



**Federal Aviation
Administration**

FY 2015 R&D Annual Review

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**Report of the Federal Aviation Administration to
the United States Congress pursuant to Section
44501(c) of Title 49 of the United States Code**

FY 2015 R&D Annual Review-Final

April 2016

The Research and Development (R&D) *Annual Review* (AR) is a companion document to the *National Aviation Research Plan* (NARP), a report of the Federal Aviation Administration (FAA) to the United States Congress pursuant to Section 44501(c)(3) of Title 49 of the United States Code. The R&D *Annual Review* is available on the internet at (<http://www.faa.gov/go/narp>).

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Introduction

The FAA uses R&D to support policy and planning, regulation, certification, standards development, and modernization of the 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 following table, Strategic Alignment of FAA R&D Principles, shows the primary relationship among the FAA R&D principles and elements from other pertinent strategic documents. The following chapters will provide greater detail about the 25 underlying goals that support FAA’s accomplishment of these three principles.

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

Characterize the Effects of Blunt Impact on Composite Structures Typically Used in Fuselage Applications:

The overarching goal of research has been to establish validated modeling protocols to simulate damage to composite aircraft structures when subjected to soft or blunt impact loads. This study focuses on two types of structures; large transport aircraft stiffened skin (e.g., fuselage) subjected to Ground Service Equipment (GSE) impact, and sandwich panels subjected to impacts from hail and large-radius objects. This work was performed through the FAA's Joint Advanced Materials and Structures Center of Excellence (JAMS) University of California San Diego. For GSE impact on fuselage structures, progress has been made in two main areas, by demonstrating methodology for establishing accurate procedures for Finite Element (FE) modeling of progressive damage of aircraft structures under blunt impact loading, and by sub-element level testing of composite C-frame conducted in support of the development of FE models predicting frame failure modes.

The FE analysis methodology is based on the build-up of physics-based models using coupon and sub-element level tests for validation. A key initial failure mode is shear tie delamination/crushing, which exhibited inherently Three-Dimensional (3D) behavior requiring the use of 3D solid elements in their modeling (see figure 1 left and below). This model has been incorporated into the full panel model (see figure 1 right and below) to accurately capture:

- Full panel response including shear tie delamination;
- Crushing;
- Frame rotation and contact sliding along stringers;
- Progressive fracturing of the shear ties, and
- Frames cracking.

Comparison of FE prediction and experimental measurement in figure 2 below, shows the model accurately capture each failure mode together with the associated load and displacement levels. The final failure, frame fracture under combined bending and torsion has been further investigated by following the FE methodology established for this program. Bending and bending torsion tests of frame-element specimens were conducted as shown in figure 3 below. The measured load and strain data from these tests (5 specimens total) will be used for developing accurate FE model predicting frame cracking under combined loading conditions.

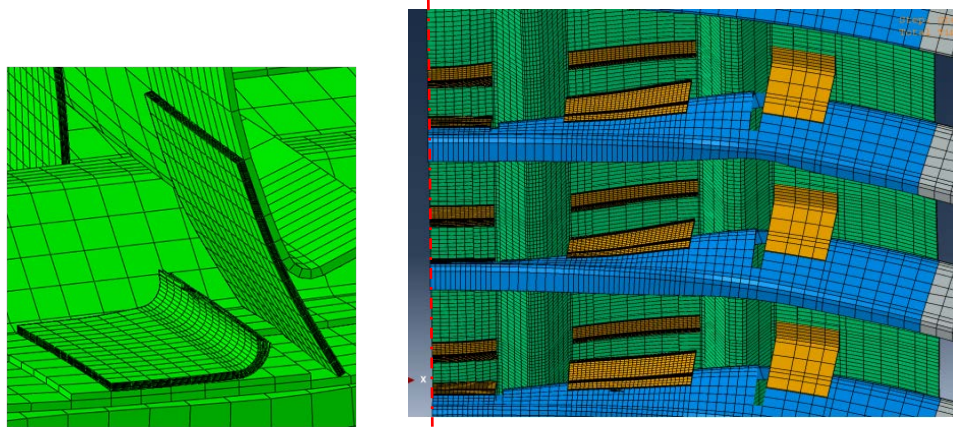


Figure 1: (Left) Accurate Shear Tie Crush Model, (Right) Response to Shear Ties in Large Panel Half Symetric Model

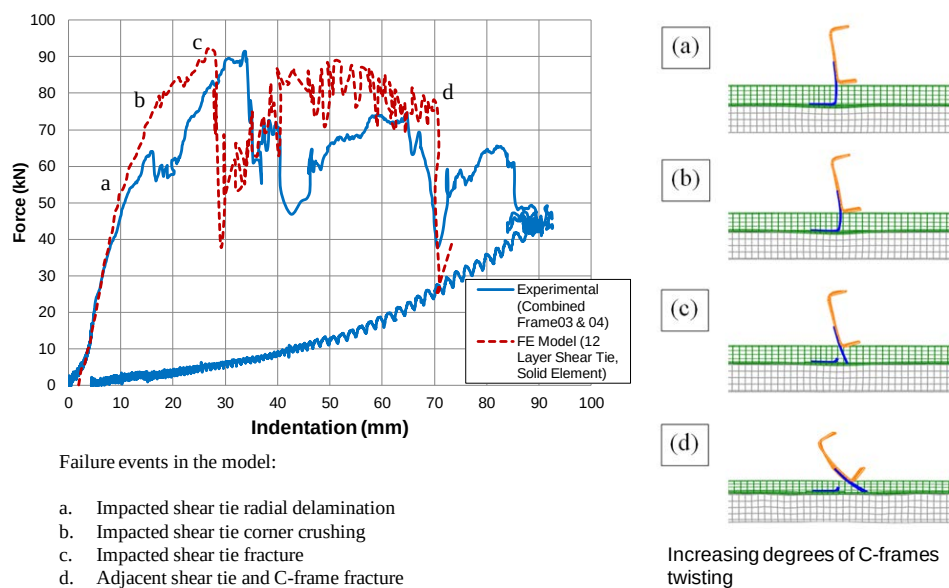


Figure 2: Contact Force vs. Indentation Plot of the Frame 03 Test and FE model with Solid Element Shear Ties

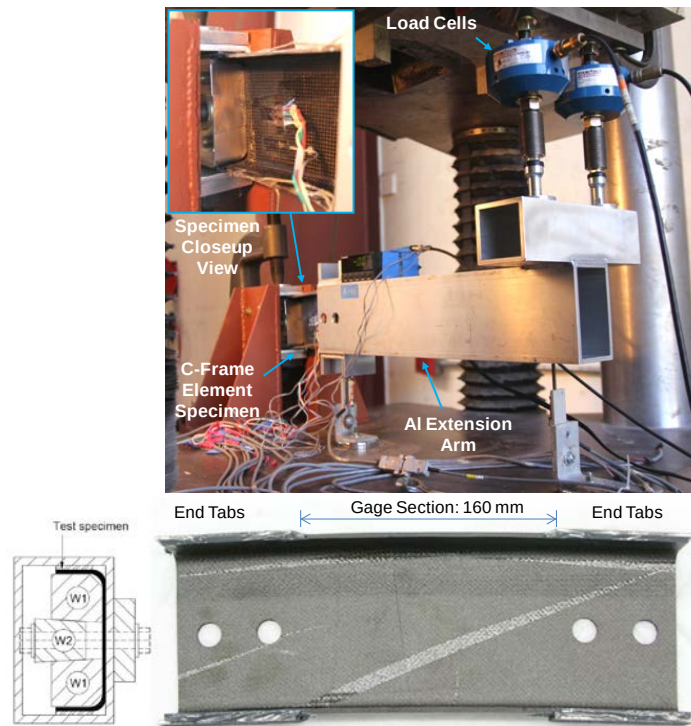


Figure 3: Composite C-Frame Bending Test Specimen and Setup

For impact onto sandwich panels, the focus is on soft/blunt impacts, which produce internal damage to the core. In particular, the prediction of fracture failure of Nomex® honeycomb core and the resulting residual dent is of interest. Static and dynamic indentation experiments on honeycomb core specimens have been conducted to measure the core response, namely the elastic regime, cell wall buckling, core crushing, and unloading response. The load versus displacement of a core experiment, as shown in figure 4 below, indicates significant residual dent following unloading. Current existing models, while able to accurately predict the core crush up-loading response, are not able to accurately capture the unloading, as indicated by the residual dent prediction discrepancy. Thus, further research is needed to clearly understand the mechanisms of residual dent formation and define modeling capability for predicting the state of internal core damage and associated residual dent.

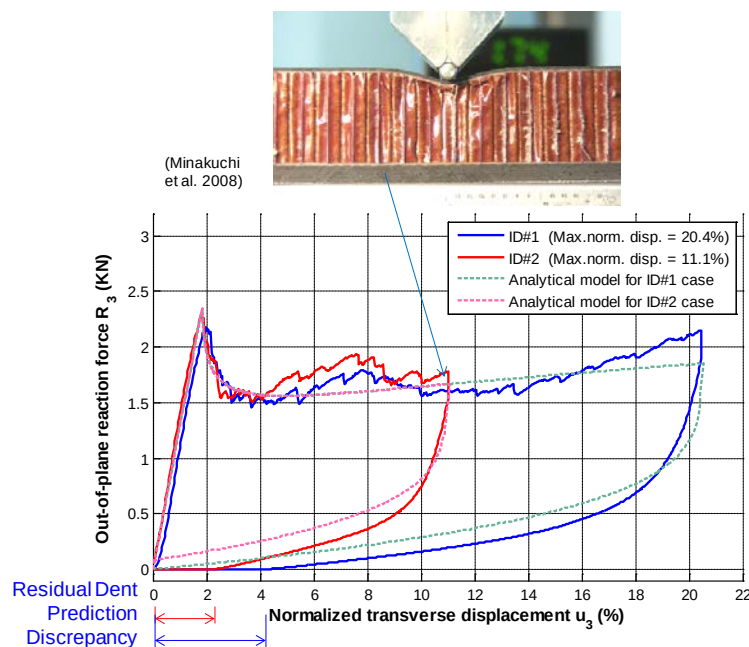


Figure 4: Nomex Honeycomb Core Indentation and Unloading Measurement and Model Comparison

Aeromedical Research Conducted

Accomplish Experimental Projects in Support of Regulations, Certification, and Operations for Existing Aviation Rulemaking Committees by Providing Data and Guidance for New or Revised Regulation of Airliner Cabin Environment Standards:

This research will be completed in September 2015 with final documentation of all research completed by December 2015. It is not a single activity, rather, this milestone is the culmination of much of the research that the Airliner Cabin Environment Research (ACER) Center of Excellence (COE), now called the National Air Transportation Center of Excellence. To date, the Research in the Intermodal Transport Environment (RITE) has been completed and will finalize by the end of 2015 (calendar year). The RITE/ACER COE was given an extension to enable the completion of participation in an oil ingestion experiment as part of the joint United States Air Force (USAF), along with NASA and the Federal Aviation Administration (FAA) Vehicle Integrated Propulsion Research (VIPR) Program that was completed in July 2015. The termination date for the RITE/ACER COE is set as September 30, 2015. As COE's have up to three months to complete documentation of their studies, the Technical Monitor for the RITE/ACER COE anticipates that the participants in the VIPR work will complete their final reports by the end of calendar year 2015. The RITE/ACER COE research completed or soon to be completed which supports includes reports issued by the FAA Office of Aerospace Medicine, papers published in peer-reviewed journals and presentations given at national and international symposiums. Over 100 papers and presentations have distributed the results of the research of the COE. Some of the research article titles include:

