FY 2016 R&D Annual Review

April 2017

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INTRODUCTION

The FAA uses Research and Development (R&D) to support policy and planning, regulation, certification, standards development, and modernization of the National Airspace (NAS). The FAA R&D portfolio supports both the day-to-day operations of the NAS and the development of NextGen. To achieve balance between the near, mid, and far-term, the FAA has defined three R&D principles. The R&D principles help the FAA align, plan, and evaluate its R&D portfolio. The R&D principles are:

- **Improve Aviation Safety** – systematically expand and apply knowledge to produce useful materials, devices, systems, or methods that will improve aviation safety and achieve the lowest possible accident rate.

- **Improve Efficiency** – systematically expand and apply knowledge to produce useful materials, devices, systems, or methods that will improve access to and increase the capacity and efficiency of the Nation’s aviation system.

- **Reduce Environmental Impacts** – systematically expand and apply knowledge to produce useful materials, devices, systems, or methods that will reduce aviation’s environmental and energy impacts.

The Annual Review is a companion document to the National Aviation Research Plan (NARP). This report highlights selected completed projects by various entities within the FAA research community. These projects benefit the American flying public by significantly contributing to aviation safety, efficiency, and environmental sustainability. A more comprehensive account of research activities, including the status of project milestones, can be found in the NARP.
R&D PRINCIPLE 1
IMPROVE AVIATION SAFETY

Systematically expand and apply knowledge to produce useful materials, devices, systems, or methods that will improve aviation space safety and achieve the lowest possible accident rate.
ADVANCED MATERIALS/STRUCTURAL SAFETY RESEARCH CONDUCTED

Develop Standards and Methods to Characterize Dynamic Properties of Composite Material Systems

The use of composite materials, which can simply be thought of as a combination of two or more materials (i.e., fiberglass), is quickly becoming an alternative to the use of traditional materials such as wood and metal. Typical composite materials for aircraft use include carbon and glass fiber reinforced plastic, metal hybrids and ceramics. Many of the existing material properties and behaviors/responses of composites have been characterized at what is considered quasi-static or relatively slow loading conditions. In addition many of the existing tests performed to determine these properties and behaviors cannot be used as is to determine results at faster loading rates/conditions. Therefore there exists limited research, standardized protocols, and information regarding the dynamic properties and behaviors (e.g., high strain rate sensitivity and failure characteristics) of composite materials.

The overall research effort was focused on developing and evaluating a test methodology/apparatus and a force measurement method that would accurately determine composite material properties under dynamic conditions. This particular effort was focused on tensile (tension) dynamic loading conditions using a servo-hydraulic test machine (load frame).

Due to interaction of the load frame dynamic response being super imposed on the load frame force measurement load cell signal the actual applied load is inaccurately measured. Therefore a force signal correction methodology was developed to correct for this effect. To evaluate the test methodology and the force correction methodology a round robin exercise was performed by several participating research institutes. The accompanying figure shows the effect of the load frame influence on the force load cell signal.

![Figure 1: Effects of Load Frame Influence on the Force Load Cell Signal](image-url)
The study developed and demonstrated methodologies to determine material properties of composite materials under dynamic tensile loading conditions using servo-hydraulic test machines. These methodologies can also be used in other scenarios (e.g., compression and bending etc.) to determine additional dynamic material properties. The study also made recommendations on test procedures and other considerations to improve the quality of the measured data. The results of this study will be used to support the development of standardized test methods to determine dynamic material properties of composite materials.

AEROMEDICAL RESEARCH CONDUCTED

Selective Serotonin Reuptake Inhibitors (SSRIs) by the Pilot Population

The Numerical Sciences Research Team of Civil Aerospace Medical Institute (CAMI) described the use of SSRIs by the pilot population. Selective Serotonin Reuptake Inhibitors was a disqualifying medication for U.S. civil pilots before April 5, 2010. After this date, an FAA policy was created that allowed airmen, on select SSRIs, a pathway to hold a valid medical certificate.


Figure 2: The Use of SSRI Medications May affect Human Performance in-Flight (image obtained with permission from Aeroweb)
AIR TRAFFIC CONTROL/TECHNICAL OPERATIONS
HUMAN FACTORS RESEARCH CONDUCTED


FAA Order 9550.8 Human Factors Policy requires that FAA programs and activities address human factors through systematic integration into planning and execution of all elements and activities associated with system acquisitions and system operations. HF-STD-004 is the primary tasking document used for specifying human factors engineering efforts during system acquisition. The revised standard FAA HF-STD-004A Human Factors Engineering Requirements, published in September 2016, defines the requirements for a vendor to implement a successful human factors program as part of a system acquisition.

The revision of HF-STD-004 aligns the process with the FAA Acquisition Management System, making it possible to better integrate the human factors engineering process with the system acquisition process as a whole. The updated document reflects the increasing importance of data in system development. The document includes new Data Item Descriptions that provide guidance on how to handle and record data critical to the human factors engineering efforts so that information critical to operational success does not get lost or mishandled. Based on lessons learned from past acquisition programs, the revised HF-STD-004 also contains a new Human Factors Engineering Closeout Report Data Item Description designed to ensure that human factors engineering risks are clearly identified, and addressed prior to system deployment.
Figure 3: At Acquisition Management System (AMS) Solution Implementation Phase, FAA HF-STD 004A Mandates and Guides the System Integration Contractor’s Robust Human Factors Program

The development of major systems in the FAA relies heavily on the involvement of both government and contract personnel. The revised document contains contractual language to ensure vendors address human factors in the acquisition management system, potentially increasing efficiency. Several benefits can be expected when human factors principles are applied early in the lifecycle acquisition management process, including increased performance, safety, and productivity; decreased lifecycle staffing and training costs; and better integration of human factors into the program’s strategy, planning, cost and schedule baselines, and technical trade-offs. Although it uses language appropriate for contracts, the standard could also be used to guide government-conducted human factors tasks. The document is published in the FAA Technical Library at http://www.tc.faa.gov/its/worldpac/standards/faa-hf-std-004a.pdf.
AIRCRAFT CATASTROPHIC FAILURE PREVENTION RESEARCH CONDUCTED

Complete MAT224 Anistropic Metal to Account for Cold Working and Directional Manufacture

George Mason University working with Livermore Software Technology Corporation (LSTC), National Aeronautical and Space Administration (NASA), and the FAA has completed development of a new metal failure model that can accurately model anisotropic material. When the model was implemented into LS-DYNA it was given a new number rather than making it an option in MAT224. The new number and title is MAT_264: *MAT_TABULATED_JOHNSON_COOKORTHO_PLASTICITY.

Anisotropic materials present different responses when strained in different directions. Creating computational Finite Element Models (FEM) which can capture this behavior is important because lightweight aerospace metals such as Aluminum-2024 (Al-2024) and Titanium-6Aluminum-4Vanadium (Ti-6Al-4V) may exhibit anisotropic effects which develop from the residual stresses in plates from rolling in the manufacturing process. Aerospace manufacturers and the FAA need robust computational models which can predict the deformation and failure of these materials in the event of uncontained turbine engine failure.

MAT_264 includes tabulated input for the rolling direction, identified as zero degrees and also data for 45 degrees, 90 degrees and through the thickness (see figure 4). This effort has built upon the recent development work of an isotropic material model, MAT_224. In addition to tabulated input for each direction, MAT_264 also includes strain rate and temperature dependency, damage, failure; asymmetric tension and compression yield, as well as mesh regularized failure. These features are essential for accurately modeling the engine fragments which can impact the aircraft during an uncontained turbine engine failure. The in plane anisotropy is shown in the comparison of MAT224 output which is symmetric compared to MAT264 output with the asymmetry (see figure 5). MAT_264 is being fully implemented in the FEM commercial software LS-DYNA made by LSTC. The effort concluded with a Ph.D. thesis which will be published as an FAA report on the material model.
The red, green, and blue curves correspond to the experimental data from the red, blue, and green samples cut from the plate in the zero degree, 45 degree, and 90 degree directions with respect to the rolling direction. The MAT_264 anisotropic material model (black curves) is able to accurately match the experimental data for all directions. This is a significant improvement in capability since an isotropic model would only be able to match one direction, not all of them.
Figure 5: Stress Directionality in Anisotropic Models

The anisotropic model (bottom) shows clear stress directionality when compared with isotropic model (top) which has the same stress in all directions. The anisotropic model has a greater stress in the zero and 90 degree directions and less stress in the 45 degree direction. The anisotropic model simulation results are consistent with experimental results in Ti-6Al-4V 0.25 inch plate samples.

AIRPORT COOPERATIVE RESEARCH PROGRAM (ACRP) RESEARCH CONDUCTED

*Develop a Toolkit to Assist Airports in Effectively Planning for, Responding to, and Recovering from Significant Weather Events*

The objective of this research was to develop a guide and toolkit that (a) raises airport operator awareness about vulnerabilities caused by significant weather events; (b) helps airports develop more robust contingency and recovery plans, in addition to their airport emergency plans; and (c)
describes impact prevention and mitigation strategies. It is based on a review of the historical weather data and impacts, as well as best practices and lessons learned from airports’ responses to recent significant weather events to assist airports in effectively planning for, responding to, and recovering from significant weather events by addressing airport infrastructure, safety, security, emergency management, operations, maintenance, business continuity, financial, and environmental issues.

The Excel-based Airport Weather Advanced Readiness (AWARE) Toolkit first helps airports identify significant weather event types they may prepare for, drawing on historical weather data relevant to the airport’s specific location. AWARE also contains seven readiness modules that allow the user to review best practices for preparing for these different weather events, assess their readiness for those events, and generate customized checklists for preparing for and recovering from weather events. The seven modules are: Administration & Finance, Planning & Environment, Airfield Operations, Terminal Operations, Ground Transportation and Parking, Safety and Security, and a consolidated streamlined version of the full toolkit for small airports. The Toolkit also contains the Impacts Tracking Module - a tool to help airports track the costs and other impacts of weather events (e.g., flight delays) over time as events occur.

