Facility Risk Assessment Tool for AOV inspectors	Reduce duplicate safety-related software development efforts
		Standardized enterprise safety measures
	Integrated domain assessment of future system for AOV's strategic oversight of NextGen systems integration	Increase capabilities to integrate and analyze information from multiple sources to support AOVs oversight activities
AIRCRAFT ICING	High Ice Water Content Ice Crystal Threat to Engines	Reduce threat to current and future designs
	Ground Icing	Greater safety and efficiency entering the NextGen era.
	Develop Experimental Database of Ice Shapes and Aerodynamic Effects on 3D Swept Wings	More efficient and thorough (because more critical cases can be examined using CFD tools verified with database) certification of swept wing aircraft
TERMINAL AREA SAFETY	Develop models that enhance the ability to use advanced flight simulators for advanced maneuvers	Reduce fatalities due to loss of control accidents Determine required simulator modeling to train stall and upset recoveries in accordance with August 2010 public law
	Determine available runway friction level from airplane data	Reduce accident rate due to runway overruns and veer-offs Improve runway utilization in adverse weather conditions
	Develop simulator motion cueing criteria	Minimize inappropriate simulator training for pilots Reduce the attribution of unsatisfactory motion cueing as a contributing factor in NTSB accident reports
	Develop stable approach criteria	Reduce accident rate due to runway overruns and veer-offs Respond to NTSB recommendations to define detailed parameters for a stabilized approach

PROGRAM AREA	CURRENT PROGRAM	EXPECTED BENEFIT
HUMAN FACTORS	Fundamental Research	Improve NextGen Workstation requirements through prototyping efforts
		Data to support Fatigue Risk Management policies through Technical Operations Field Study
	Translational Research	Improve usability and more effective tools for TFMS
		Validate NextGen concepts through ATC Human-In-The-Loop Simulation
AVIATION SOFTWARE, ELECTRONICS AND DIGITAL SYSTEMS ASSURANCE	Advanced Circuit protection	Reduction in the amount of electrical damage during Arcing events
	Cyber Security	Provide insight into vulnerabilities of aircraft network systems to update and amend policy, rulemaking, guidance, and training for cyber security.
	Development of Solid State Power distribution	Provide Aircraft Certification personnel with information on the design trade-offs, benefits and weaknesses of solid state switching.
	Support to Update Do178 and Do254	Provide updates to changes in technology and streamline certification issues without compromising current safety levels.

APPENDIX C
AVIATION RESEARCH DIVISION STRATEGIC PLAN