- *Health Effects of Aircraft Cabin Pressure In Older and Vulnerable Passengers Prediction of Particle Transport in Enclosed Environment;*
- *Ozone Levels in Passenger Cabins of Commercial Aircraft on North American and Transoceanic Routes;*
- *On the Use of Reconfigurable Hardware in Sensor System Integration for Airliner Cabin Environment Research;*
- *Creation of Airliner Sensor and Cabin Environment Network (ASCENT);*
- *Selection of Sensor Technologies for Further Evaluation or Implementation (Chem.–Bio.Sensors);*
- *Electrochemical Detection of Tricresyl Phosphate(TCP);*
- *A Carbon Paste Electrode for TCP Detection;*
- *A Review of Sensor Technologies for the Detection of Harmful Chemical and Biological Agents On-Board Commercial Aircraft;*
- *Comparison of Large Eddy Simulation Predictions with Particle Image Velocimetry Data for the Airflow in a Generic Cabin Model;*
- *Review of the Draft American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard for Air Quality within Commercial Aircraft;*
- *The Need for Standards in the Evaluation of the Applicability to Civil Aviation of Chem.–Bio Sensors and Decontamination Technologies;*
- *Optimizing Contaminant Sensor Locations in a Twin-aisle Aircraft Cabin;*
- *Experimental and Numerical Investigation of Airflow and Contaminant Transport in an Airliner Cabin Mock-up;*
- *Response of Contaminant Detection Sensors and Sensor Systems in a Commercial Aircraft Cabin;*
- *Detection of Bacillus Anthracis Spores Using Magnetostrictive Microcantilever-Based Biosensors, and*
- *Ozone-Initiated Chemistry in an Occupied Simulated Aircraft Cabin.*

The completed research has extended the knowledge base of FAA and industry on the environment within the cabin from a theoretical basis and from actual commercial revenue

flights. This research has conducted inflight measurements of contaminants. It shows contaminants are transported on airplanes and created new inflight sensors to provide real-time warning of the presence of contaminants. It also established test protocols for their use in commercial airplanes and it has recommended the use of new industry standards for adoption by the FAA on commercial airplanes. This research will enable the FAA to proceed with rulemaking to revise the existing regulations to improve the level of safety while providing savings to industry. Eliminating the current fixed ventilation flow rate requirement (i.e., 14 CFR Part 25.831) as well as requiring real time monitoring of Carbon Monoxide (CO), Carbon dioxide (CO₂), Ozone (O₃) and particulate material along with High-Efficiency Particulate Arrestance (HEPA) filters and ozone converters, enables the FAA's new regulations to ensure a safe cabin environment.

By requiring real-time alerting of these contaminant levels, FAA will enhance the level of safety by eliminating the current trial-and-error approach to unknown cabin fumes and replace it with sensors that will alert the crew of the source of contaminants. The potential reduction in fuel burn will save the airline industry millions of dollars a year in operating expenses and help airlines and airplane manufacturers to lower engine/airplane emissions. Lastly, the culmination of this research provides the FAA with the means to bring the regulations governing the cabin environment into the 21st century. The Transport Airplane Directorate (TAD) proposed an Aviation Rulemaking Advisory Committee (ARAC) task to review the current FAA regulations governing the cabin environment (i.e., §§ 25.831 and 25.832) in 1999. ARAC accepted the tasking in 2001, and TAD prepared a tasking notice to appear in the federal register in 2002. Upon review, the Director of Aircraft Certification placed this task on hold pending completion of industry research, in particular, research from the AHSRAE with the completion of the ASHRAE Phase II Report (second quarter 2016), and the completion of the RITE/ACER COE. The FAA will have all the information necessary to conduct this rulemaking task.

Aerospace Accident - Injury and Autopsy Data System (AA-IADS):

The Office of Aerospace Medicine (AAM) conducts medical investigations of fatal and non-fatal aircraft accidents and incidents to determine the relationships of medical, toxicological, and human factors to the probable cause of the accident. In addition, AAM investigates the relationship between aircraft design, injury, and survival. The findings are applied toward improving aviation safety through proven recommendations by which regulatory and educational activities and best-practice standards are exercised. In 2015, the FAA Aerospace Medical Research Division of the Civil Aerospace Medical Institute (CAMI) deployed several upgrades to the Aerospace Accident - Injury and Autopsy Data System (AA-IADS); initially deployed in April 2013. The main purpose of the AA-IADS is to provide researchers with the ability to efficiently analyze injuries within the broad context of the accident or event that caused the injury. To accomplish reduction to injury and fatality rate, as well as improve safe certification of airmen; CAMI conducts four main research activities:

- Investigation of injury and death patterns in civilian accidents along with meticulous analysis to determine cause(s) and prevention strategies;
- Development of recommendations for protective equipment and procedures;

- Evaluation of options, addressing all aircraft cabin occupants, and
- Analysis of medical conditions identified on autopsy or treatment records but not necessarily causal to the accident, i.e., incidental medical findings.

The AA-IADS software tool supports research efforts undertaken to reduce injuries and fatalities caused by aircraft accidents or incidents and assist aeromedical certification in accurate issuance of medical certificates by evaluating IMFs in accident victims. The AA-IADS integrates data from multiple external sources, provides metadata, standardizes key data elements, and allows researchers to correlate an injury with multiple variables. The system provides flexibility to accommodate the future integration of advanced data visualization capabilities. In addition, the system allows for express generation of custom data sets that addresses fundamental research questions. AA-IADS is a web-based intranet application that resides on FAA servers behind the FAA firewall. It interfaces with the CAMI toxicology database, the Aviation Safety Information Analysis and Sharing (ASIAS), and the CAMI Document Imaging and Workflow System (DIWS). Current AA-IADS technology is based on Microsoft SQL Server 2005, IIS 6.0 and Microsoft .NET framework 4.0 running on Windows 2003 R2 servers.

NTSB Number	Event Type	Event Status	Event Date	Event Location State	Record Start Date	Registration Number
N71136	Open	Open	5/12/2013	TX	5/12/2013	N71136
N71137	Open	Open	5/12/2013	TX	5/12/2013	N71137
N71138	Open	Open	5/12/2013	TX	5/12/2013	N71138
N71139	Open	Open	5/12/2013	TX	5/12/2013	N71139
N71140	Open	Open	5/12/2013	TX	5/12/2013	N71140
N71141	Open	Open	5/12/2013	TX	5/12/2013	N71141
N71142	Open	Open	5/12/2013	TX	5/12/2013	N71142
N71143	Open	Open	5/12/2013	TX	5/12/2013	N71143
N71144	Open	Open	5/12/2013	TX	5/12/2013	N71144
N71145	Open	Open	5/12/2013	TX	5/12/2013	N71145
N71146	Open	Open	5/12/2013	TX	5/12/2013	N71146
N71147	Open	Open	5/12/2013	TX	5/12/2013	N71147
N71148	Open	Open	5/12/2013	TX	5/12/2013	N71148
N71149	Open	Open	5/12/2013	TX	5/12/2013	N71149
N71150	Open	Open	5/12/2013	TX	5/12/2013	N71150

Figure 5: Aerospace Accident Injury and Autopsy Data System (AA-IADS) Screen Shot

Develop Bleed Air Contamination Models of Engine Compressors and High Temperature Air System for Effects on the Health and Safety of Passengers and Crew:

This research is part of the activities that the ACER COE, now called the National Air Transportation COE Research in the Intermodal Transport Environment (ACERite) has completed to date and will finalize by the end of 2015 (calendar year). The ACERite COE was given an extension to enable the completion of their participation in an engine oil ingestion experiment, part of the joint USAF/NASA/FAA VIPR Program completed in July 2015. The data obtained from this study will enable the COE to complete a bleed air-contamination model

of an engine compressor and provide insight into the potential effects on the health and safety of passengers and crew. The termination date for the ACERite COE was September 30, 2015. Although COEs have up to two months to complete documentation of their studies and the Technical Monitor for the ACERite COE anticipates that the participants in the VIPR work will complete their final report before the end of calendar year 2015. This research and that of the ACERite COE will extend the FAA's knowledge base of the environment within the cabin during air contaminant events and provide needed information on contaminant formation and transport within the engine. It will provide valuable data to industry that may result in improvements in air-contaminant transport standards. The data should improve the design and operation of new sensors required with improved Environmental Control Systems (ECS) that monitor air quality within the cabin and vary the amount of ventilation flow, in order to ensure a safe environment within the cabin. The use of these sensors could enhance safety by indicating the source of air contaminants. Several industry members have been developing improved ECS concepts and this research will improve the FAA's understanding of contaminant development and necessary sensors to ensure a safe cabin environment.

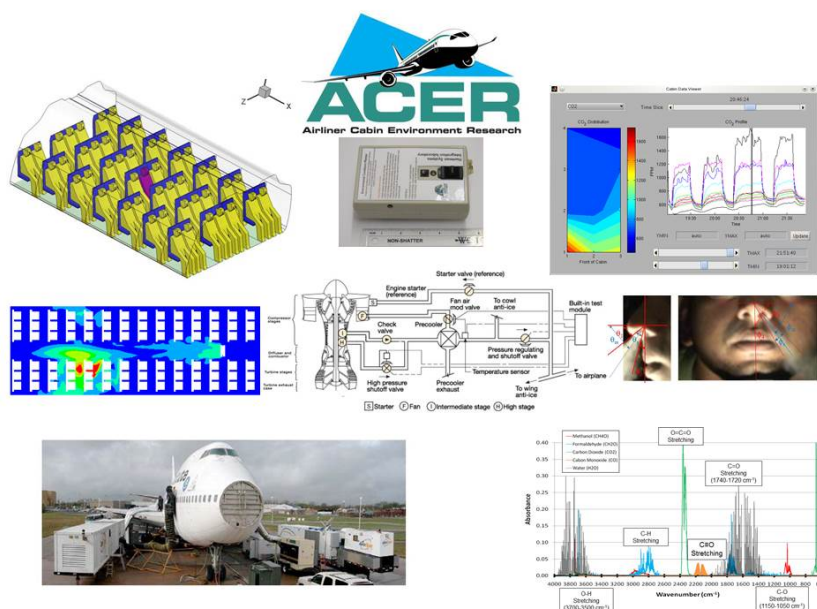


Figure 6: Images Capturing Work from the Start to Finish of the ACERite COE (2004-2015)

FAA will study the results of the ACERite COE research to determine if revisions to our existing regulatory guidance are needed. Companies have approached FAA with concepts for improved ECS that purport to offer potential fuel savings and the lowering of engine emissions on commercial transport category airplanes while providing a safe cabin environment. These systems may require real time monitoring of some gaseous contaminants and particulate material. The culmination of the ACERite COE research provides the FAA and industry with the knowledge to improve the cabin environment in the 21st century.

High Performance Computing (HPC):

HPC enables the realization of Safety Management Systems (SMS) to provide a systematic way to control risk and to provide assurance that those risk controls are effective. SMS is an International Civil Aviation Organization (ICAO) requirement for all its member states, U.S. being one of them. In line with this requirement, the general goals of HPC capability towards and aeromedical SMS are to:

- Capitalize on collaborative knowledge and expertise – enable the integration of research data; molecular, aeromedical, cognitive, psychological, behavioral, and other information from disparate sources and/or seemingly random data;
- Develop HPC based equivalence models – towards an economically feasible answer to the rising cost of conventional research;
- Develop paradigms validated by mathematical modeling and advanced variable computation – minimize the cost of simulator research;
- Develop risk models and probability distribution functions for end states, events, and accident scenarios;
- Identify & evaluate risks for refinement of standards & medical certification requirements, and
- Transform current analytical paradigms: go from simple questions, e.g., linear queries based on samples (incomplete data), to complex questions based on integrated population data.

The FAA Aerospace Medical Research Division of CAMI has integrated an HPC analytic engine (hardware and software) with enough memory and power to execute pilot population queries. This used to run for days or longer, now allowing statistical analysis of aeromedical safety issues to complete in much shorter time intervals and update the results of earlier studies with new data. This resulted in output closer to real time analysis, versus traditional study periods of many months activities including:

- Rebuilding the CAMI Scientific Information System on the HPC, demonstrating it can perform longitudinal studies;
- Preparing the system to execute pilot population longitudinal research studies to include the examination of a disqualifying pathology over a pilot's entire aeromedical history, and
- Demonstrating the utility of HPC using Monte-Carlo techniques applied to aviation epidemiology (i.e., the use of the entire U.S. pilot population).