The research team distributed a Significant Weather Impact Survey which sought to understand how airports throughout North America are impacted by significant weather events as well as their readiness for such events. The team conducted interviews with 15 airports and developed case studies from these airports. The report has been published and the Toolkit, a Toolkit overview, a brochure, and other supplemental information are available at: http://www.trb.org/Main/Blurbs/174950.aspx.
Statement of the Problem

In an effort to increase situational awareness among pilots and vehicle operators at U.S. civil airports, the FAA Office of Safety and Standards Airport Engineering Division has proposed updating its standards for runway approach hold position signage and marking based on recommendations proposed by the FAA Approach Hold Workgroup. The Airport Safety Research and Development Branch was tasked with evaluating the safety and effectiveness of the recommended signs and markings. Operational evaluations were then conducted at three airports: Chicago O’Hare International Airport, Nashville International Airport, and Cleveland-Hopkins International Airport.

AIRPORT TECHNOLOGY RESEARCH PROGRAM (ATRP) RESEARCH CONDUCTED

Report Published on the Findings of the Approach Hold/Runway Safety Area (RSA) Study

In an effort to increase situational awareness among pilots and vehicle operators at U.S. civil airports, the FAA Office of Safety and Standards Airport Engineering Division has proposed updating its standards for runway approach hold position signage and marking based on recommendations proposed by the FAA Approach Hold Workgroup. The Airport Safety Research and Development Branch were tasked with evaluating the safety and effectiveness of the recommended signs and markings. Operational evaluations were then conducted at three airports: Chicago O’Hare International Airport, Nashville International Airport, and Cleveland-Hopkins International Airport.
It was found that a majority of aircraft and ground vehicle operators agreed that inclusion of the departure runway increased situational awareness and that the signs were understandable at an adequate distance. However, some aircraft and ground vehicle operators did report the additional information made the signs more difficult to understand. This indicates the meaning of the proposed signage and surface marking may not be intuitive for some aircraft and ground vehicle operators without additional training and familiarization. It was found that the level of Air Traffic Control (ATC) workload initially increased at the Chicago O’Hare International Airport after the signage was installed, but decreased over time as aircraft and ground vehicle operators become more accustomed to the changes. The survey data show the proposed signage and Pattern B marking increased awareness that stopping at approach hold locations was conditional on explicit ATC instructions rather than mandatory. It is recommended that this signage be installed as a pair of separate sign units with full-sized legend text. The energy and maintenance costs for airport operators are projected to be proportional to the size of the proposed signs installed. It is advised that extensive pilot and vehicle operator education and outreach be conducted prior to the proposed changes going into effect. In April 2016, the findings of the approach hold/runway safety study were published in report number DOT/FAA/TC-16-26 titled, "Evaluation of Enhanced Visual Cues for Runway Approach and Runway Safety Areas.”

**CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD) RESEARCH CONDUCTED**

**FAA Cybersecurity Threat Model**

MITRE CAASD partnered with the FAA to address the need for an agency-wide cybersecurity threat model. The cybersecurity threat model is intended to help the FAA make informed decisions regarding cybersecurity improvements to the FAA enterprise and the aviation services it provides. The basis for the FAA threat model is MITRE’s Threat Assessment and Remediation Analysis (TARA) model. MITRE worked with FAA to adapt TARA to FAA needs which resulted in the FAA Cybersecurity Risk Model (CyRM). The CyRM Framework is illustrated in figure 9 below. Initially, FAA is focusing on the National Airspace System (NAS) and the services it provides. The nine NAS domain aviation services are depicted in the figure below. There are other FAA services within the Mission Support and Research and Development (R&D) domains that FAA plans to evaluate in the future using the same framework.
Overarching FAA Mission
“Provide the Safest, Most Efficient Aerospace System in the World”

![Diagram of FAA Mission and Services](image)

<table>
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<tr>
<th>Flight Planning</th>
<th>Traffic Management Synchronization</th>
<th>Navigation</th>
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<td>Air Traffic Control (ATC) Advisory</td>
<td>Emergency and Alerting</td>
<td>Government/Agency Support</td>
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Select a Service

Critical Systems and Operations Knowledge ➔ Threats, Susceptibility, and Risks ➔ Countermeasures ➔ Candidate Recommendations

Security Improvements

Knowledge Management

CyRM Catalog

Select New Service

Figure 9: The CyRM Framework

The FAA Threat Model is created by applying the Threat Assessment and Remediation Analysis Methodology to each of the services. The NAS domains and services are depicted above. The methodology consists of:

- Selection of a service and identification of the critical functions and supporting systems to develop an understanding (operations knowledge) that represents the end-to-end service thread.

- Identification of threats to the service thread, the susceptibility of those critical systems to the threats, and an assessment of the risks if the threats are identified. The threat information is retained by entering it into the CyRM catalog.

- Identification of countermeasures, maps them to the threats, and enters them into the CyRM catalog.

- Identification of a selected subset of the countermeasures, based on a predetermined selection strategy, to form the recommendations to improve service security.

The methodology was successfully tested with the Flight Plan Filing Service and produced a prioritized set of threats, risks, and countermeasures. Applying the CyRM Framework to all the services.
FAA services will produce a complete FAA Threat Model which will enable the FAA to make informed decisions on agency-wide cybersecurity improvements.

**Improving General Aviation Safety with a Digital Copilot**

The safety record for General Aviation (GA) flight is much worse than the airlines. There are many reasons for this, such as a lack of redundant equipment on GA aircraft and the fact that GA pilots tend to have less overall experience. Additionally, research has shown that single-pilot operations (which make up the majority of GA flights) are riskier than flights with two pilots. There's no mystery as to why this is; flying an aircraft alone is demanding. There is a good deal of information competing for the pilot’s attention, and he or she must attend to the correct information at the correct time while avoiding distractions. If pilots are unable to do so, they can lose situation awareness or as pilots call it, “get behind the airplane.” Sometimes, this is a precursor to an accident.

To address this shortfall, and with the support of the FAA and General Aviation Joint Steering Committee, MITRE CAASD has defined and researched the feasibility of a Digital Copilot concept. This objective of the concept was to bring the benefits associated with Crew Resource Management in a multi-pilot cockpit to the single-pilot cockpit environment. The Digital Copilot concept relies upon an inference of a pilot’s intent and actions. Based on this understanding, Digital Copilot can provide relevant information at the right time. For example, under this concept, the Digital Copilot can provide radio frequencies, read checklists, monitor progress, and alert to potential safety issues. While some information is presented automatically, other information can be provided when requested verbally by the pilot. The focus of the research has been to determine which types of information are most beneficial to safety (right information), when to provide that information (right time), and how best to present that information to the pilot (right format). MITRE CAASD has evaluated the concept through a pilot workshop, simulations in MITRE CAASD’s GA simulator, and also tested the Digital Copilot in actual flight. Feedback from pilots has been positive and has highlighted the potential of Digital Copilot to reduce workload and increase safety.

MITRE CAASD envisions transferring the Digital Copilot research and technology to industry. In order to have an impact on safety, this technology needs to be integrated into the systems pilots are using today. MITRE CAASD is working with MITRE’s Technology Transfer Office to coordinate transferring the Digital Copilot concept to a number of hardware and software companies for incorporation into their existing products. Future plans include continuing efforts to make this technology available to pilots and continuing to develop additional capabilities and refinements.
COMMERCIAL SPACE RESEARCH CONDUCTED

Advances in Commercial Human Spaceflight Research

As part of the FAA Center of Excellence (COE) for Commercial Space Transportation, researchers at the University of Texas Medical Branch have been studying what is potentially
most significant barrier to flying ordinary citizens (by which we mean ‘non-astronauts;’ people who have had back and neck injuries, heart problems, diabetes, asthma, implanted devices such as pacemakers, etc.) into space. After "spinning" more than 150 average individuals in a centrifuge that simulates suborbital space travel, researchers found that anxiousness could have the biggest impact on their ability to fly, resulting in a negative experience, or endangering the flight itself.

Ideally, space flight candidates who may experience a panic attack would be identified before they invest a lot of time and money on tickets and training. At the present time, however, there are currently no known effective methods to predict who will react negatively to the space flight experience.

The most recent set of studies addressed this issue, comparing different training techniques, and trying to identify different predictive indicators of an individual's likelihood of experiencing high anxiety during space flight. A new set of centrifuge trials were conducted between November 2015 and June 2016, "spinning" another set of subjects through simulated suborbital space flight experiences, bringing the total to over 300. Preliminary results of this research indicate that of the 157 subjects recruited, ten opted out of one or more centrifuge runs due to "poor tolerance" generally related to anxiety, motion sickness, or both. The most successful training techniques that improved the subject's comfort included high-fidelity simulations and repetitive exposure. Regarding the prediction of an individual's anxiety, few reliable factors were identified.
Congress authorized Air Transportation COE under the FAA’s Research, Engineering, and Development Authorization Act of 1990. This legislation enables the FAA to work with universities and their industry partners to conduct research in environment and aviation safety, and other activities to assure a safe and efficient air transportation system. The FAA COE for Commercial Space Transportation (COE CST) is sponsored by the FAA Office of Commercial Space Transportation in 2011 and is now completing its sixth year of operation. There are nine member universities of the COE CST, including: Florida Institute of Technology, Florida State University, New Mexico Institute of Mining and Technology, New Mexico State University, Stanford University, University of Central Florida, University of Colorado Boulder, University of Florida, and the University of Texas Medical Branch.

CONTINUED AIRWORTHINESS RESEARCH CONDUCTED

Composite Inspector Training Program

The objective of the Composite Inspector Training Program was to enhance inspector’s ability to inspect composite laminate structures by developing training curriculum and proficiency specimens. Several years ago the FAA initiated the “Quantitative Assessment of Conventional NDI Techniques for Detecting Flaws in Composite Laminate Aircraft Structures” study, which provided Probability of Detection values for inspecting composite laminate structures, and a series of recommendations for improvements. A primary recommendation from this study and from the Commercial Aircraft Composite Repair Committee Inspection Task Group is to enhance inspector’s preparation and training by focusing on the unique challenges and signal differences associated with composite inspections. Subsequently, the FAA conducted two industry workshops which brought together top airline inspectors, Original Equipment Manufacturers (OEMs), and Maintenance and Repair Organizations to provide feedback and develop the material.

Figure 12: Participants in a Composite Inspector Training Workshop
This year, the curriculum for the course was developed and finalized. Proficiency specimens, along with training exercises were also developed. The beta course was also offered for the first time. This course and the designs for the training specimens are available to the industry. This effort will provide the industry the education and practice they need to be prepared for the arrival of composite aircraft and will enhance aviation safety.