Figure 7: High Performance Computing Capability at CAMI

Aircraft Evacuation Passenger Behavior:

Computer simulation of aircraft evacuation has been reported in recent years. However, there is only very limited study on the grouped passenger behaviors during emergency evacuation. On the other hand, group passengers such as families and friends travel together may be reluctant to separate from the group during an emergency evacuation. At the same time, the leader of the group may wait for the rest of the group members in order to ensure safety for the entire team. This scenario might affect the evacuation patterns and ultimately affect the evacuation time of the entire plane. The FAA Aerospace Medical Research Division of CAMI collaborated with Rutgers University to develop data from computer simulations of the grouped passenger behaviors for analysis. Group parameters, such as passenger combinations of the groups, number of groups, and seating locations of the groups, random and pre-defined, and moving speed of groups are studied using Monte Carlo simulations. Emergency evacuations of airplanes with grouped passengers and without grouped passengers were compared in terms of total evacuation time and each egress usage. Findings included:

- Seating assignment and the concentration of grouped passengers will impact the total evacuation time due to group evacuation behaviors;
- Total evacuation time of randomly seated group passengers on a double aisle vehicle may increase more than that on a single aisle vehicle;
- Group passengers with clustered seating should be located towards the end (or front) of airplane.

In conclusion, clustered seating in the center of airplane is the worst and group passengers with a line-pattern seating is better than clustered seating. In a double aisle vehicle, a line pattern along the center seats is the best.

Group Speed = Speed of the **slowest passenger**

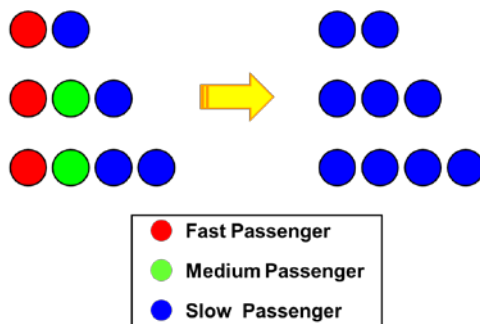


Figure 8: Group Speed and Speed of the Slowest Passenger

Rapid Decompression as a Worst Case Scenario:

Sudden decompression of an airliner passenger cabin due to structural failure or damage is unlikely, but it poses a potentially life-threatening event for occupants. The Aerospace Medical Research Division of CAMI investigated a worst-case scenario, where the passenger fails to receive supplemental oxygen during a Rapid Decompression (RD) and the subsequent emergency descent to 25000 ft., required by FAA policy. The research question is whether an individual's oxygen stores will deplete prior to the aircraft descending to an altitude that will permit inward fluxes of oxygen that exceed the resting oxygen consumption requirement. The experimental protocol included the exposure of 24 human subject volunteers to normobaric (sea level) instantaneous decompressions to a simulated altitude of 35000 ft. The peak altitude was held for 10 seconds, followed by a 5000 ft. per minute descent to 25000 ft. Resting oxygen consumption was measured prior to the hypoxia exposure. During each trial, tidal volume, respiratory rate, and breath-by-breath inhalation and End-Tidal Oxygen (ETO₂), CO₂, and Nitrogen (N₂) tensions were measured. The net directional oxygen flux was also computed. All subjects had an initial reversal of the direction of oxygen flux following the RD that persisted until after the descent commenced with outward flux predominating at higher altitudes of the profile. Return to net inward flux usually occurred near 29000 ft. and the altitude at which the mixed venous and alveolar Oxygen Partial Pressure (PO₂) gradient approximates nil. The inward flux of oxygen approached but never surpassed each subject's resting oxygen consumption as the altitude approached the 25000 ft. endpoint. Based on the data; computational methods were used to predict the O₂ fluxes that would have occurred during normobaric exposures to 40000 and 45000 ft., along with Boyle's Law effects expected during an actual rapid decompression.

In a cohort of 24 healthy young adults, exposure to a normobaric RD to simulated 35000 ft., followed by the two-minute FAA flight profile, the total inward O₂ flux was less than resting oxygen consumption requirements, but did not exceed theoretical exchangeable reserves. This data is unique in that it is the first to result from actual human exposure to the descent profile required by FAA policy. By permitting airplanes to fly above 40000 ft., it offers real and tangible benefits to the aerospace industry, the traveling public, and the U.S. economy, by reducing air traffic congestion, pollution, and improving fuel economy. The results of this

research serve to quantitatively define risk associated with a high altitude decompression, and may be useful in future policy decisions.

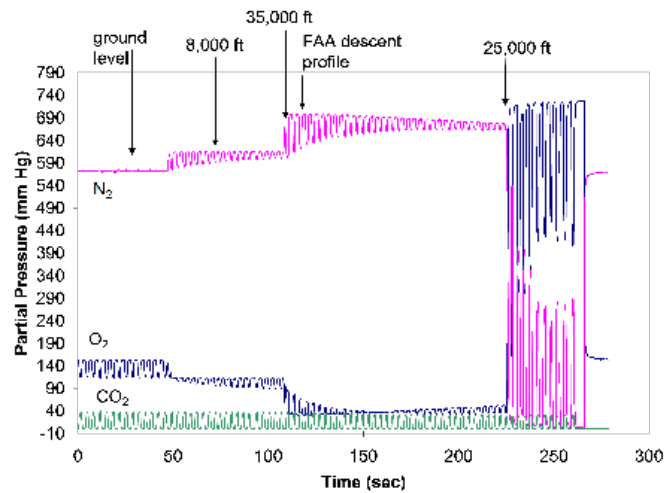


Figure 9: Breath-by-Breath Inhaled and Exhaled Respiratory Gases during a Normobaric RD to Simulated 35000 ft. and Subsequent Two-Minute Descent to 25000 ft.

Air Traffic Control/Technical Operations Human Factors Research Conducted

Conduct a Human-in-the-Loop Experiment to Assess the Possible Effects of Integration of UAS into Class C Airspace, Including Effects on Terminal Controller Workload and Communications:

Unmanned Aircraft Systems (UAS) access to the NAS is a priority because public and civil users are increasingly interested in using UAS for a broad range of purposes. Current requests for access to the NAS are subject to technical and operational assessments of the specific UAS operation in question based on interim approval guidance. UAS operations are subject to operational limitations when there is any perceived risk to the public. The FAA and the broader UAS community are interested in reducing such restrictions to improve and advance integration of UAS into the NAS. Therefore, validated operational standards and policies need to be established. The goal of this research is to determine the certification obstacles for UAS and equipment that will replace the pilot's see and avoid functions in order to provide a means of compliance to 14 CFR Part 91. The results of this simulation will be identified and document issues associated with UAS integration in Class C airspace and the potential impact to Air Traffic Control Specialists (ATCS). The results will inform FAA policy and decision-making, provide recommendations, and identify areas for further research to determine how to best to integrate UAS into the NAS. The research described in the report addresses the inability of UAS to comply with FAA regulations and Air Traffic Control (ATC) clearances that rely on direct pilot observation (i.e., visual compliance) and the resulting impact to the NAS.

Currently, each UAS in controlled airspace must be accompanied by a chase aircraft with an onboard observer or a ground observer. This is meant to address components of the visual compliance requirement. Additional horizontal separation is required between UAS and other aircraft as a result. The visual compliance requirement also prevents ATCS from clearing a UAS pilot to maintain visual separation from another aircraft, asking a UAS pilot to report an aircraft or airport in sight, clearing a UAS pilot for a visual approach, and providing control instructions that would cause the UAS to fly into Instrument Meteorological Conditions (IMC). All of these limitations posed by the visual compliance requirement may affect ATCS and the airspace they manage.

Three experiments were conducted using a high fidelity, Human-In-The-Loop (HITL) simulation as a research platform. Six groups of two ATCS participants each ($n = 12$) provided data in the experiments. The first experiment examined UAS integration in the Terminal Radar Approach Control (TRACON) traffic pattern using low approaches. Experiment 2 examined how missed approaches at a secondary airport interact with UAS approaches at a primary airport. Experiment 3 examined different levels of UAS integration in the arrival stream. During each experiment, the participants controlled traffic in two Class C airspace arrival sectors derived from Northern California TRACON airspace. Multiple objectives and subjective measures were collected, including airspace efficiency, participant workload, communications, and performance. Data was analyzed separately for each experiment and each sector.

Overall, the participants were able to manage traffic safely in all three experiments, as measured by the relatively low number of losses of separation and absence of mid-air and near mid-air collisions. However, airspace efficiency was affected and the participants' perceptions of traffic management were often lower in conditions that included UAS. In experiment one, aircraft spent more time and traveled a greater distance in the final approach sector, and more aircraft were handled in the adjacent sector when UAS were in the airspace. UAS also affected communication patterns. The participants made more but shorter communications when UAS were in the airspace possibly because more control actions were required to manage UAS due to their inability to accept visual clearances. Shorter communications may suggest an increased urgency or pace. The participants reported that UAS had a negative effect on their performance. They reported that their efficiency was lower, their workload due to separation requirements was higher, the overall difficulty of scenarios was higher, and some aspects of their situation awareness were lower when UAS were in the airspace.

The results of experiment two indicated that the integration of UAS in the airspace may affect aircraft handling and ATCS perceptions of traffic management. In one sector, the participants issued more altitude and approach commands and the participants and pilots made shorter transmissions when UAS were in the airspace. Workload rating response times—a secondary measure of workload, were also higher when UAS were in the airspace. In one sector, workload-rating response times were affected by both the presence of UAS and the scenario time interval. The longest rating response time occurred during the time interval when a missed approach interfered with UAS operations. The participants reported that the presence of UAS increased scenario difficulty and had a negative effect on their performance for sequencing aircraft and on aspects of their situation awareness. The results of experiment three included scenarios with lower and higher levels of UAS operations; indicated that the integration of UAS in the airspace

may negatively affect airspace efficiency, aircraft handling, and ATCS perceptions of traffic management. The most negative effects were obtained with higher levels of UAS integration.

In one sector, the participants handled more aircraft and the aircraft spent more time and travelled longer distances in scenarios with a higher level of UAS integration compared to scenarios without UAS or with a lower level of UAS integration. There were also fewer full stop arrivals in scenarios with a higher level of UAS integration. The participants issued more commands overall, including heading commands when a higher level of UAS operations were integrated in the airspace and issued more speed and approach commands whenever UAS were present. In the final approach sector, the participants made more and shorter transmissions with a higher level of UAS operations, suggesting more urgency. Workload ratings were higher and scenarios were rated more difficult with a higher level of UAS integration, but overall workload was negatively affected whenever any UAS were integrated into the airspace. Overall, the results indicated that efficiency, communications, and workload may be impacted when UAS are integrated in the NAS. UAS integration did not affect measures of risk or safety. It is important to note that none of the participants in this simulation had experience controlling UAS prior to participating in these experiments. Their comments indicated that substantial training is required for ATCS to become familiar with UAS performance characteristics and capabilities. ATCS negative perceptions of the impact that UAS had on various aspects of their performance should be reduced or subside with training and increased experience with UAS operations. Data suggests that a low number of UAS operations in Class C airspace are tenable and should have relatively small effects on the airspace and ATCS. However, until UAS are able to meet the requirements for visual compliance, rising levels of UAS operations in busy Class C airspace may have significant effects on ATCS communications, workload, and airspace efficiency.

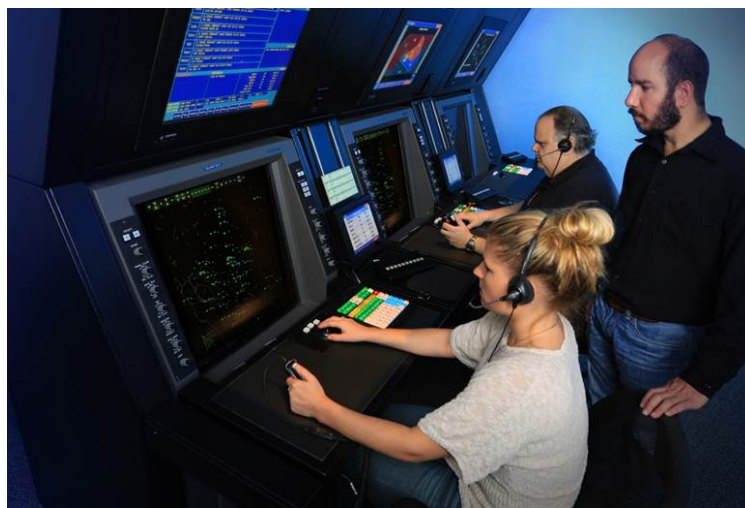


Figure 10: Human-in-the-Loop Studies Lead to Improvements in Information Display

Conduct Strategic Job Analysis for Operations Research Analyst Occupation in Support of Administrator's Risk-Based Decision Making Strategic Initiative:

Operations Research Analysts (ORA; FV-1515) play a critical role in risk and safety data analyses under the FAA Administrator's Risk-Based Decision Making (RBDM) strategic

initiative. The goal of this research was to identify how work performed by, and competencies required of ORA in the FAA aviation safety community, are likely to change over the next five to seven years. The changes will come as a response to major trends, such as UAS integration, big data and analytics, and the shift from reactive, enforcement-orientated, towards a proactive, compliance-based regulatory model for oversight of operators in the NAS. To achieve this goal, a strategic job analysis was conducted by a cross-functional team with technical direction from researchers from the FAA CAMI. A strategic job analysis has three basic phases, which are to:

- Describe the current work performed and competencies required (as is analysis);
- Describe the work likely to be performed as well as the competencies likely to be required at some time in the future (to be analysis); and
- Analyze the gap between the ‘as is’ and the ‘to be’ descriptions (gap analysis).

As of summer 2015, the FAA employed 178 ORAs, with 69 in the aviation safety community and 109 employed in other organizations within the FAA. Previous work under the RBDM strategic initiative from 2014 describing the work performed and competencies required, position documentation, and other descriptions of ORA work and competencies were reviewed. A job analysis survey was constructed based on that review; the job analysis survey was distributed to 176 ORAs (excluding senior executives), with 114 completed (56 from the aviation safety community, and 58 from other organizations). The survey data was used to construct an ‘as is’ description of ORA work and competencies to complete the first phase of the strategic job analysis. For the ‘to be analysis,’ 14 supervisors and managers of ORAs and safety program managers in the aviation safety community, were interviewed regarding how work performed by, and competencies required of ORAs might change over the next five to seven years in response to eight major trends likely to impact the safety ORA community. The trends were:

- Integration of UAS into the NAS;
- Integration of commercial space operations into the NAS;
- Changes in the FAA regulatory roles;
- Shift from reactive to proactive oversight of the NAS and industry;
- Advances in mathematical modeling of structures, systems, and operations;
- ‘Big data’ and related analytic tools;
- Implementation of NextGen, and
- Increasing cockpit automation.

A timeframe of five to seven years from now was used to keep the analysis grounded and constrain overly optimistic ‘blue sky’ responses. The participants were asked to evaluate whether major ORA job activities would become more or less important and more or less frequent in the future as consequence of these trends. They were also asked if any new activities or duties were likely to be performed by ORAs five to seven years from now.

Similarly, the participants in the ‘to be analyses were asked to evaluate if competencies identified in the ‘as is analysis’ would become more or less important to future work. They were also asked to identify if any new competencies would be required in the future. The interview

data was summarized in a ‘to be’ description of work likely to be performed by ORAs in the safety community and the competencies likely to be required. The final phase of work was the ‘gap analysis’ comparing the ‘as is analysis’ to the ‘to be analysis,’ to identify changes in the work performed and competencies required of ORAs. Overall, no new activities or competency requirements were identified. However, there were shifts in importance and frequency for both the work performed and the competencies required. Specifically, work activities related to communications and collaboration are likely to be more important to ORA work than currently. Other technical activities such as research planning, risk analysis, methods and models development, and solutions development are also likely to become both more important and more frequent in the future. No competencies are likely to become less important to ORA work in the future. The importance of the technical competencies is likely to be unchanged in the future as well. However, the importance of abilities related to interpersonal relations and deductive and inductive reasoning, appear likely to increase in the future. This is consistent with the increasing importance of collaboration and communications and the increased complexity and volume of analyses anticipated in the future.

Comparison of “As Is” versus “To Be” ORA activity importance

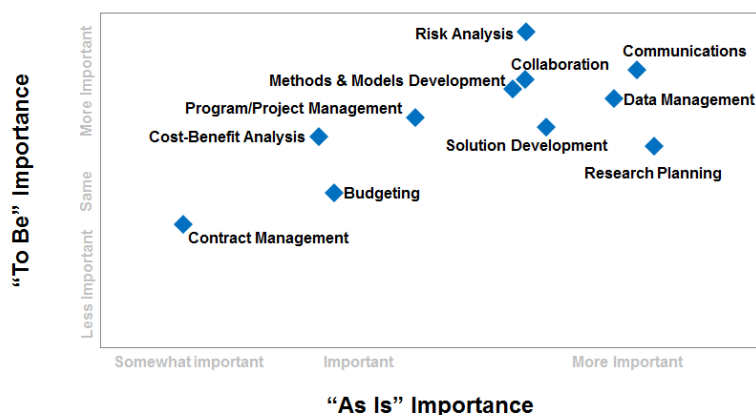


Figure 11: Comparison of “As Is” versus “To Be” ORA Activity Importance

The results of the ‘as is analysis,’ ‘to be analysis,’ and ‘gap analysis’ provide a basis for the development individual development plans for incumbent ORAs to keep them abreast of technical developments in the occupation and to enhance interpersonal relations abilities in support of work requiring greater communications and collaboration. The job analysis data also provide a basis for standardizing (to a greater degree than at present) the documentation for ORA positions. The ORA job analysis dataset, reports, and recommendation were provided to the office of the Assistant Administrator for Human Resources Management for their use in future recruitment and selection of ORAs.

Evaluation and Improvement of the Air Traffic Organization (ATO), Air Traffic Manager and Tech Ops Manager Succession Planning Program (SPP):

AJG-L3 initiated the ATO SPP to ensure adequate bench strength for mission-critical, managerial positions within the ATO. A pilot of the program includes two cohorts, aspiring Technical Operations Managers (second-level managers over system support center front-line managers) and those who aspire to become Air Traffic Managers in level 10-12 facilities. Workshops were conducted in Fiscal Year (FY) 2013 and FY14 to identify the competencies and critical job tasks for each position, and were used as the basis for creating the application materials and selection process. Research products in FY15 included:

- Stakeholder interviews;
- Assessment of the selection process through selection board input and analysis of selection ratings;
- Applicant perceptions of the selection process, and
- Evaluation of training workshops provided to the SPP cohorts.

Future evaluation products will address the relative effectiveness of developmental activities on behavior change and impact on team and organizational performance. Results will be used to identify program improvements that increase program effectiveness, provide evidence of program effectiveness or value, and generate useful knowledge of succession planning for the ATO and the FAA.



Figure 12: Participants in Succession Planning Program Workshop for Air Traffic Managers at Level 10-12 Facilities

Examining the Success of Developmental Air Traffic Controllers Transferring to Lower-Level Air Traffic Facilities:

The FAA's Office of Technical Requirements and Forecasting Group (AJG-R4) is responsible for technical workforce planning, prioritization, and hiring plan development for ATO, as well as onboarding and placement of newly hired developmental controllers and maintainers. CAMI researchers support AJG-R4 in making decisions about the hiring and placement of developmentals by conducting analyses on the training performance of developmental controllers. To do so, CAMI established a longitudinal database containing information about developmental controller training performance. The longitudinal database allows conducting research to support AJG-R4 by providing data that support development of recommendations for improving controller hiring and training practices. The longitudinal database combines data from application through achievement of Certified Professional Controller status for each ATCS developmental hired by the FAA.

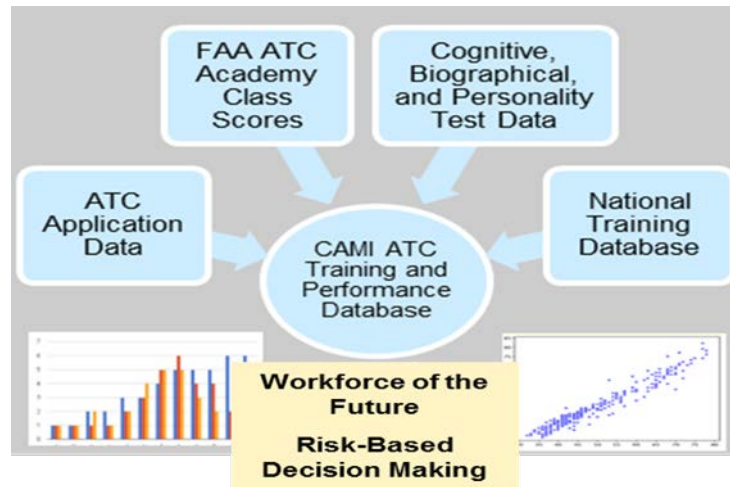


Figure 13: Longitudinal Training and Performance Database of ATCS

In FY15, CAMI researchers assessed the training outcomes for developmentals allowed to transfer to fewer complexes, lower-level ATC facilities following failure at more complex, higher-level ATC facilities. The process to allow some developmentals to transfer lower is administered by the ATO National Employee Services Team (NEST), a team chaired by AJG-R4. If a developmental is allowed to transfer following failure, the NEST will decide the type and level of ATC facility to which the developmental in training may be transferred. The research conducted by CAMI examined the training outcomes of these developmentals when allowed to transfer. The type and level of facility to which the retained developmentals were transferred had an impact on their success in training at the second facility. Developmentals succeeded significantly more often if transferred to a small (level 4-6) or medium (level 7-9) Airport Traffic Control Tower (ATCT) facility than if assigned to any level of a combined ATCT/TRACON facility, whether transferring from an en route or a terminal ATC facility. Developmentals allowed transferring, to small and medium level ATCT facilities did as well as those assigned to these facilities as a first facility; yet did less well at combined ATCT/TRACON

facilities. Therefore, the likelihood that transferred developmentals will succeed at a second terminal facility is significantly higher at ATCT facilities than at combined facilities. We provided the results of our analyses to AJG-R4 for their use in determining if developmentals should be allowed to transfer to less complex, lower-level facilities following failure. If so, to what type and level should they transfer the developmental?

Provide a Draft of a Revised Human Factors Design Standard for Human Factors Application to Air Traffic Control System Acquisition:

FAA HF-STD-001A was developed by the Human Factors Division at FAA Headquarters Washington, D.C., to consolidate and capitalize upon multiple sources of human factors design including evaluation guidelines. It provides FAA system modernization programs access to the most applicable human factors guidance. This document is intended to serve as a one-stop, general resource for human factors design requirements and guidance, useful to the development of current and new FAA systems. The document compiles extensive guidance from diverse sources for human factors applications integral to the procurement, acquisition, design, development, and testing of FAA systems, facilities, and equipment. It will aid in identifying functional, product, and NAS specification requirements and in ensuring acceptable human factors practice and products.

FAA HF-STD-001A is applicable to Commercial Off-The-Shelf and Non-Developmental Item procurements as well as new developmental system or equipment acquisitions. FAA HF-STD-001A reflects a complete revision of the 2003 FAA-STD-001 and subsequent addenda. In the 2003 version there were 15 chapters, 11 of which were dedicated to the detailed technical human factors design requirements and guidance. FAA-STD-001A reflects a new organizational structure, one based on the requirements for FAA standards mandated by FAA-STD-068(2007).

Aircraft Catastrophic Failure Prevention Research Conducted

Certification by Analysis:

Engine certification procedures require tests to certify an engine for fan blade containment. Policy Memo ANE-2006-33.94-2 provides an opportunity for certification of derivative engine designs by some combination of rig test and analysis. Engine manufacturers often present analysis to certify derivative engines with limited design changes. The analysis is usually proprietary with no FAA standard reference. Research funded by the FAA for the uncontained engine debris aircraft barrier and engine containment programs has funded teams in academia and industry to investigate modeling challenges. Research into the non-linear codes used by the different organizations has led to inconsistent answers when comparing results for the same problem. This highlights a lack of standardization that makes it difficult for the FAA engineers to evaluate the analyses for certification credit. To address this shortfall, a joint FAA, NASA, and industry program has been working to understand the issues for non-linear modeling and to develop predictive methods. Guidelines for aerospace problems are also developed. In 2015, the program officially transitioned to include composite material failure in addition to metals. A

composite material model is in development, composite testing is being performed, and the legacy metals work is completing development and moving into validation. Three sub-tasks are described below:

1. Development of an Enhanced Material Model for Certification by Analysis – Composite:

In 2015, the composite failure model in LS-DYNA known as MAT213 progressed into the damage portion of the program, and was completed. Asymmetry in the material is being handled in the new material model with tabulated data. This effort is being performed with NASA Glenn Research Center (NASA GRC) and Arizona State University. The new model will use 12 stress-strain curves to define the hardening of the material in a tabulated way. The curves will come from material tests, which are under development. Testing performed at NASA GRC will support composite work as follows:

- Ballistic impact testing of T700/MTM45-1 triaxially braided composite material for posttest analysis of an open rotor engine fuselage protection concept, and
- Static mechanical testing of T700/MTM45-1 triaxially braided composite material for input to an improved impact failure model (MAT213) in the LS-DYNA explicit FE code.