**Develop Property Standards for Emerging Process Intensive Materials**

The standardization of metallic materials design data acceptable to certification agencies is very beneficial to aerospace manufacturers and government agencies, for both military and commercial products. This led to the creation of MIL-HDBK-5, which in time has evolved to the Metallic Materials Properties Development and Standardization (MMPDS) Handbook. The MMPDS Handbook is recognized worldwide as the most reliable source for verified design allowables needed for metallic materials, fasteners, and joints used in the design and maintenance of aircraft and space vehicles. The continued acceptability of values published in MMPDS is based on consistent and reliable methods used to collect, analyze, and present statistically based design allowable properties for the traditional metallic materials (i.e., plate, sheet, and bar).

Over the past decade, new and Emerging Metallic Structural Technologies (EMST) have evolved at record pace for implementation into transport category aircraft as manufacturers continually strive to reduce weight and drive down the cost of manufacturing. These technologies consist of new materials, processes, and novel designs and include metal additive manufacturing, friction stir welding, and other non-traditional processes. However, material properties for these EMST are highly dependent on the manufacturing process. Generally these material systems are not purchased by aircraft manufacturers as sheet, plates of bar stock, but in an intermediate state such as powder, wire or some other form which must be consolidated into usable components using a number of manufacturing methods. Due to the unique dependency on the manufacturing process of these technologies, existing MMPDS procedures and statistical tools used to derive acceptable design allowable properties for traditional metallic materials, (i.e., plate, sheet, and bar) are generally not applicable.

The MMPDS organization has been approached on several occasions by various groups to promote the publication of material design allowable properties for EMST materials. Recognizing that the current MMPDS guidance for the submission and publication of material allowable properties is not appropriate for these new materials, the Emerging Technologies Working Group (ETWG) was established within the MMPDS organization to determine the feasibility of establishing procedures and guidelines for determining design values and their use by potential users for these highly process dependent materials, Figure 13. The intention of the ETWG was to develop the statistical tools and procedures needed for a potential new volume to MMPDS to address the unique challenges of these systems which were drafted and documented in MMPD Agenda Item 11-40. While the draft does provide the expected statistical tools, the FAA has concluded that the underlining infrastructure which is outside the scope of MMPDS is not available at this time. Until the underlying technology and supporting infrastructure has matured, (i.e., material standards, testing standards, common terms such as heats and lots defined, etc.) and general design practices are available to industry, it is not possible to publish
generic material properties for these unique material systems at this time. As the required industry standardization efforts mature for a given EMST, the MMPDS organization has better positioned itself of address their introduction through the procedures and guidelines documented in MMPDS Agenda Item 11-40.

Figure 13: Flowchart for Development of Design Minimum Properties for Materials Produced with an Emerging Technology
DIGITAL SYSTEM SAFETY RESEARCH CONDUCTED

Assurance of Multicore Processors in Airborne Systems

Most avionics systems use Single Core Microprocessors (MCPs) since multi-core processors are relatively new, are very complex, and may exhibit non-deterministic behavior when multiple threads share the same internal resource. Single core microprocessors will eventually become obsolete forcing the aerospace industry to use multi-core microprocessors in airborne equipment. The goal of this research was to investigate and make recommendations to address the potentially non-deterministic behavior with multi-threading on a real time operating system running on two or more processor cores.

In recent years, the use of MCPs in avionics has supported the increase in performance and level of integration of safety-critical functions. However, MCPs stretch the current hardware and software assurance processes. Since MCPs were not initially designed for aircraft applications, a preemptive investigation of the potential safety concerns is warranted. This research documents
the issues related to software assurance applied to MCPs and the safety implications of pertaining to the use of MCPs in flight-critical applications. Since the main concern with regards to the use of MCPs is their lack of predictability, their use must be integrated into a systems approach wherein the need for determinism is considered for each function implemented on the MCP. This in turn justifies the use of a top-down safety method as the primary approach to be applied to all failure conditions, including those specific to MCPs. The outcome is a set of qualitative and quantitative safety requirements, and the allocation of Development Assurance Levels (DALs) to each software application according to the identified criticality level. This conventional process substantiates implementing different functions on an MCP. Consideration of the DAL refinement process allows for dissociating real-time constraints from safety constraints as independent sets.

The proposed approach to interference analysis in the context of safety processes is close to partitioning analyses. It is composed of two complementary analyses: a top-down analysis followed by a bottom-up analysis. The top-down analysis allows for isolating high-level sources of non-determinism affected by the function/task allocation to cores, the software scheduling strategy, and the selection of MCPs based on usage domain (UD). This consideration of UD is used to orient and bound the complementary bottom-up analysis. Finally, the top-down analysis prepares for the determination of mitigation strategies for the sources of non-determinism that remain in the UD. The bottom-up analysis is conventional from a safety standpoint. The key point is that the complexity of MCPs no longer allows for claims of exhaustiveness, unless the top-down analysis is performed beforehand to bind its scope.

To address the interference issues, this research recommends interference-aware safety analysis which consists of three sequential steps: the identification of an interference path; the performance of an interference analysis to tag each interference channel as acceptable, unacceptable, unbounded, or faulty, and the determination of interference mitigation. The last step is to implement mitigation for interference channels identified as bounded but unacceptable, unbounded, and faulty. The mitigations can be internal or external to the processor. This research documents details each of the steps of the proposed safety analyses.

To conclude, the limitations in existing guidance can be mitigated by the implementation of the proposed complementary top-down and bottom-up analyses. This approach is close to that for integrated modular avionics, and is, therefore, dedicated to complex computational systems with high integration levels. It is perfectly adapted to MCP concerns.
Define and Measure System Complexity in the Context of Safety Assurance

Airborne system complexity has been increasing rapidly in the recent past with the advent of newer technologies. There are multiple interpretations of complexity and it is difficult to measure system complexity in a meaningful way. The goal of this research effort was to define an appropriate type of complexity and come up with a measure to estimate the complexity of avionics systems. This measure would help the FAA predict when systems are too complex to be able to assure their safety for use on certified aircraft.

The word ‘complexity’ implicitly suggests that some causes create effects; without elucidation of which causes and which effects, the word is being used in a casual manner and is not adding facts to the discussion. After a detailed review of the literature, a taxonomy of complexity was developed and this taxonomy is used to determine the impacts and measurement of system complexity. A measure of complexity was developed using the number of ways that an avionics system error (fault) could propagate from one element to another. Since each potential propagation requires another sub-argument in the safety case, the number of such arguments should be linear with certification effort. Thus the ability to show that the system is safe, through the assurance process, should depend on whether a system has small enough complexity (number of ways for errors to propagate).
The results of this research include a formula for calculating the “error-propagation complexity” from a system design, the results of using that formula for small and medium systems, and steps for using the formula. The formula was tested on small system (stepper motor), a redesigned stepper motor systems, a medium complex system (wheel braking system), and a larger system (SAAB-EH-100).

To get a better feeling to the complexity measure, an attempt was made to convert the measure into an estimate of assurance safety review effort. The review effort is a good surrogate measure in order to compare systems of different complexities and to determine whether or not a system is too complex to assure safety. It estimated the review time for the small cases and extrapolated up to larger cases, assuming a spread of small, medium, and large designs included within a typical avionics system. Many of the numbers used are not tested and validated in terms of relationships and assumptions. Hence, the proposed boundary of systems “too complex to assure safety” should be treated with caution.

**FIRE SAFETY AND RESEARCH, RESEARCH CONDUCTED**

A *Comparison of Performance of OSU Compliant Versus Non-OSU Compliant Thermoplastics used in the Lower Area of Aircraft Seats during Simulated Post crash Fire Scenario*

The FAA established the Aviation Rulemaking Advisory Committee (ARAC) in 1991 to provide advice and recommendations to the FAA Administrator on the FAA’s rulemaking activities with respect to aviation safety issues. On August 27, 2010, the FAA issued a Notice of New Task Assignment to the ARAC to review and submit recommendations in response to the FAA’s approach to update, reorganize, and improve the level of safety of requirements for the flammability of materials. As a result of this notice, a new Materials Flammability Working Group (MFWG) was established to support this task. The MFWG was comprised of over 20 participants from airframe manufacturers, equipment manufacturers, and operators, and representatives from the FAA and other foreign regulatory authorities. In general, the MFWG found many positives to the FAA’s proposed new structure, but was concerned about the cost of implementation. The FAA conducted an investigative effort of its own to determine the cost of implementation, and ultimately requested a continuation of the MFWG in January 2015. The main task was to quantitatively evaluate the proposed changes for cost impacts.

One area that the FAA requested feedback from the MFWG pertained to the flammability requirements of items located near the floor of the aircraft. Based on a cursory review of past accidents and numerous full-scale realistic tests simulating post crash fires, it could be concluded that cabin items located near the floor do not significantly contribute to the overall occupant survivability in post crash fire accidents. As such, the FAA proposed a willingness to modify the flammability requirements in these areas, if test data could support this position. More specifically, the FAA considered whether items located within 15 inches of the floor need be subject to the stringent heat release requirements. In addition, seats that included large surface
parts (e.g., large shrouded and pod-designed seats typical of business and first-class cabin areas) would require further consideration, which could reduce the proposed 15-inch dimension.

In order to investigate the impact of using non-heat-release-compliant materials in the lower portions of seats, the FAA Fire Safety Branch conducted two full-scale tests under simulated post crash fire conditions. The tests were conducted with a large external fuel fire adjacent to a B-707 standard body aircraft fuselage, simulating a severe but survivable accident in which the fire entered the cabin through a simulated fuselage rupture (figures 16 and 17).

The fuselage was instrumented with thermocouples, toxic gas sampling lines, heat flux transducers, and smoke meters to monitor conditions during the test. The fuselage was also outfitted with four simulated triple seats constructed of steel angle (figure 18).
The upper section of the seats contained fire-hardened seat cushion bottoms and backs that met current FAA flammability requirements, while the lower area contained thermoplastic sheet on the aft and side areas. During the initial test, thermoplastic paneling that met the current FAA heat release requirements was used, while during a second test the thermoplastic paneling did not meet current requirements.