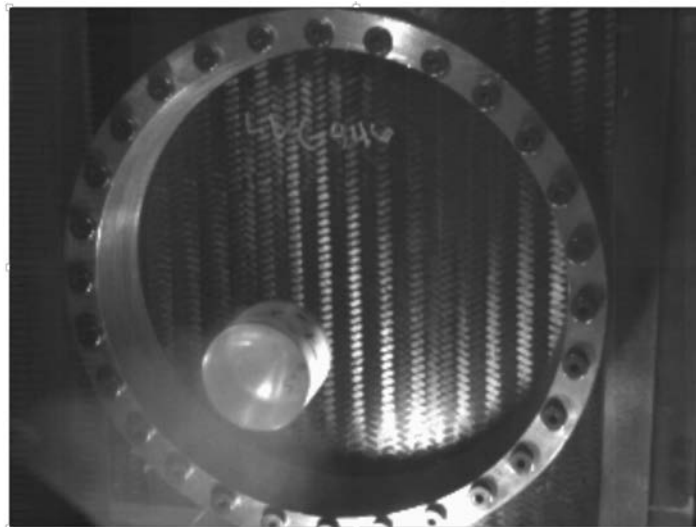


Figure 14: Ballistic Impact Testing of T700/MTM45-11 Triaxially Braided Composite Materials

2. Development of an Enhanced Material Model for Certification by Analysis – Metals:

In 2015, a research team, industry, and academia completed documentation and testing of the new predictive material model for metal impact and failure. This research team enhanced the metal failure analysis capability known as MAT Tabulated Johnson Cook (LS-DYNA MAT 224) with the development of a new LS-DYNA Material Model (MAT 264) to accommodate yield stress differences in different directions in the material. A beta version of the model was completed and will be verified and run through quality assurance tests in 2016. This improvement will make it easier for engine manufacturers

to demonstrate close correlation between test and analysis, as it takes into account the directional material differences that exist in materials often from manufacturing, allowing the simulation to be more accurate. The improvement is another step towards predictive analysis.

3. Tabulated Material Model for Inconel 718MAT-224:

A team consisting of The Ohio State University, George Mason University, and NASA-GRC, worked with the FAA Aircraft Catastrophic Failure Prevention Research Program to develop a new material model in LS-DYNA for Inconel 718. In 2015, all of the testing for the Inconel material model was completed and a significant portion of the tabulated material model was developed. This work will continue into 2016. The experimental material characterization work investigated plastic deformation and ductile fracture behavior of 12.7 mm, Inconel 718 plate and sheet at OSU. Tension, compression, and shear experiments were conducted over a wide range of strain rates and temperatures. The objective of the test program was to generate load displacement curves that can be converted into stress strain curves, and used as tabular input to the material model. Specimen geometry was varied to create tests with specific values of triaxiality and lode, which are easily calculated in the FE program as the simulation progresses. Shapes and general layout are depicted in figure 15 below.

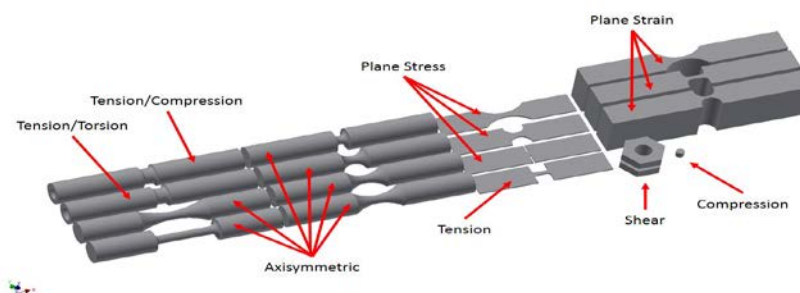


Figure 15: Orientation of Specimens from Plate Material of Ti-6-4

Each of the test specimens has a location in the three dimensional failure surfaces. For MAT-224, the Von Mises Theory uses a tensile stress-strain curve for damage, which is adjusted for both strain-rate and temperature test data. The failure strain is adjusted for the actual stress condition. This improves accuracy over the standard Johnson-Cook (MAT-15) failure model. The failure surface is still under development at this time. Tests will be modeled to test the predictability of the new material models.

Uncontained Engine Failure Vulnerability Analysis:

In 2015, damage information from the 2009 uncontained engine failure on an A380 in Singapore was evaluated for inclusion into the uncontained engine debris fragment model. The new information from this event and other recent events is being used to update the fragment model

and the corresponding FAA Report DOT/FAA/AR-99/11 Large Engine Uncontained Debris Analysis. In addition to the investigative review work, Version 4.3 of the UEDDAM code was completed in FY2015. This new version includes new additions to the penetration equations. The first addition is the gamma factor, which was developed by FAA commercial space for more accurate penetration at oblique angles, and the second is the Cs for shielding which was developed for the open rotor-shielding program. These changes allow more accurate estimates of shielding capability and penetration of the structure. In the analysis fragment definitions from the debris model are used in a Monte Carlo analysis to assess the vulnerability of the airplane to uncontained engine failure.

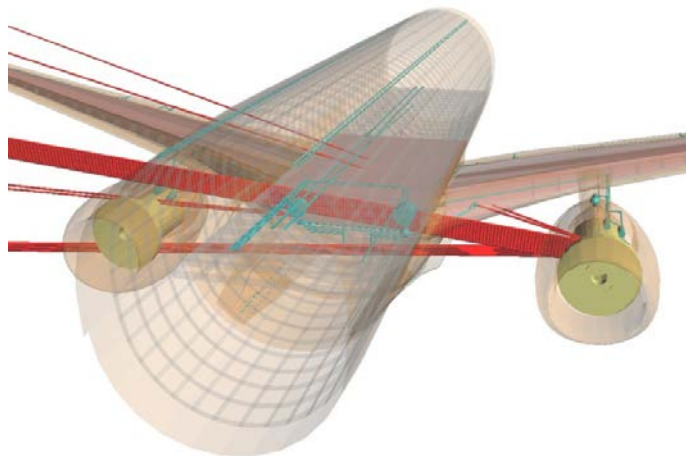


Figure 16: Example of a UEDDAM Event on a Commercial Twin

Aircraft Icing Research Program, Research Conducted

Engine Ice Crystal Icing:

The Aircraft Icing Research Program develops and assesses technologies that predict ground anti-icing fluid failure and ensure safe operations in icing conditions for takeoff and in-flight. A major goal of the program is to provide the necessary data and analysis to improve guidance materials and technical standards for icing operations, and to develop databases and test methods that will support certification for operations in icing conditions. There have been approximately 200 documented engines icing events since 1990 in High Ice Water Content (HIWC) ice crystal conditions, mainly at high altitude in deep and extended convective cloud formations. High concentrations of ice crystals are ingested by the engine, partially melting in the compressor air or upon striking a surface in the low-pressure compressor – cooling the compressor surface and leading to the formation of an ice accretion in a warm engine environment where there is no ice protection. The ice may partially block the airflow, resulting in engine stall, shed into the combustor, resulting in flameout, and damage the engine blades. The ice accretion physics in the compressor and how it is affected by a variety of parameters including temperature, humidity, pressure, ice crystal size and concentration, is still not well understood. This understanding is needed for effective simulation in engine facilities or analytical simulation using computer

modeling. Research on the ice accretion physics has been conducted by the National Research Council of Canada using their Research Altitude Test Facility (RATFac) with support from the FAA to simulate an engine compressor environment. This work has supported the development of a parameter-scaling framework for testing of engines in non-pressurized sea level facilities.

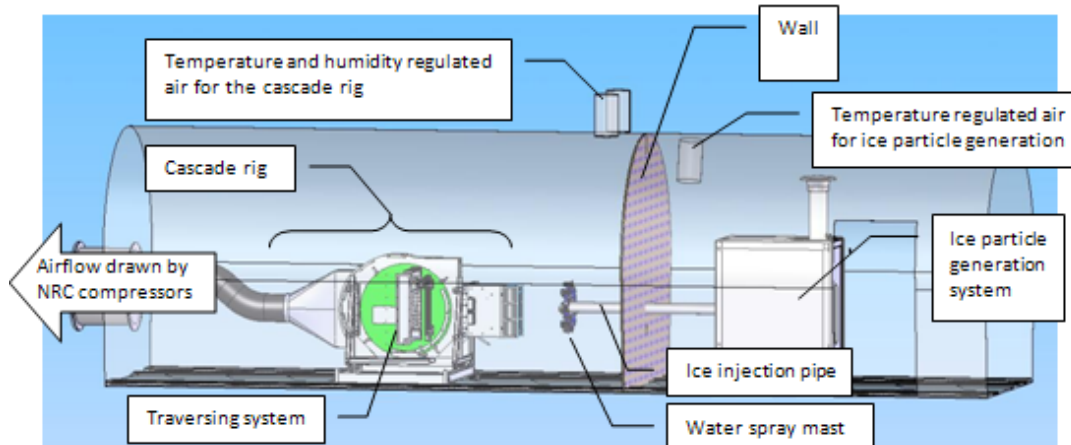


Figure 17: Research Altitude Test Facility

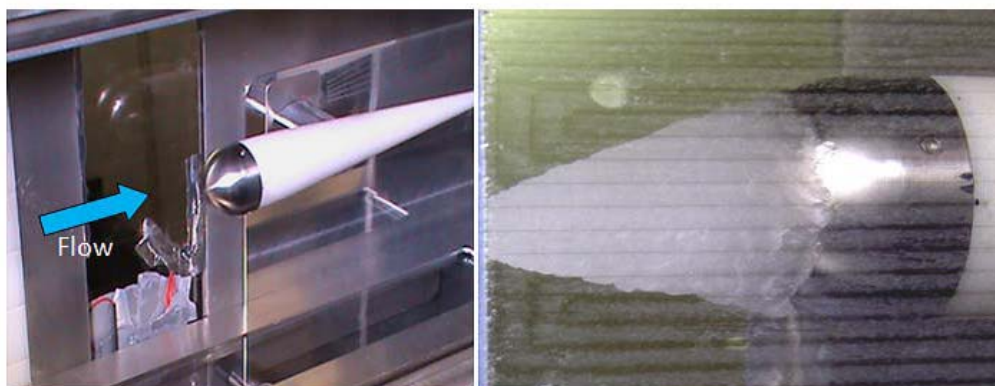


Figure 18: Axisymmetric Test Article in RATFac; Ice Accretion on Article Following Test

Three research flight campaigns have been conducted to collect data in HIWC ice crystal conditions. These campaigns provide data used to evaluate, and revise as necessary, current ice crystal icing envelopes used in certification, as well as establish realistic conditions for simulation in ground test facilities and computer modeling. In addition, the campaigns provide information for now casting and forecasting of potentially hazardous HIWC conditions, evaluation of on-board reactive detection, and development and evaluation of on-board radar for avoidance.

Two campaigns were completed in FY2015 with collaborating and support by the FAA. The first was a collaborative campaign led by the European High Altitude Ice Crystal project, using a Falcon 20 aircraft. This campaign was conducted in May 2015 out of Cayenne, French Guiana. Environment Canada also participated with a Convair 580 and Honeywell with a Boeing 757. Processing and analysis of data from the campaign is underway.



Figure 19: Cayenne Atmospheric Flight Research Campaign

The second was a collaborative campaign of NASA and the FAA, part of the NASA HIWC On-Board Radar Project. This campaign was conducted in August 2015 out of Southern Florida using the NASA Armstrong DC-8 research aircraft. The campaign evaluated the latest generation of on-board radar for in-flight recognition of potentially hazardous HIWC ice crystal conditions, and the collection of further atmospheric data in those conditions.