A comparison of the test results is shown in figure 19. It is evident that there was significantly more fire spread in the test with non-compliant paneling. This may have been caused by the direct exposure of the lower paneling in the center outboard seat to the intense radiant heat from the fuel fire. From the data it was determined that the use of the non-compliant paneling resulted in increased toxic gas generation and elevated temperatures, which reduced occupant survivability. The impact on survivability was calculated using a Fractional Effect Dose (FED) model and the temperature and gas data collected during the tests (figure 20).
The difference in survivability was a significant 94 seconds, demonstrating that the fire resistance of lower seat paneling can impact post crash fire survivability.

**NEXTGEN – AIR GROUND INTEGRATION HUMAN FACTORS RESEARCH CONDUCTED**

*Complete Research and Recommendations for Developing, Evaluating, and Approving Standard Operating Procedures in NextGen*

The evolution of the air transport system under NextGen necessitates the development and successful implementation of new flightcrew procedures. This research program conducted a review of the scientific literature on crew procedures. From the research, guidelines were developed for designing and evaluating effective crew procedures. The process was divided into seven phases and guidance was provided for each:

1. Determining when procedures need to be designed or modified;
2. Creating a procedure development process;
3. Understanding the relevant issues;
4. Crafting procedural solutions;
5. Writing procedures;
6. Implementing new procedures, and;
7. Evaluating and monitoring the conduct of procedures in practice.
The FAA has used these guidelines for the update of Advisory Circular 120-71 (Standard Operating Procedures for Flight Deck Crewmembers). AC 120-71 provides guidance for the design, development, implementation, evaluation, and updating of Standard Operating Procedures (SOP), and for pilot monitoring duties. SOPs are universally recognized as basic to safe aviation operations. Their importance cannot be overstated, especially in light of the advent of pilot monitoring standards with respect to the use of increasingly modernized automated systems. The AC provides a process for developing procedures that meet clear and specific requirements. Safe operations are founded on comprehensive SOPs made readily available within the manuals used by flight deck crewmembers. The AC also provides guidance for definition and training of pilot monitoring duties and their integration into SOPs. Although the AC is directed towards part 135 and 121 air carriers, all air carriers, aircraft operators, pilot schools, and training centers are encouraged to utilize the guidance.

**NEXTGEN – WEATHER TECHNOLOGY IN THE COCKPIT RESEARCH CONDUCTED**

*Initial Verification Demonstrations of Recommended Implementations of Adverse Weather Alerting Functions for the Flight Deck*

Turbulence encounters continue to be one of the major causes of crew and passenger injuries for commercial airlines. In addition, turbulence encounters cause significant passenger discomfort. In most cases, injuries occur when the encounters are unexpected or the level of turbulence encountered is greater than expected. In addition, injuries typically occur due to crew or passengers not being properly seated belted. Currently, most turbulence information is used for route planning since it does not identify with a high level of accuracy an impending encounter,
but it does identify areas of expected turbulence. The Weather Technology in the Cockpit (WTIC) program has been doing research to develop Minimum Weather Service (MinWxSvc) recommendations for an accurate and low latency turbulence notification function that will notify cockpit crews of likely encounters with turbulence within the next few minutes. This notification function is intended to assist with crew management though it may also enable avoidance of some turbulence encounters. The objective of this notification function is to alert the crew of ensuing turbulence with sufficient time for passengers and crew member to put on seat belts and to have a low false alarm rate so that the notification is not ignored.

The notification function being researched and demonstrated by the WTIC program is based on the NEXRAD Turbulence Detection Algorithm (NTDA) which has a proven capability to detect turbulence. For the algorithm to provide benefit, the notification must be generated and uplinked to the cockpit with minimum latency to enable sufficient time for the aircrew to take action. This has been the primary challenge in the WTIC research. The other challenge is determining which aircraft are proximate to a detected turbulence event so that they receive the notification when turbulence is detected.

### WTIC Tactical Turbulence Notification

![Figure 22: WTIC Tactical Turbulence Notification](image)

The WTIC research developed a viewer and methodology for providing the NTDA notification in cockpits on a tablet device along with the Graphical Turbulence Guidance product. In addition, a process to identify proximity aircraft that should receive the notification was developed.

The WTIC program conducted two Tactical Turbulence Human over the Loop (HOTL) studies with both demonstrating significant benefits in crew management and recognition of near term...
turbulence encounters. The total latency of the NTDA detection of a turbulence event and the resulting cockpit notification were demonstrated in the HOTLs to be acceptable; however, the data-stream that was used to identify proximity aircraft has been obsoleted and is no longer available. Therefore, a new methodology needs to be developed and verified, and then test flights will be conducted to develop the final MinWxSvc recommendations for the turbulence notification function. A new data-stream has already been identified, but some additional research needs to be performed to incorporate its use into the notification function, and then the process needs to be demonstrated in another Human over the Loop before the function is flight tested. New milestones will be identified related to this research to develop the final MinWxSvc recommendations.

Weather Information Latency Trainer (WILD)

The WTIC program has been performing gap analyses for GA to identify weather-related safety hazards and risks as well as weather-related causal factors in GA accidents and incidents. As a result of these studies, latency in cockpit NEXRAD displays was identified as a risk as well as a causal factor in adverse weather encounters by GA pilots. The WTIC program research has determined that there is a disconnect of varying time intervals between the out-of-the-cockpit view and what is presented on the cockpit display, due to the latency of the information presented on the cockpit display. However, even though GA pilots are aware that their information has latency, there are many reported instances of pilots getting into trouble or having an accident/incident as a result of using the information as though it was real time. In many of the cases analyzed, the latent cockpit weather information was being used to navigate through adverse weather versus using it for adverse weather avoidance.
In an effort to resolve this safety-related operational shortfall for GA pilots, WTIC research developed a prototype capability that was successfully demonstrated that enables the incorporation of variable and realistic latency into weather displays (versus out the window views) in flight trainers. The device, referred to as the Weather Information Latency Trainer, demonstrated the feasibility of this capability and developed a prototype implementation. Based on the success of the prototype, a baseline design for the capability was established and an operator manual completed. The baseline design can be readily adapted into commercial trainers which will enable pilots to train with realistic latency in the NEXRAD presentations. The intent is that the WILD will be used to educate pilots on cockpit displayed weather information latency. This will be accomplished by the development of immersive skills based lessons for incorporation into pilot training by WTIC research. Ultimately, this training is expected to resolve or reduce the risks that were identified relative to weather information latency. Future milestones include developing web based training that will enable pilots to use the WILD capability without having access to a WILD or a commercial trainer with the WILD capability.
PROPULSION AND FUEL SYSTEMS RESEARCH
CONDUCTED

Improvement of Turbine Engine Component Risk Assessment Software to Analyze Large 3D Finite Element Models

High-energy rotating components in aircraft gas turbine engines may contain inherent or induced anomalies that can lead to rare but potentially catastrophic failures. FAA Advisory Circulars (ACs) address specific types of inherent and induced anomalies (AC 33.14-1 and AC 33.70-1) and establish a general framework for all life-limited engine parts (AC 33.70-1). DARWIN® is an acronym that stands for Design Assessment of Reliability with Inspection. The associated risk of fracture can be predicted using DARWIN®, an FAA funded probabilistic fracture mechanics software code developed by Southwest Research Institute.

Previous versions of DARWIN® did not provide adequate support for large Finite Element (FE) models with large numbers of load steps. The time required to import and display large FE models in the GUI could be measured in double digit minutes or even hours. The time required to process FE models in the Risk Assessment Code was also extensive. This was primarily due to the use of text-based FE model files. DARWIN® 9.1 introduces a new hierarchical binary file format HSIESTA to store FE results data. This substantially reduces computation time and memory requirements for large FE models. HSIESTA replaces an earlier FE model file format that stored data as ASCII text. These enhancements have significantly reduced the time required to read and display the stresses and temperatures associated with large FE models. For example, an FE model with approximately 100,000 nodes and 1,000 load cases required nearly ten minutes to import and display in the previous DARWIN version for a single load case. Using the HSIESTA capability implemented in DARWIN® 9.1, the same FE model was imported and displayed in approximately ten seconds, or roughly sixty times faster than DARWIN 9.0.

The DARWIN “Autoplate” algorithm rapidly identifies the size and orientation of fracture mechanics models (i.e., rectangular plates) based on the geometry, temperature, and stresses at a specified location in an FE model. In previous versions of DARWIN®, users could invoke the Autoplate algorithm when manually creating zones, but this capability was limited to 2D FE models. For 3D FE models, users were required to use their own engineering judgment to determine the size and orientation of fracture mechanics models when building zones manually. Initial crack locations for 3D FE models were also limited to surface nodes. DARWIN® 9.1 enables use of Autoplate for automatic creation of fracture mechanics models when creating zones manually in 3D FE models. When the user selects an initial crack location on the 3D FE model, the slice plane and fracture model are created simultaneously using a single mouse click. DARWIN® 9.1 also enables users to specify an initial crack location anywhere on the surface of a 3D FE model. These enhancements provide a common interface for creating zones manually in both 2D and 3D FE model geometries.

DARWIN® also provides several probabilistic methods for computing the fracture risk of components, including a method entitled ‘Monte Carlo with Gaussian Process (GP) Response
Surface.’ This method creates a GP response surface model to estimate the relationship among input variables and Fatigue Crack Growth (FCG) lifetimes. Monte Carlo Simulation is then applied to the response surface for fracture risk computations. In previous versions of DARWIN, this method was limited to five random variables. DARWIN® 9.1 extends the Monte Carlo with GP Response Surface method to provide treatment for all random input variables except those related to manufacturing process models. A new response surface capability was implemented to model the relationship among formation life and its associated input random variables. The FCG life response surface was also enhanced to support additional random variables. This enhancement also provides significant reductions in computation time for assessments employing additional random variables that were not previously supported by this method.

![Image](image-url)

Figure 24: Example of DARWIN 9.1 to Place an Initial Crack

DARWIN® 9.1, with these enhancements to analyze large 3D FE models, is currently under formal review by the four major aircraft engine manufacturers who are part of the FAA project team. Following extensive evaluation and any necessary bug fixes, DARWIN® 9.1 will be released for production use by the industry. The figure above is an example of DARWIN 9.1 to place an initial crack on any surface of a 3D FE rotor and automatically create a fracture mechanics model using its Autoplate algorithm.
SYSTEM SAFETY MANAGEMENT RESEARCH CONDUCTED

Facility Risk Assessment Tool (FRAT)

The FAA established the Air Traffic Safety Oversight Service (AOV) to provide independent safety oversight of the Air Traffic Organization’s (ATO) provision of air traffic services. To support AOV’s mission, a prototype decision support tool called Facility Risk Assessment Tool was developed to assess, rank, and track air traffic facility safety. FRAT provides a common platform for data-driven, risk-based safety analysis of ATC facilities - also known as Service Delivery Points (SDPs).

Safety associated with an SDP was modeled as an influence network using a set of risk factors. Risk factors are defined as safety hazards, causes of hazards, or indicators of potential safety issues associated with the technical, operational, organizational, or environmental aspects of an SDP. An analytical approach integrating various techniques was employed to identify, describe, and categorize 16 risk factors and 71 input variables. Subsequently, they were used to develop four separate prototype models for FRAT that represent the Air Traffic Control Tower, Terminal Radar Approach Control (TRACON), combined ATCT-TRACON, and Air Route Traffic Control Center facility types.

A hybrid approach employing Adaptive-Network based Fuzzy Inference Systems was developed for FRAT to propagate the facility models and calculate safety ratings for risk factors and other model components. Ratings are envisioned as dimensionless scores on a scale of zero to 100, common across the entire model to enable comparative analysis. The quantification method FRAT uses to establish risk-based ratings relies on statistical analysis of NAS-wide data to identify outliers and understand the underlying distribution of facility data for each risk factor. Thus, FRAT’s quantitative approach is fundamentally data-driven and minimizes the use of subjective judgment. A software code was developed to automate the inferencing methodology employed by the FRAT framework. This self-contained code is called FRAT inference engine, which accepts input data, interacts with facility models, and produces model outputs, thereby generating input and results data sets for the web-based FRAT user interface.

Finally, the FRAT technical framework and the prototype technology developed at the FAA William J. Hughes Technical Center were transferred to MITRE/CAASD. The scope of the tech transfer activities included (a) transfer of the input data collection to achieve fully-automated data extraction, transformation, and loading for FRAT, (b) transfer of the FRAT inference engine, including the facility models and the engine source code, and (c) transfer of the analytical functions developed for the prototype web-based user interface. FRAT is currently being deployed by MITRE as an operational decision support tool for the internal use of the AOV.

FRAT facilitates detailed data-driven comparative analysis of SDPs that are of interest to the AOV. It enables proactive management of safety risk by identifying facilities with the highest priority. FRAT was designed to help identify candidate audit topics to support AOV oversight.
mission by determining top risk factors for facility specific audits. It provides SDP-specific quantitative ratings in support of comparative assessment and analysis. It is envisioned that such a comparative assessment provides an objective, risk-based focus to AOV safety oversight function when conducting system audits to determine the ATO compliance with safety standards and ATO Safety Management System requirements.

Figure 25: FRAT Overview
UNMANNED AIRCRAFT SYSTEM RESEARCH CONDUCTED

Multi-Sensor Surveillance Data Fusion Strategies

The ANG-C and ANG-E Unmanned Aircraft System (UAS) Matrix team located at the FAA William J Hughes Technical Center is conducting research on the Multi-Sensor Surveillance Data Fusion Strategies. As background, the FAA Federal Aviation Regulation (FAR) requirement of “See and Avoid” is essential to safe flight in manned aircraft. See and Avoid refers to the ability of the pilot to visually scan the surrounding airspace and determine possible risks. It is then the pilot's responsibility to avoid these risks by following the rules defined in the FAR or by any means in the case of an emergency. Thus, UASs are required Detect and Avoid (DAA) systems that comply with 14 CFR 91 without a pilot on board the aircraft. DAA systems have significant technical challenges in establishing and maintaining the relative position of one or more external threats (i.e., aircraft) during an encounter. Multiple sensors are needed to assure all threats (e.g., cooperative and non-cooperative) can be detected and tracked to remain well clear and safely separated in compliance with 14 CFR 91. The use of multiple sensors requires strategies to combine (fuse) the position information obtained over time from each sensor. Under this task, software models were built for sensors that were deemed mature. These models depict surveillance noise and performance that is to be expected in the real world. Additionally, multiple filtering techniques and fusion strategies were investigated and developed. The goal of filters is to smooth sensor data before sending it forward for fusion. The tracker mechanism is responsible for conducting track association, validation, and correlation. Utilizing a particular fusion strategy, it combines the incoming tracks from multiple sensors into one single track output. This single track output is then fed to the DAA algorithm, which is responsible to provide a well clear alert if necessary.
One of the goals of this research task is to develop multiple fusion strategies within the tracker and measure their performance from software simulations which utilize a large set of aircraft encounters and conduct an overall trade-off analysis of the different fusion strategies. In addition to investigating multiple fusion strategies, this research task is also supporting the Radio Technical Commission for Aeronautics (RTCA) SC-228 Phase 1 Minimum Operational Performance Standards (MOPS) for UAS. The research team is supporting the validation of surveillance performance requirements to determine the minimum performance standards for each sensor. This analysis work will validate the minimum surveillance quality required as input to the DAA Remain Well Clear guidance algorithms, so that they perform with the appropriate levels of safety and operational suitability. This work will also help to validate the performance of the Remain Well Clear guidance algorithms given the anticipated surveillance “noise” from real-world implementations of these DAA systems. The validated tracker with one of multiple fusion strategies developed under this task will be included as a reference implementation in the appendix of the MOPS. The document will be a blueprint of a tracker that meets the minimum requirements to support DAA.

Unmanned Aircraft System Airborne Collision Severity Evaluation

The FAA’s COE for UAS is conducting research on UAS Ground and Airborne Collision Severity. As background, UAS airworthiness considerations require an understanding of the hazards for UAS operations in the NAS. Included in those hazards are the severity and likelihood of ground and airborne collisions. Furthermore, the new risk based approach for
certification requires an understanding of all of the risks that UAS operations will pose in the NAS, including the collisions that we study under this tasking.

Credible encounter scenarios for UAS collisions with persons/property on the ground and aircraft in the air are utilized to test for UAS hazard severity characteristics. The airborne collision encounters include scenarios similar to bird strikes, including windshield, fuselage, and turbofan engine strikes. The initial airframes included for the airborne collisions are a business jet and a narrow body transport aircraft. Efforts are also focused on modeling the engine dynamics of a UAS ingested into a turbofan engine. Ground collision studies are focusing on the risk factor of colliding with people on the ground and the subsequent severity of those collisions and how to classify the risks.

![Unmanned Airborne System Model](image)

Figure 27: Unmanned Airborne System Model

The studies for both airborne and ground collision, utilized modeling techniques to be able to test a wide variety of UAS characteristics and sizes. These models are validated by testing the material properties of the UAS models with component level testing of the UAS parts. These component tests included live testing of UAS parts colliding with aluminum plates so that the deformations of the plates and UAS parts can be corroborated with the modeling techniques to ensure that the models match up.
The up-to-date research results have helped inform the Micro Arc recommendations for operating over people. In addition, the COE has created a technical approach to create a safety case for operating UAS over people that is currently going on to help enhance the Pathfinder programs underway to create a waiver application to Part 107.39.

WEATHER RESEARCH PROGRAM RESEARCH CONDUCTED

Zero-36 Hour Probabilistic Forecasts of Oceanic Convection

In order to help improve the available information for strategic planning, and mitigate weather-related aviation hazards for offshore and transoceanic flights, the Weather Program has sponsored a research and development effort that aims to improve the prediction of oceanic convection. The overarching goal of this effort is to generate probabilistic oceanic convective hazard guidance with forecast lead times up to 36 hours. Probabilistic convective hazard guidance forecasts are generated by harvesting global ensemble model output from select Numerical Weather Prediction (NWP) centers around the world. This project develops techniques for optimally combining forecast information from multiple NWP model ensembles into a single, reliable, calibrated forecast depicting the chance of aviation-impacting convection to occur at a given location and time. The work supports the Aviation Weather Center (AWC) and the Washington and London World Area Forecast Center efforts to produce gridded global aviation hazard forecasts as a supplemental product to the current operational forecast product (e.g., SIGWX Charts). In regard to the NextGen era, probabilistic forecasts will likely be used by automated Decision Support Tools (DSTs) to route transcontinental flights, significantly improving efficiency and risk management, and may also be a candidate for the FAA’s NextGen Weather Processor.
In FY 2016, the initial prototype was developed and delivered to the Weather Program. The original domain was expanded from a test area of the Pacific to near-global coverage from 60°N to 60°S. The algorithm was successfully shown to provide a probabilistic forecast of convection worldwide out to 36 hours. A sample output is displayed in Figure 29 below. Validation was performed to verify that the algorithm performed as expected over a geographical and seasonal basis. Additionally, a real-time feed has been established to provide AWC with output in order to conduct a live evaluation of the algorithm versus current forecast capabilities. An independent quality assessment to determine and validate the meteorological accuracy of the algorithm will be conducted in FY 2017.

![Sample representation of a 24 hour forecast of precipitation probability (filled contours) generated by the algorithm, along with the actual areas of precipitation analyzed at the forecast valid time (white contours)](Figure 29: Precipitation Probability 24 Hour Forecast)

**Enhanced Ceiling and Visibility (C&V) Information**

The National Weather Service (NWS) does not currently produce C&V grids for aviation that have been reviewed and/or modified by a qualified meteorologist. Numerical weather models are not always accurate, especially in areas with fine-scale terrain effects or other local phenomenon that are well known to experienced meteorologists. As such, the FAA is currently collaborating with the NWS to create probabilistic and deterministic C&V grids that are high quality and nationally consistent. These grids can be used to create automated Terminal Aerodrome Forecasts (TAFs) or to provide reliable guidance for their manual creation, as well as Graphical Airmen’s Meteorological Information (G-AIRMETs), and other weather products. More accurate and dependable C&V information will improve GA safety and airport efficiency by providing greater situational awareness to pilots and air traffic managers.
In FY 2016, the FAA, jointly with the NWS conducted an experiment to demonstrate and evaluate the C&V grids, the collaboration methods, and the preliminary automated TAFs. The FAA is providing expertise and guidance to ensure that the C&V grids and automated TAFs meet the needs of aviation users. The NWS is leading the development of a process for the AWC to collaborate with local Weather Forecast Offices to produce nationally consistent C&V grids. The NWS is also designing algorithms to create automated TAFs.