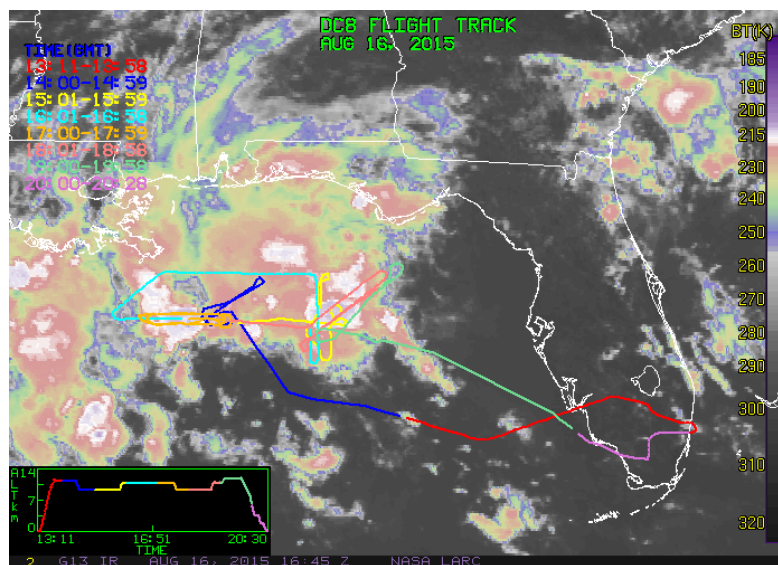


Figure 20: DC-8 Flight Track Superimposed on IR Satellite Image Over Gulf of Mexico, August 16, 2015

Ground Icing Artificial Snow Generation System:

Artificial snow generation system has been used to supplement results of outdoor testing of fluid failure times in snow conditions. Due to climate change and other factors, its use has become

increasingly important, and a necessity to validate its performance in a wider range of conditions, was found vital. Artificial snow tends to provide shorter endurance times than those observed in corresponding real snow under outside conditions, so the research required both outdoor and cold chamber testing and comparison of the results. Results of this work are presented in the report titled, *Determining the Discrepancies Between Outdoor versus Indoor-Derived Holdover Times Using an Artificial Snow Generation Machine*; yet to be published.

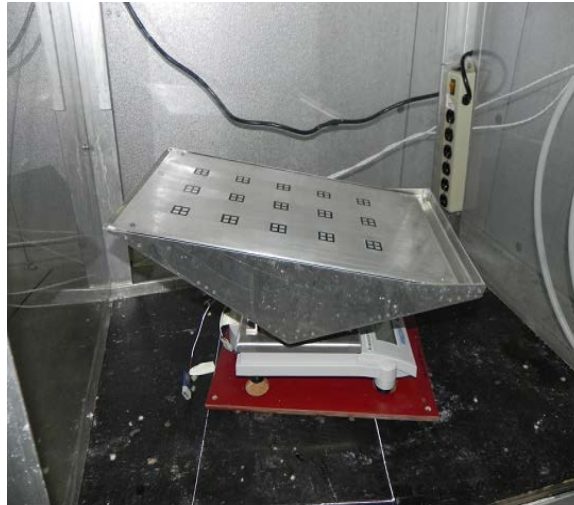


Figure 21: Indoor Frosticator Plate and Tray Assembly on Mass Balance in Artificial Snow Generation System

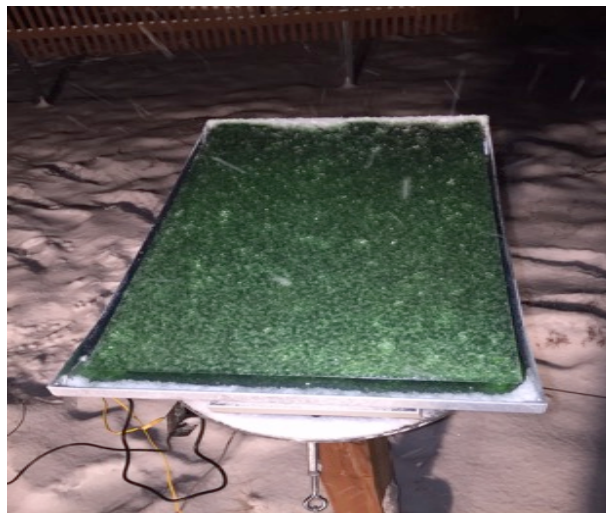


Figure 22: Snow Buildup/Fluid Failure Beginning Near the Top of Standard Frosticator Assembly in Outdoor Testing

Swept Wing Icing: Ice Accretion and Aerodynamic Effects:

The great preponderance of research on ice accretion and aerodynamic effects has been done with Two-Dimension (2D) airfoils. The accretion process and aerodynamic effects have been

fully described. It is recognized that research on 3D swept wings is needed, but only limited work has been done, reflecting the much greater complexity and cost of this research. The FAA has joined with NASA and ONERA; the government agency in France, on a major multi-year project to develop an extensive, high quality database of ice accretions and their aerodynamic effects for 3D swept wings. The database will be available to industry and the FAA for evaluation of 3D computation fluid dynamics methods proposed for use in certification. Research under an FAA grant at the University of Illinois focused on the development and assessment of 3D flow diagnostic techniques using the university wind tunnel. The main findings were published in a report completed in FY2015, *Effect of Ice Accretion on Full-Scale, Swept-Wing, Aerodynamic Performance and Control Effects*; yet to be published. These techniques are candidates for testing in the Wichita State University 7x10foot tunnel and the ONERA F1 pressurized tunnel scheduled over the next two years.

One of the experimental techniques investigated was the Five-Hole Probe wake survey, a pressure probe capable of measuring total and static pressure and the 3D velocity vector at a point in space. In 2D airfoil testing, only measurements of total pressure in the wake of the body are needed. In 3D swept wing testing, the flow is much more complex, and a correspondingly more complex measurement technique is needed. Figure 23 below, illustrates the use of these measurements to relate the flow velocity in the wake to the profile drag on the model.

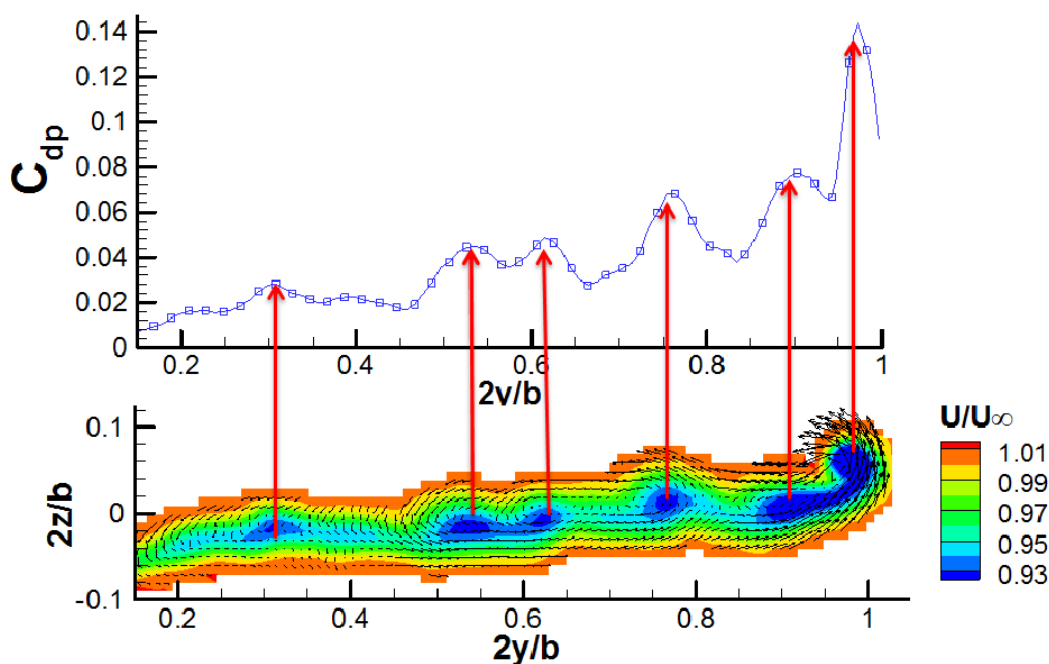


Figure 23: Correlation between Velocity Deficits in Wake and Local Peaks in Profile Drag for Iced Wing Model

Tests were conducted at Wichita State University tunnel using a semi span swept wing model in late FY 2014. Results are described in a report completed in FY 2015 titled, Preliminary Assessment of Low-Reynolds Number Aerodynamics for a Swept Wing with Artificial Ice Roughness; yet to be published. The model was constructed with a removable leading edge, so

that different artificial ice shapes and ice roughness could be readily attached to the wing. Rapid prototyping techniques were shown to be capable of producing roughness elements of approximately 0.01 inches, and full-span roughness ice shapes were created using such methods. The performance differences between the various roughness sizes and applications types (rapid prototype manufactured or grit applied to the clean model) were found to be small, especially at low angles of attack.

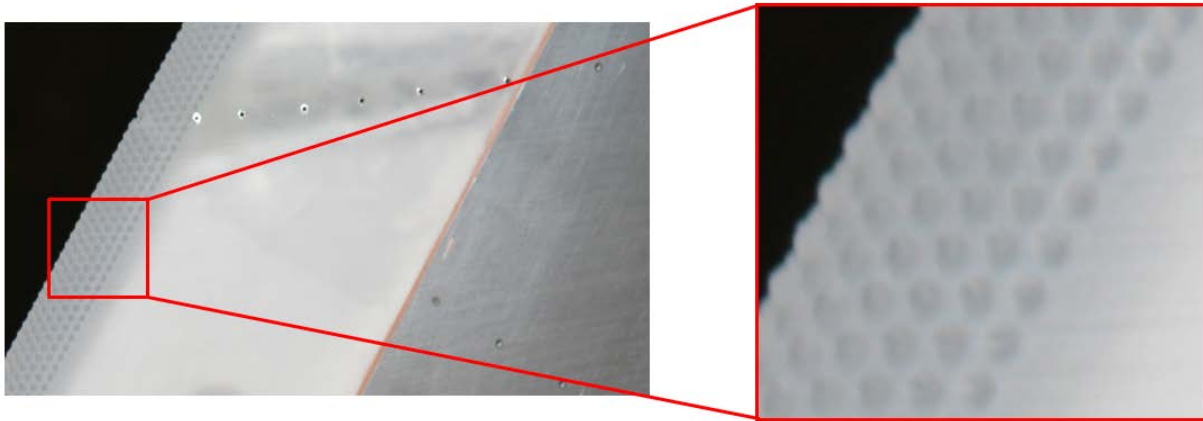


Figure 24: Leading Edge Roughness Produced by Rapid Prototyping Method on Wing Model

Airport Technology Research Program (ATRP), Research Conducted

Complete the Approach Hold/Runway Safety Area (RSA) Field Evaluations at Chicago O'Hare International Airport and Cleveland International Airport:

In an effort to increase situational awareness among pilots and vehicle operators at civil airports, the FAA Office of Safety and Standards – Airport Engineering Division, has proposed updating its standards for runway approach holding position signage and marking, based on designs proposed by the FAA's Approach Hold Workgroup. The purpose of this research effort consisted of validating the feasibility, safety, and effectiveness of the proposed visual cue designs. Initial sign development and evaluations were conducted at the FAA William J. Hughes Technical Center (WJHTC). Operational evaluations were conducted at three airports: Chicago O'Hare International Airport, Nashville International Airport (BNA), and Cleveland-Hopkins International Airport.



Figure 25: Approach Runway Sign –9R APCH-27L DEP

This research effort found that 65% of pilots and 69% of vehicle operators surveyed agreed that the inclusion of the departure runway information increased their situational awareness. Furthermore, it was found that the use of the Pattern B (ladder) ILS holding position marking rather than the Pattern A runway increased the percentage of pilots and vehicle operators correctly identifying that an approach hold is conditional on ATC instructions, from 17% to 36%. Only seven percent of pilots and nine percent of vehicle operators who viewed the visual cues did not consider these to be understood at an adequate distance. The signs and markings indicated that it might pose some difficulty for the understanding of certain individuals. Overall individuals reported the signage and marking were understandable at a distance they considered adequate.