The work proposed for FY 2017 will include additional real-time tests of the collaboration methodology, as well as improvements to the way that forecasters interact with the C&V grids. This collaborative effort will include an analysis of how aviation end-users interpret probabilistic products. The first version of guidance grids will also be improved through targeted numerical model developments and post-processing techniques. One of the areas where this is most needed is in the statistical combination of multiple model inputs to create a single deterministic forecast that can be used to help derive non-probabilistic forecasts like TAFs and G-AIRMETS. Additionally, efforts will be undertaken to ensure that the official deterministic forecast is consistent with the probabilistic information.

Figure 30 is an image of the National Oceanic and Atmospheric Administration (NOAA) Graphical Forecast Editor display of forecast ceiling heights for the western United States. During a 2016 summer experiment, these experimental grids were produced by forecasters in the Aviation Weather Testbed (AWT), sent to the NWS Operations Proving Ground, and local input was provided back to the AWT. Experimental TAFs derived from these gridded forecasts were provided to the FAA's Aviation Weather Demonstration and Evaluation services for end-user evaluation and feedback.

Figure 30: Ceiling Heights Forecast Display
R&D PRINCIPLE 2
IMPROVE EFFICIENCY

Systematically expand and apply knowledge to produce useful materials, devices, systems, or methods that will improve access to and increase the capacity and efficiency of the Nation’s aviation system.
AIRPORT COOPERATIVE RESEARCH PROGRAM (ACRP), RESEARCH CONDUCTED

Use Disaggregated Socioeconomic Data in Air Passenger Demand Studies

The objectives of this research was to evaluate the feasibility and potential benefit of using disaggregated socioeconomic data (e.g., income distributions, age cohorts, ethnicity, trip purpose), in order to improve local air passenger demand studies (e.g., airport planning, forecasting, marketing, air service development, passenger leakage) as well as develop a guidebook to assist practitioners in incorporating disaggregated socioeconomic data for the aforementioned studies.

Air passenger demand studies for airport planning, forecasting, marketing, air service development, and passenger leakage typically correlate activity to aggregate socioeconomic data. However, there is concern that emerging socioeconomic changes, such as the age structure of society, increased immigration, wealth concentration, geographic redistribution of the population, and changing views on the use of disposable income, may not be well captured in current analytical methods. These changes may be better represented using disaggregated socioeconomic data. Yet there has not been definitive research demonstrating the potential benefit of using more detailed data, nor is there guidance to help incorporate these data in air passenger demand studies. This research identifies and summarizes long-term socioeconomic trends, highlight their potential impact, and provide guidance for incorporating disaggregated socioeconomic data into air passenger demand studies.

AIRPORT TECHNOLOGY RESEARCH PROGRAM (ATRP), RESEARCH CONDUCTED

Publish a Report on the Findings of the Artificial Turf Installation and its Effectiveness in Mitigating the Burrowing of the Protected Gopher Tortoise

A number of airports in the FAA Southern Region have difficulty meeting the regulations under 14 CFR 139 for holes in RSAs caused by burrowing of gopher tortoises. Gopher tortoises are listed as a threatened species in Florida, and mitigation efforts (i.e., tortoise removal or relocation and burrow eliminations) are heavily regulated, expensive, and time-consuming. However, gopher tortoises burrowing in such close proximity to runways are a safety hazard to aircraft that may leave the runway pavement surface. Artificial turf that meets the specifications in FAA AC 150/5370-15B has been identified as a material that can be used to cover large portions of airport property with multiple benefits, such as providing consistent ground cover, as well as reducing maintenance costs and attractive vegetative food sources for hazardous wildlife species. It was determined that research was necessary to assess artificial turf as a potential solution for mitigating the burrowing behavior of gopher tortoises on the airport property. The FAA Airport Technology Research and Development Branch entered into an agreement with Orlando Sanford International Airport to conduct a study on the applicability of artificial turf in the RSA to
mitigate potential hazardous conditions resulting from the presence of burrowing gopher tortoises. The study also investigated the ability of the artificial turf system to withstand exposure to harsh environmental conditions, and the occasional, inadvertent passage of vehicles and aircraft, which was tested by using a specialized vehicle retrofitted with an aircraft nose wheel. An area adjacent to the blast pad at the approach end of Runway 18 was selected as the test site, and construction on the test area commenced in February 2014.

Figure 31: Artificial Turf Burrow

In January 2016, the findings of the artificial turf installation and its effectiveness in mitigating gopher tortoise burrowing were published in report number DOT/FAA/TC-15-61 titled, *Artificial Turf, and Gopher Tortoises at Orlando Sanford International Airport*. The results from over a year of data collection at Orlando Sanford International Airport and directed studies demonstrated that artificial turf is compatible with safe airport operations, is durable to passive environmental factors, is not attractive to other hazardous species, resists burrowing by gopher tortoises, and does not exhibit detrimental reduced braking during aircraft or vehicle excursions.

**CAASD RESEARCH CONDUCTED**

*Assessment of Controller Path Stretch Advisories to Support Efficient Metering*

Today’s metering capabilities are designed to increase NAS efficiency by timing the flow of arrival aircraft for the correct volume, sequencing, and spacing which is reflected by a schedule. The objective is to use primarily speed control to keep flights on their assigned Performance Based Navigation (PBN) routes and procedures. When speed control alone is insufficient for achieving the flight adjustments needed to meet the schedule, controllers will stretch the path of an aircraft by turning it off route and then back to route. This stretching, called vectoring can be inaccurate for meeting the scheduled time. In addition, other ground-based automation systems
(and the aircrew and aircraft systems) do not know when and where the aircraft will be turned back to route. Path Stretch advisories address this shortcoming by supplying the controller with a precise trajectory that includes the additional distance needed to meet the metering schedule; advisories consist of the lateral path and an accompanying speed. The automation generates a trajectory that defines a precise path change maneuver to meet the schedule while also adhering to any facility adapted preferences. Path Stretch is a candidate capability being investigated by FAA for inclusion in Time Based Flow Management (TBFM) Work Package 4. The capability uses trajectory modeling to compute the additional distance needed to absorb a flight’s metering delay at an adapted speed, or a speed assigned by the controller. Based on the additional distance, the automation generates a precise, two-legged lateral maneuver (with an accompanying speed) that absorbs the required delay while adhering to any facility-adapted preferences. The advisory is presented to the controller and can be used as-is, or tailored to better align with the controller’s practices and plans for managing the sector (e.g., by specifying a right turn maneuver instead of a left).

Figure 32: Assessment of Controller Path Stretch Advisories to Support Efficient Metering

Path Stretch is intended to improve the En Route controller’s ability to accurately and efficiently meet metering schedule times. In addition, because the Path Stretch advisories are closed-loop maneuvers, their entry into the ground automation will improve flight intent data, thereby increasing trajectory accuracy. The improved trajectory and delivery accuracy is expected to:
support increased effectiveness for other time-based scheduling and management of arrivals in the terminal environment as defined by the Terminal Sequencing and Spacing concept, increase the likelihood that a flight can fly (uninterrupted) a PBN Optimized Profile Descent by absorbing the needed delay at level, cruise altitudes, and enhance both the En Route Automation Modernization conflict detection capability as well as the TBFM system’s scheduling functionality.

Path Stretch is built upon the research and requirements for a 3-Dimensional Path Arrival Management capability developed by the NASA Ames Research Center. MITRE has enhanced the initial capability over the course of several years and conducted multiple laboratory assessments of it using operational Subject Matter Experts (SMEs). The results of the evaluations have validated the operational acceptability of the Path Stretch functionality and showed that the use of this capability improved delivery accuracy to the En Route meter point as compared to a baseline condition (i.e., without Path Stretch). Based on the laboratory evaluations, a preliminary set of requirements has been transferred to the FAA. Additional research and analyses will still be necessary in order to mature Path Stretch as part of the normal acquisition process.

**FACILITIES and EQUIPMENT (F&E) AIR TRAFFIC MANAGEMENT REQUIREMENTS RESEARCH CONDUCTED**

*NextGen – Multifunction Phased Array Radar*

In partnership with the NOAA, FAA has been conducting Concept Maturity and Technology Development around Multifunction Phased Array Radar (MPAR) to address aging surveillance infrastructure and emerging performance requirements, while striving to reduce recurring operations and maintenance costs. The MPAR concept also supports Presidential and Congressional initiatives to make federal use spectrum available for non-federal use through consolidation of incumbent radar systems operating in three separate radio frequency spectrum bands.

To demonstrate the viability of meeting multiple agency missions on a common radar platform, FAA and NOAA (with the Massachusetts Institute of Technology’s Lincoln Laboratory, General Dynamics, and other System Engineering and Technical Assistance contractors) are developing an Advanced Technology Demonstrator (ATD). Upon completion of development and integration (planned Q2 FY18), the ATD will be the first of its kind dual polarized active electronically scanned phased array radar. The antenna hardware will consist of commercially available components and manufacturing techniques. The radar ‘back end’ processing will leverage past Office of Naval Research investment in Affordable Common Radar Architectures, where previously developed hardware and software designs and interfaces, and all software source code, were made available for re-use saving FAA and NOAA tens of millions of dollars.
Figure 33: Existing Phased Array Antenna to be replaced with MPAR ATD

System requirements and designs have been completed, as well as the definition of subsystem interfaces. Antenna and backend hardware, and additional software development is underway, as well as planning for design verification tests and initial operating capability demonstrations. The ATD will be installed in Norman, OK, and replace the existing National Weather Radar Testbed. ATD activities will not only serve as a proof of concept for MPAR, and in a broader sense, surveillance consolidation; but will also provide valuable inputs into investment analysis artifact such as cost models, final performance requirements, and business case analysis reports.

F&E – WAKE TURBULENCE RE-CATEGORIZATION

Complete Changes to FAA Orders for Implementing Leader/Follower Pairwise Static Wake Separation Standards

During FY 2016, the ATC order JO 7110.123 that covers use of the new Wake Re-Categorization (RECAT) leader/follower (Phase II) wake hazard mitigation procedures and associated separation standards was completed and approved for ATCs use. The FY 2016 initial version of the order included a unique appendix of the RECAT Phase II wake separations that optimized the separation standards for increased runway throughput at the major southern California airports (Los Angeles and San Diego International Airports). Additional optimization appendices will be added as RECAT Phase II airport implementations continue. With the RECAT Phase II set of wake separation standards, the FAA is now able to configure wake separation standards applied at a particular airport in order to deliver optimal runway throughput capacity for the mix of aircraft types operating at that airport. To develop these standards, detailed safety assessments were done as part of the FAA Safety Risk Management review process resulting in the approval by the FAA of the Order and its associated Safety Risk
Management Document (SRMD). Based on the approved separations in the SRMD, wake categories were defined for the key site implementation of RECAT Phase II procedures and standards at the southern California airports. The automation systems used by ATC at these and other surrounding southern California airports were adapted for use of the new RECAT Phase II standards. In September 2016, ATC servicing the southern California airports began use of the RECAT Phase II wake separations, delivering additional runway throughput for the users of the National Airspace System. The chart below shows how RECAT Phase II allows flexible grouping of aircraft for additional airport runway throughput.

Figure 34: RECAT Phase II Allows Flexible Grouping of Aircraft
NEXTGEN – WAKE TURBULENCE RESEARCH CONDUCTED

Development of Initial Performance Measures of Air Traffic Control Terminal Automation Systems for Dynamically Setting Wake Separation Minima in the Terminal Airspace for each Pair of Aircraft

The initial identification of aircraft flight performance measures along with measures of the weather through which the aircraft is flying was completed in August 2016 - with the completion of the draft RTCA publication Minimum Aviation System Performance Standards for Aeronautical Information/Meteorological Data Link Services. It represents the next step in a multi-year effort by aviation’s research and development community (government, and industry) to reach consensus on the aircraft based data to be broadcasted as part of the Aeronautical Information and Meteorological Data Link Services.

The following is a sample of the RTCA proposed flight performance and observed weather measures to be included in an aircraft’s broadcast message:

Extract from ‘Table 0-1: WxS Input Data Ranges and Resolutions’

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Resolution</th>
<th>Range</th>
<th>Preferred Acquire Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft ID</td>
<td>Character</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Computed Airspeed</td>
<td>Knots</td>
<td>1</td>
<td>0 thru 800</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Latitude</td>
<td>Degrees, Minutes, Seconds</td>
<td>1 Second</td>
<td>90 S thru 90 N</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Longitude</td>
<td>Degrees, Minutes, Seconds</td>
<td>1 Second</td>
<td>180 E to 180 W</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Pressure Altitude in ICAO Standard Atmosphere</td>
<td>Feet above Mean Sea Level</td>
<td>1</td>
<td>-1000 thru 50000</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Static Air Temperature</td>
<td>Degrees Celsius</td>
<td>0.1</td>
<td>-99.9 thru +99.9</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Static Pressure (Note 1)</td>
<td>Hectopascals (millibars)</td>
<td>1</td>
<td>900 thru 1050</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Wind Direction (True)</td>
<td>Degrees</td>
<td>1</td>
<td>0 thru 359</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Description</td>
<td>Unit</td>
<td>Resolution</td>
<td>Range</td>
<td>Preferred Acquire Rate</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------</td>
<td>------------</td>
<td>------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>Knots</td>
<td>1</td>
<td>0 thru 800</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Vertical Speed (Note 2)</td>
<td>Feet per Minute</td>
<td>1</td>
<td>-2000 thru 2000</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Gross Weight (Note 3)</td>
<td>Kilogram</td>
<td>1</td>
<td>N/A</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Groundspeed</td>
<td>Knots</td>
<td>1</td>
<td>0 thru 800</td>
<td>1 Hz</td>
</tr>
</tbody>
</table>

Also during 2016, a report, *Feasible Parameters for use in Dynamically Changing Minimum Required Wake Mitigations Separations Between Aircraft* (September 2016), written by FAA researchers, provided an overview and assessment of how the RTCA proposed aircraft observation transmitted data can be combined with other NextGen advances to enable the dynamic determination of required wake separation minima between pairs of aircraft.
R&D PRINCIPLE 3 – REDUCE ENVIRONMENTAL IMPACTS

Systematically expand and apply knowledge to produce useful materials, devices, systems, or methods that will reduce aviation’s environmental and energy impacts
AIRPORT COOPERATIVE RESEARCH PROGRAM (ACRP)

Track Aviation Alternative Fuel

The objective of this research was to develop guidance to help airports identify the potential needs for, the types of, and most convenient mechanisms for consistent tracking of alternative jet fuel into the airport. This guidance will reflect the full range of fuel supply approaches currently used recognizing the diversity of airports as well as incorporate a decision support tool/s (e.g., a matrix/decision tree) for airports.

As alternative jet fuels start to enter the supply chain, there will be a need to keep track of such fuel for technical (e.g., quality control, fuel efficiency), regulatory e.g., tracking reductions in local air quality pollutants or greenhouse gasses, and commercial (e.g., contract verification, communications service request marketing/sustainability reporting) reasons. A logical point to institute fuel-tracking mechanisms may be at the airport because the supply chain for conventional and alternative jet fuels converge before the fuel gets loaded into the aircraft. Airports can play a key role to incentivize the commercialization of alternative jet fuels by helping to facilitate some of the logistics associated with using these drop-in fuels, in particular fuel tracking.

CAASD RESEARCH CONDUCTED

Concept Exploration Addressing PBN Operations at Low Altitudes

PBN is one of the foundational improvements under the FAA Next Generation Air Transportation System (NextGen). PBN enables more predictable and direct routes unconstrained by the location of ground-based navigational aids, thereby reducing congestion, flight time, flight distance, fuel consumption, and carbon emissions. Given the predictable flight paths offered by satellite navigation, PBN flight paths are often more geographically concentrated, whereas conventional flight paths are less accurate and may spread out across a broader expanse of airspace. As a result, while PBN flight path concentration reduces noise exposure for broad areas in the vicinity of airports, it may also have the opposite effect of increasing noise exposure for sensitive locations near or directly under the PBN procedure.

Adverse community reaction to the concentration of flight paths from PBN procedures presents a challenge to the implementation of PBN in the U.S. The FAA is exploring ways to balance operational efficiency with the need to address this noise concentration from PBN procedures. Considering the requirements of multiple stakeholders (communities, airlines, airports, local jurisdictions, and others) in design decisions represents a “trade space” in which the best solution may come at a cost to some or all stakeholders. To inform potential solutions, the FAA has been conducting research in several areas such as aircraft noise modeling techniques, alternative noise metrics or measurements, enhanced community outreach and, in this case, potential operational mitigations.
MITRE CAASD has conducted research to identify candidate operational concepts for the near, mid, and far-term to help mitigate noise issues from flight path concentration. The near-term candidate concepts may be implementable between 2016-2020 using current technology and design criteria. The mid-term candidate concepts may be implementable between 2021-2025 leveraging emerging technologies and modest changes to design criteria. Finally, the far-term candidate concepts may be implementable between 2026-2030 using future technologies and, as required, changes to design criteria. For the near-term candidate operational concepts, a detailed assessment was completed to assess tradeoffs between noise and operational impacts, and identify implementation challenges. A qualitative assessment was completed for the mid and far-term concepts. The candidate near-term operational concepts provide procedure designers with a toolbox of options to be considered during the airspace and procedure design process.

Figure 35: Concept Exploration Addressing PBN Operations at Low Altitudes

**ENVIRONMENT AND ENERGY (E&E) RESEARCH CONDUCTED**

*Development of an Aircraft Carbon Dioxide (CO₂) Standard*

The FAA is committed to managing the carbon footprint of U.S. aviation while simultaneously enhancing the safety and efficiency of the NAS. Following six years of development with significant contributions from FAA, the International Civil Aviation Organization’s (ICAOs) Committee on Aviation Environmental Protection (CAEP) finalized a new CO₂ emissions
certification standard for aircraft at its tenth meeting (CAEP/10) in February 2016. The aim of this first global technology standard for CO\textsubscript{2} emissions is to incorporate more fuel-efficient technologies into aircraft designs. This technology-based approach is in parallel to the current ICAO Annex 16 Standards on engine emissions for local air quality (Annex 16 Volume II) and aircraft noise (Volume I). The CO\textsubscript{2} standard will be published as a new Annex 16, Volume III. The CO\textsubscript{2} standard framework largely consists of a certification requirement and regulatory limit, and accordingly the work was divided in two phases.

The CO\textsubscript{2} metric system measures fuel burn performance, and therefore CO\textsubscript{2} emissions, fairly across aircraft categories. The system, shown in Figure 36, can both equitably reward fuel efficient technologies that reduce aircraft CO\textsubscript{2} emissions as well as differentiate between generations of these technologies. The ICAO Annex 16 Volume III CO\textsubscript{2} Standard certification requirement was developed based on this metric system, and also includes information such as flight test procedures and measurement methodologies. The metric system was a crucial component in the standard development.

![Figure 36: An Overview of the CO\textsubscript{2} Metric System](image)

Aviation environmental standards are designed to be environmentally effective, technically feasible, economically reasonable, and consider environmental interdependencies. These pillars guided a comprehensive assessment of the costs and benefits of all the options that could be selected to form the complete CO\textsubscript{2} standard. The agreement on the CO\textsubscript{2} standard relied heavily on this data informed process. Details are in the report of CAEP/10.

Taking into account all the analysis and data, the standard was agreed to apply to subsonic jets over 5700kg and turboprop aircraft over 8618kg. New Type designs must comply after January 1, 2020, while In-Production (InP) aircraft that are modified and meet a specific change criterion must comply after the first of January, 2023. This is subsequently followed by a production cut-off on the first of January, 2028; whereby noncompliant InP aircraft can no longer be produced unless their designs are modified. Figure 37 shows the agreed NT and InP regulatory limit lines. It is estimated that the CO\textsubscript{2} standard will reduce emissions from commercial aviation by 650 metric tonnes between 2020 and 2040. Further, this new standard will increase the importance of fuel efficiency in the design process. Manufacturers will be encouraged to meet the regulatory limits, as well as obtain competitive product positioning in terms of margins to the limit.
The completion of the international aircraft CO₂ emissions certification standard signals the start of domestic promulgation within ICAO member states’ legislative frameworks. Rulemaking on the U.S. aircraft CO₂ certification standard is expected to be complete in 2019.