Based on the research conducted for this report, it is recommended that the proposed visual cues be adopted by the FAA for use on taxiways and on runways when found to be operationally beneficial. The signage should be installed as two, collocated sign units rather than a single unit. It is recommended that the signage legend correspond with the operations for which the associated runway is used. For instance, for a runway used exclusively for departing traffic, only the departure runway should be included. Signage with stacked or reduce-sized legend text is not recommended due to feedback indicating these lowered sign legibility. It is recommended that the Pattern B marking be made standard for most approach holding positions. However, it is recommended that the Pattern A marking be used on runways protecting an RSA for a non-intersecting runway. It is advised that extensive pilot and airport vehicle operator education and outreach be conducted prior to the proposed changes going into effect. It is also recommended that airport diagrams include approach/departure holding positions at hot spots and other locations with recurring runway incursions. By implementing the recommendations outlined in the sections above, it is expected that safety will be increased at airports with approach holding position areas compared to existing signage and marking. A final report describing the details of this research effort will be published in early FY16.

Complete Construction of the High Temperature Pavement Test Facility:

Construction of the National Airport Pavement and Material Research Center (NAPMRC) was completed and officially opened on August 27, 2015. NAPMRC is a state-of-the-art test facility that houses the Heavy Vehicle Simulator – Airfields (HVS-A). Six instrumented pavement test

strips (four outdoor and two indoors) were constructed at NAPMRC. The FAA standard P401 HMA mix was used for two outdoor (with PG64-22 and PG-76-22 binders) and one indoor (with PG-76-22 binder) test strips. Warm Mix Asphalt (WMA) mix design was used for two outdoor test strips with PG64-22 and PG-76-22 binders and one indoor test strip with PG-76-22 binder. The HVS-A will be used for full-scale accelerated pavement tests to study the effects of high tire pressures on the pavement surface layers, test the performance of greener/sustainable technologies and layer materials (such as, WMA, stone matrix asphalt, recycled asphalt pavement), and study the performance of asphalt pavements at high temperatures. HVS-A is 121 ft. long, 16 ft. wide and 14 ft. high, making it the world's largest, heaviest, and one-of-a-kind HVS in the world. The HVS-A is capable of applying bi-directional and unidirectional loading using a single wheel (maximum wheel load of 100000 lbs.) or dual wheel gear.



Figure 26: National Airport Pavement and Materials Research Center

Complete Definition of Airport Pavement Failure for 40 Year Pavement Life Project:

A definition of pavement failure consistent with Life Cycle Cost Analysis (LCCA) concepts was completed with input from the Subject Matter Expert (SME) group made up of experts from airport consultants, airport authorities and the concrete and asphalt industry, for the Extended Airport Pavement Life Project. Essentially, this definition will replace the current definition of pavement life that is tied to structural failure of pavement only. The new definition includes structural failure aspects, but also includes function failure aspects as well, including such items as pavement roughness, potential for Foreign Object Debris (FOD) damage and loss of pavement friction. When an LCCA recommends full reconstruction as the best option for maintenance and rehabilitation, it defines a pavement as failed. Also adopted, was a detailed definition of full reconstruction applicable to rigid and flexible pavements. This definition will be used in conjunction with construction and performance data collected under the Extended Airport Pavement Life Project to develop design models valid for up to 40 years.

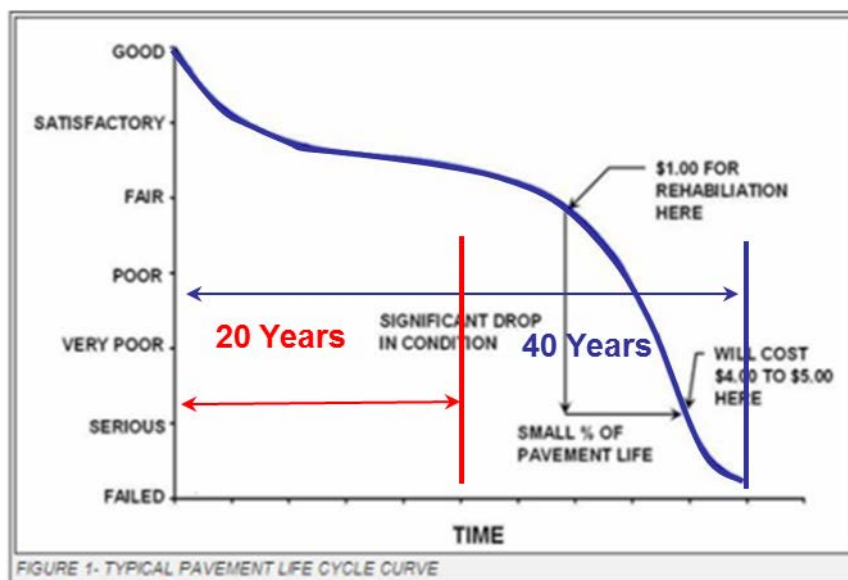


Figure 27: General Pavement Life Cycle Curve

Complete Draft Advisory Circular on Guidance for Selection, Procurement and Management of SMS Software:

SMS can be considered a proactive strategy towards improving safety at airports through four primary components:

- Establishing a safety policy;
- Promoting a safety culture;
- Performing Safety Risk Management (SRM), and
- Performing safety assurance.

A study was conducted through a cooperative agreement with the COE for General Aviation Research – Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) to gain an understanding of the variety of software being used by airports as part of their respective Airport SMS strategies. The goal was to establish guidance towards recommending the use of SMS software at airports, including minimum functionality standards. Preliminary research during the study found several commercial products marketed as Airport Safety Management Software. In addition to commercial products, some individual airports have created in-house SMS software or have used fundamental office-based software (such as generic database and spreadsheet products). There is a gaining wealth of institutional knowledge at individual airports regarding the strengths and weaknesses of the varying SMS software platforms that have been used. Despite these gains, there are many airports in the U.S. that have yet to embark on an SMS program, and as such have no institutional knowledge or guidance towards selecting an appropriate SMS software tool.

This study addressed the FAA's desire to provide such guidance, through a thorough investigation of the use of SMS software products, and a study of what airports need in terms of software tools to operate a successful SMS strategy. A draft Advisory Circular (AC) was created

on July 30, 2015. It provides guidance on the use of computer software systems to assist in managing and airport's SMS. The AC also describes the capabilities of airport SMS software systems and contains minimum performance specifications for applying software systems to the various components of airport SMS.

Complete Human Factor Laboratory/ Simulation Tests on Use of Linear Light Sources on Airports:

Research to determine if linear light sources can provide an advantage over currently used point-source light sources in airfield applications continues. Researchers developed a three-phase approach for investigating this concept. The first phase consisted of a series of laboratory and controlled field experiments conducted by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute. It sought to determine whether the visual acquisition times for different simulated taxiway/runway intersection configurations could be reduced by using linear source elements in place of discrete point source elements when they are equally spaced. Conversely, linear elements could be placed further apart than point sources in order to maintain visual acquisition times. As a result, LRC developed and validated a model to predict relative visual acquisition times under delineation configurations with different element lengths and spacing. The second phase was to conduct subject pilot trials utilizing a flight simulator representing an airfield environment. The results provided similar findings as the laboratory tests. However, it was recommended that conducting field evaluations in real world conditions would help validate the relationship between length and spacing of linear application and generate pilot's feedback on various linear lighting configurations at Ohio State University Airport (KOSU). The third phase is to conduct actual airfield evaluations, given the difference between the laboratory environment found at LRC and the airport field test environment at KOSU Airport. This research will provide results with comparable analysis of the accuracy and reaction times of test subjects viewing linear LED lights of varying lengths and spacing in varying taxiway centerline configurations. Results from this simulator evaluation are consistent with result from phase 1 laboratory evaluation conducted.



Figure 28: Linear Light Source

Evaluation of Safety Orange Airport Construction Signage:

In April 2010, the FAA ATO created the Airport Construction Advisory Council (ACAC) to identify hazards due to airfield construction activities. The ACAC has recently proposed the use of safety orange for temporary airport construction signage to reduce adverse operational incidents. In response to this proposal, the Airport Technology Research and Development Branch researchers from WJHTC visited ongoing airport construction projects and collected information to identify shortfalls and determine compliance with related AC. They were also tasked to develop and evaluate prototype signs in an airport environment. Site visits were conducted to existing construction sites at several airports to collect information regarding the airport's existing airfield construction projects. Pilots of varying backgrounds evaluated several design concepts utilizing the simulation technology of the Airway Facilities Tower Integration Laboratory at WJHTC.

Outdoor evaluations were conducted using sign prototypes to determine the optimal height and color used for the sign legend. To validate the final sign prototypes, evaluations were conducted at several airports where construction projects were occurring, including ORD, Portland International Airport (PDX), Oregon; Theodore Francis Green State Airport (PVD), Rhode Island; Long Island MacArthur Airport (ISP) New York; Orlando Sanford International Airport (SFB), Florida; and John F. Kennedy International Airport (JFK).

No shortfalls with respect to compliance with the related ACs were identified during the site visits. Several types of visual aids were used at the airports in accordance with AC 150/5370-2F. The airport operators indicated that besides using the current visual aids, found in AC 150/5370-2F, the use of the temporary safety orange signs would be advantageous if they were available. During the field evaluations of the prototype signs, a combined total of 131 individuals participated in the survey, including 98 vehicle operators and 33 pilots. Overall, vehicle operators and pilots overwhelmingly agreed the messages, character heights, and colors of the signs were comprehensible, conspicuous, and adequate in alerting individuals about existing construction.



Figure 29: Airport Construction Sign –RWY 22R Takeoff Run Available 10, 130 ft.

Based on the results of this study, it was advised that AC 150/5370-2F be updated to include safety orange construction signage as a visual aid to alert pilots and vehicle operators of existing airport construction. Signs displaying *construction on ramp* and *construction ahead* are recommended to be placed at locations leading to ramps and other areas with construction activity. When a runway is temporarily shortened due to construction, it is recommended that Takeoff Run Available (TORA) signs be placed at the runway entrances to display the current takeoff run available. Additional education was recommended to increase understanding of the TORA acronym to ensure pilots have adequate situational awareness. A final report titled DOT/FAA/TC-15/52, Development and Evaluation of Safety Orange Airport Construction Signage, was published to document this research.

Evaluation of Structured Methyl Methacrylate Marking to Increase Paint Conspicuity:

The FAA Airport Technology Research and Development Branch undertook a research effort to determine if a new application technique for painting pavement markings would increase conspicuity over the useful life of the marking. A paint manufacturer presented the FAA with information on a new paint marking called Structured Methyl Methacrylate (SMMA). Methyl Methacrylate (MMA), paint without the structured component, is currently approved for use on runways and taxiways. SMMA differs from traditional MMA because it is applied using a splatter pattern. When applied to a pavement using the splattered application technique, SMMA creates a thicker, textured surface with peaks and valleys, while still creating a visible solid line. The manufacturer claims this application technique will enhance wet, nighttime retro-reflectivity by allowing water to flow off the peaks and into the valleys of the marking, thus making the paint and beads on the peaks more visible. The manufacturer also suggested using a slightly modified paint formula, which will provide enhanced visibility when used with this unique application technique.



Figure 30: Structural Methyl Methacrylate Paint Markings on Runway

The research objective was to compare the suggested SMMA paint to traditional MMA paint, and further evaluate whether the proposed splatter application technique, thicker application, and modified formula offer improvements over the currently accepted MMA application techniques and formula. A complex test plan, containing a variety of tests, enabled researchers to evaluate each element that makes up the SMMA paint markings. Testing activities included retro-reflectivity, chromaticity (color), friction, pull-off strength, water run-off, and heavy vehicle simulator studies.

The results of this research effort were favorable, indicating that the new SMMA paint, when used with Type III glass beads, showed an improvement over conventionally installed MMA markings. Although the SMMA paint does not fully cover the pavement surface, the material does appear to be a continuous marking when viewed from a distance. The SMMA paint possessed higher friction values, shed water faster, and improved the visibility of the paint marking over the conventional MMA markings. The modified, softer paint formula proposed by one manufacturer did not appear to have any adverse effect on the SMMA paint markings. A technical note titled DOT/FAA/TC-TN15/50, Evaluation of Structured Methyl Methacrylate Marking to Increase Paint Conspicuity, was published and documents this research.