**Figure 37: The CO₂ Standard Regulatory Limits**

**NEXTGEN – ALTERNATIVE FUELS FOR GENERAL AVIATION RESEARCH CONDUCTED**

*Develop Engine and Fuel Test Methods to Evaluate the Performance, Safety, Durability, and Operability of Unleaded Aviation Gasoline*

Research into the potential use of alternative fuels poses significant challenges in maintaining the safety of the legacy GA fleet of approximately 167,000 aircraft in the U.S. This fleet currently relies on 100 Low Lead (100LL) Aviation Gasoline (Avgas) for safe operation. 100LL is also the only remaining transportation fuel in the U.S., that contains the Additive Tetraethyl Lead (TEL). TEL has been used as an Avgas additive for decades to create the very high octane levels required to prevent detonation (engine knock) in high power aircraft engines. Operation with inadequate fuel octane can result in engine failure and aircraft accidents. Furthermore, the impacts on performance, safety, operability, and compatibility with existing aircraft fuel system materials and engines must be carefully evaluated before approving an alternative fuel.
In order to do a fleet-wide authorization on a new fuel; a novel approach for the FAA, a comprehensive research and test program was implemented under the Piston Aviation Fuels Initiative (PAFI). The initial efforts focused on developing a test program for candidate fuels. This included initial laboratory and rig test procedures and down-selecting candidate fuels to be comprehensively tested further in fleet representative engine and flight testing as well as additional laboratory testing. This milestone is for the development of the comprehensive fleet assessment and testing plans and procedures with the down-selected fuels. To achieve this milestone, a team of SMEs had to take a preliminary plan and prepare detailed, comprehensive, test plans and procedures that would address the performance, safety, and operability characteristics of candidate fuels with the final selection of test engines and aircraft representative of the transparent fleet. In all, over 49 test plans and procedures were prepared to support testing of the 10 aircraft and 15 engine models that were selected.
This effort represents a true collaborative effort between the FAA and industry under PAFI. Industry representatives including OEMs are part of an advisory committee that have provided subject matter expertise and technical support and input into the program. Furthermore, they have been essential in adding their concurrence to the test program as well as committing substantial resources to perform industry In-Kind test support. This support includes providing engines, aircraft and other test articles as well as actually conducting portions of the test program with FAA representatives present to witness test conduct.

NEXTGEN ENVIRONMENTAL RESEARCH – AIRCRAFT TECHNOLOGY, FUELS AND METRICS RESEARCH CONDUCTED

Continuous Lower Energy, Emissions, and Noise (CLEEN) Program: Phase II, Year Two

The CLEEN Program is the principal environmental effort under FAA’s NextGen aviation modernization program to accelerate the development of new aircraft and engine technologies as well as advance sustainable alternative jet fuels. The CLEEN Program is a key element of the NextGen strategy to achieve environmental protection that allows for sustained aviation growth.

Following the success of the initial CLEEN Program, initiated in 2010, the FAA awarded CLEEN II in late FY 2015 and kicked off the program in early FY 2016 to develop new aircraft technologies to further reduce fuel burn, emissions, and noise and conduct new alternative jet fuels projects. The CLEEN II Program is planned to run from 2015 through 2020.
The CLEEN II Program goals include developing and demonstrating:

- Certifiable aircraft technology that reduces aircraft fuel burn, and/or supports the FAA’s goal to achieve a net reduction in climate impact from aviation;
- Certifiable aircraft technology that reduces Landing and Takeoff Cycle (LTO), Nitrogen Oxide (NO\textsubscript{X}) emissions below ICAO CAEP standards, and/or reduces absolute NO\textsubscript{X} production over the aircraft’s mission;
- Certifiable aircraft technology that reduces noise levels relative to the FAA’s Stage 4 noise standard and/or reduces the noise contour area in absolute terms; and,
- “Drop-in” sustainable alternative jet fuels, including quantification of benefits – drop in alternative fuels will require no modifications to aircraft or fuel supply infrastructure.

The following table represents the quantitative goals for the fuel burn, emissions, and noise metrics under CLEEN II alongside the aspirational goals for the initial CLEEN Program.

<table>
<thead>
<tr>
<th>Goal Area</th>
<th>CLEEN Goals</th>
<th>CLEEN II Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise (cumulative below Stage 4)</td>
<td>-32 decibels (dB)</td>
<td>-32 decibels (dB)</td>
</tr>
<tr>
<td>LTO NO\textsubscript{X} Emissions (Below CAEP/6)</td>
<td>-60 percent</td>
<td>-75 percent (-70 percent relative to CAEP/8)</td>
</tr>
<tr>
<td>Aircraft Fuel Burn</td>
<td>-33 percent</td>
<td>-40 percent</td>
</tr>
</tbody>
</table>

The goals for CLEEN II reflect aspirations for aircraft technology advancements that reduce commercial aircraft’s environmental footprint while taking into account the progress achieved in the first phase of the CLEEN Program. The FAA has selected partner companies to participate in CLEEN II through a cost-sharing program. The awarded CLEEN II companies are:

- Aurora Flight Sciences
- The Boeing Company
- Delta TechOps/MDS Coating Technologies/America’s Phenix
- GE Aviation
- Honeywell Aerospace
- Pratt & Whitney
- Rolls Royce
- Rohr, Inc./UTC Aerospace Systems

In FY 2016 CLEEN II reached two major project milestones. Boeing completed conceptual design of their Structurally Efficient Wing technology. The conceptual design review, which
Boeing completed in March 2016, moves the project into the preliminary design phase, building toward fabrication and structural testing of the wing, which will conclude in 2019. The team of MDS Coating Technologies, Delta Tech Ops, and America’s Phenix completed data gathering and coating optimization testing on their leading edge protective coating for turbofan blades. This project team is developing an erosion resistant coating to help jet engine fans retain their efficiency in service, reducing fuel burn over the aircraft’s life. The benefits are estimated to be one percent fuel savings during aircraft cruise and two percent fuel savings at maximum power.
# Acronym List

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<td>0-9</td>
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<tr>
<td>100LL</td>
<td>100 Low Lead</td>
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<tr>
<td>2D</td>
<td>Two-Dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>Three-Dimensional</td>
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<td>AC</td>
<td>Advisory Circular</td>
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<td>AFS</td>
<td>Active Flutter Suppression</td>
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<td>AOV</td>
<td>Air Traffic Safety Oversight Service</td>
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<td>Annual Review</td>
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<td>Air Traffic Control</td>
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<td>Advanced Technology Demonstrator</td>
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<td>Air Traffic Organization</td>
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<td>Airport Technology Research Program</td>
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<td>Avgas</td>
<td>Aviation Gas</td>
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<td>Airport Weather Advanced REadiness</td>
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<td>Aviation Weather Center</td>
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<td>Aviation Weather Testbed</td>
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<td>C</td>
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<td>C&amp;V</td>
<td>Ceiling and Visibility</td>
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<td>CAASD</td>
<td>Center for Advanced Aviation System Development</td>
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<td>CAEP</td>
<td>Committee on Aviation Environmental Protection</td>
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<td>Civil Aerospace Medical Institute</td>
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<td>Code of Federal Regulations</td>
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<td>CLEEN</td>
<td>Continuous Lower Energy, Emissions, and Noise</td>
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<td>CO₂</td>
<td>Carbon Dioxide</td>
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<tr>
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<td>Center of Excellence for Commercial Space</td>
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<td>Cybersecurity Risk Model</td>
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<td>DAA</td>
<td>Detect and Avoid</td>
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<td>Development Assurance Levels</td>
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<td>Decision Support Tools</td>
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<td>E</td>
<td></td>
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<tr>
<td>EMST</td>
<td>Emerging Metallic Structural Technology</td>
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<td>ETWG</td>
<td>Emerging Technologies Working Group</td>
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<tr>
<td>Acronym</td>
<td>Full Form</td>
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<td>FAA</td>
<td>Federal Aviation Administration</td>
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<td>Federal Aviation Regulation</td>
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<td>Fatigue Crack Growth</td>
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<td>Finite Element Method</td>
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<td>Facility Risk Assessment Tool</td>
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<td>FY</td>
<td>Fiscal Year</td>
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<td>G-AIRMETs</td>
<td>Graphical Airmen’s Meteorological Information</td>
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<td>General Aviation</td>
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<td>HOTL</td>
<td>Human Over the Loop</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<tr>
<td>LSTC</td>
<td>Livermore Software Technology Corporation</td>
</tr>
<tr>
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<td>Landing and Takeoff Cycle</td>
</tr>
<tr>
<td>MCP</td>
<td>Microprocessors</td>
</tr>
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<td>MinWxSvc</td>
<td>Minimum Weather Service</td>
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<td>Materials Flammability Working Group</td>
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<tr>
<td>MMPDS</td>
<td>Metallic Materials Properties Development and Standardization</td>
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<td>MOPS</td>
<td>Minimum Operational Performance Standards</td>
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<td>MPAR</td>
<td>Multifunction Phased Array Radar</td>
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<tr>
<td>NARP</td>
<td>National Aviation Research Plan</td>
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<td>NASA</td>
<td>National Airspace System</td>
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<td>Next Generation Air Transportation System</td>
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<tr>
<td>NOx</td>
<td>Nitrogen Oxide</td>
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<tr>
<td>NTDA</td>
<td>NEXRAD Turbulence Detection Algorithm</td>
</tr>
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<td>NWP</td>
<td>Numerical Weather Prediction</td>
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<td>NWS</td>
<td>National Weather Service</td>
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<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
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<td>PAFI</td>
<td>Piston Aviation Fuels Initiative</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>PBN</td>
<td>Performance Based Navigation</td>
</tr>
<tr>
<td>POWER</td>
<td>Propulsion and Airpower Engineering Research</td>
</tr>
<tr>
<td>R</td>
<td>Research and Development</td>
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<td>RECAT</td>
<td>Wake Re-Categorization</td>
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<tr>
<td>RSA</td>
<td>Runway Safety Area</td>
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<td>RTCA</td>
<td>Radio Technical Commission for Aeronautics</td>
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<td>Service Delivery Points</td>
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<td>Subject Matter Expert</td>
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<td>Standard Operating Procedures</td>
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<td>Safety Risk Management Document</td>
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<td>Selective Serotonin Reuptake Inhibitors</td>
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<td>Tetra-Ethyl-Lead</td>
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<td>United States</td>
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<td>WILD</td>
<td>Weather Information Latency Trainer</td>
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<tr>
<td>WTIC</td>
<td>Weather Technology in the Cockpit</td>
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