Investigate the Feasibility of Conducting a Runway Centerline Deviation Study Using a Prototype Sensing and Data Acquisition System:

Three methods to identify aircraft speed and orientation were developed and tested. Evaluations to identify the ideal sensor technology were also completed. Understanding how and when aircraft deviate from centerlines is of great interest with respect to operational safety at airports. As General Aircraft (GA) aircraft evolve from the proliferation of larger piston aircraft to the introduction of personal jet aircraft (such as the Embraer Phenom 100 and Cirrus Jet), there may be a desire to allow these aircraft to utilize runways and taxiways of narrower width, which exist at many smaller general aviation airports. Additionally, the use of state-of-the-art avionics technologies by existing fleet of aircraft can enhance the accuracy of landings, particularly in inclement weather, and with respect to proximity to centerline on landing. Therefore, there may

be some justification to consider reductions in required spacing between taxi lanes or distances from runway centerline to pavement edges. In other instances, there may be situations where aircraft unintentionally deviate from centerline due to adverse wind conditions, or situations where aircraft intentionally deviate from centerline after landing to an exit taxiway.

The FAA set out to assess the capabilities of a variety of off the shelf technologies to collect centerline deviation data including high-definition cameras located on either end of the runway's threshold, laser sensors projecting across the width of pavement, and in-pavement sensors installed along the centerlines of both runways and taxiways. The study design recognized that straight-line 2D laser sensors would likely not be a cost effective solution due to the sheer number of sensors required to obtain the necessary location and position data of the intended moving targets. Therefore, a 3D scanning laser product was chosen as the initial candidate sensor.

In September 2015, three field tests were performed by researchers from the OSU as part of the FAA COE for PEGASAS at KOSU. The tests collected distance measurements on passing vehicles and aircraft using the prototype 3D scanning laser system in two different configurations. The results of testing demonstrated the feasibility of using an off the shelf scanning system to achieve the desired measurements. Further testing of this and additional systems will be performed to supplement the initial field tests.



Figure 31: Hardware Setup of Scanning System during Field-Tests at The Ohio State University Airport

Publish Report on Characterization of Foreign Object Debris Collected at ORD:

A report titled, *Foreign Object Debris Characterization at a Large International Airport* was published in February 2015. As part of the FAA FOD Research Program, the University Of Illinois Center Of Excellence for Airport Technology (CEAT) in cooperation with the staff of the Chicago Department of Aviation (CDA), Chicago O'Hare International Airport ORD Operations, engaged in a study to characterize FOD removed during periodic runway inspections conducted by airport personnel. The report documents the characterization of FOD found on an

active runway over time by analyzing the FOD collected by common mechanical FOD removal devices during routine runway inspections.



Figure 32: Common Types of Foreign Object Debris

The presence of FOD at airports is a well-known problem, but detailed information on type, size, weight, frequency, and origin of the FOD is generally lacking. A study was performed by CEAT to characterize FOD over time by analyzing the FOD collected by common mechanical FOD removal devices at a large airport. The study was conducted at ORD and included over 79 sampling campaigns, resulting in the collection of FOD samples from ORD's seven runways labeled 4R-22L, 4L-22R, 9R-27L, 9L-27R, 10-28, 14R-32L, and 14L-32R. Data sampling campaigns began in July 20, 2011 and concluded on May 8, 2013. Three FOD collection methods (i.e., mechanical sweeper, magnet bar, and laborers) were employed during periodic inspections of the runways. FOD sample data was reviewed to identify differences in FOD amounts over time for a single runway and to determine if there is a relationship between airport characteristics (such as runway length, the number of taxiway intersections, or construction activity) and the presence and type of FOD found. A general observation of the FOD material collected was that the most common hazardous items were generated from the pavement surface. Although rare, other large hazardous FOD items were also collected and recorded. Figure 32 above, shows examples of small, medium and large FOD items.

Center for Advanced Aviation System Development (CAASD)

ATO Safety Analysis and Integration:

The FAA is responsible for the development of ATO SMS and the integration of safety and training standards into the provisions of air traffic services. General objectives are to lead organizational efforts to manage risk, assure quality samples from forcible entry standards instill an open culture of disclosure and reporting, as well as educate employees, and promote continuous improvement through the application of training programs and decision support capabilities. Throughout FY15, CAASD has provided focused exploration of processes and tools that have been utilized to help FAA determine where risk should be managed, implement risk mitigation efforts, and track the effectiveness of efforts. CAASD also provided integrated development of the following six safety risk identification and mitigation initiatives, under a seamless risk management strategy.

Focus Airports – Risk Identification:

CAASD developed an analytical data-driven framework for strategic detection of runway safety risks at airports. FY15 research examined 15 metrics determined by runway safety SMEs for 78 airports, and provided a ranked order of importance for airports exhibiting risk. Those metrics span observed events that measure runway safety events, include warning indicators (based on reports or inspections), and latent factors (for suspected causality). From this research, the FAA has socialized the technique throughout the field, and established a process for refining the metrics and producing a focused airports list for runway safety risk each fiscal year. CAASD is currently developing the ranked list for FY16, and determining the key metrics to drive the FY17 ranked list.

Airborne Risk Analysis Process (RAP) Tool – Risk Mitigation:

CAASD produced a report on improvements to the RAP tool scoring methods used in quantifying the risk level for loss of separation events and Traffic Collision Avoidance System (TCAS) alerts. These enhancements evolved the present scoring methods by using radar data for trend analysis and promoting increased safety through risk mitigation and management. A newly modified RAP tool was developed for future evaluation of loss of separation events, including those involving TCAS alerts. It closely aligns with the FAA's current SMS Risk Matrix.

Arrival-Departure Window (ADW) Plug-in – Risk Mitigation:

During FY15, CAASD research enhanced the Terminal Area Route Generation Evaluation and Traffic Simulation ADW Plug-in and refined its use. This enabled the FAA to conduct standardized analyses to derive arrival departure windows for airports included in Phase III of the Converging Runway Operations initiative. FAA analysts successfully developed and delivered 79 new ADWs to the field with this capability. Additionally, the FAA is now able to make expedited updates to fielded ADWs as airport fleet mixtures, and missed approach rates change.

Top 5 Hazards Dashboard – Risk Tracking:

Since FY12, the FAA has identified the top five hazards that introduced risk throughout the NAS. CAASD has developed metrics and auto-classification text mining models to track the progress of Comprehensive Assessment Plans implemented to address these hazards. In FY15, research was focused on weather dissemination, surface memory aids, misapplied visual separation, inadequate vectors, and misjudgment. CAASD's developed auto-classification text mining models were applied to Air Traffic Safety Action Program (ATSAP) reports, and used by the local Safety Councils in partnership for safety to track mitigations.

Partnership for Safety Dashboard – Risk Tracking:

Since FY14, CAASD safety research efforts focused on the Partnership for Safety (PFS) program's data portal/dashboard, enabling local safety councils to identify, solve, and track safety risks/hazards under structured mitigation plans. FY15 saw the addition of the 2014 top

five hazards metrics to the PFS data portal, including auto-classification models for ATSAP data. These provide a benchmark comparison against similar facilities, and are used to analyze the trend before and after mitigation plans are implemented. Additionally, local safety councils are now able to track trends based upon ATSAP reports for specific Metroplex sites, related to the roll out of new/modified procedures.

Manager's Dashboard – Risk Tracking:

In FY15, CAASD developed a collection of safety risks visualizations and added them to the ATC Manager's dashboard, figure 33 below. This has enabled district, regional, and national ATC Managers to monitor and review performance and related safety data through a single portal. The dashboard consolidates useful datasets and key information and provides a standardized set of data for reviewing a facility's progress towards achieving operational skills assessments and mandatory occurrence reports.

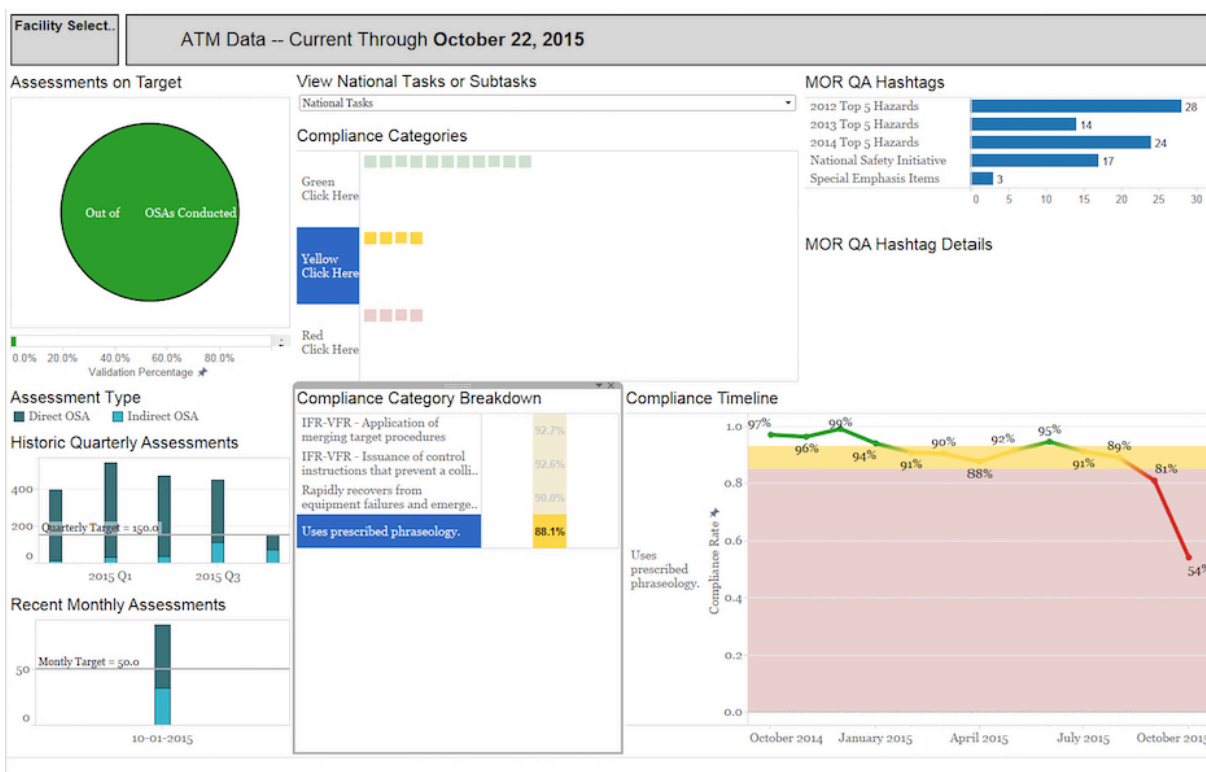


Figure 33: Illustration of Manager's Dashboard

ATC managers expressed a need for simple, up-to-date visualizations allowing for fast interpretation of performance and safety issues. This combining of ATC performance and safety metrics is currently undergoing testing on composite materials in the field, and future development efforts will include the establishment of Corrective Action Request Plan tracking as well as integrating internal compliance verifications and system service reviews as data sources.

New aircraft designs use significant quantities of advanced composite materials that present a new challenge to aircraft rescue and firefighting personnel. Challenges may include how to

safely cut into composite materials when responding to incidents involving such aircraft. A cutting test apparatus and procedure were developed to measure the force exerted by a saw blade on a panel made with aircraft-grade, advanced composite materials, as well as measuring blade wear and particulate production caused by this type of cutting. Tests were conducted to compare the performances of three different types of saw blades: metal, concrete, and diamond-tipped. Each saw blade was tested by cutting panels of various thicknesses of aluminum, Glass Reinforced Aluminum Laminate (GLARE), and Carbon Fiber-Reinforced Plastic. These tests examined saw blade cutting performance in both dry and wet cutting conditions. In general, the carbon fiber composite generated much more respirable particulates than the GLARE composite. In every carbon fiber test with analysis for elemental carbon, real-time concentrations and time-weighted averages of total elemental carbon (not respirable) exceeded the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limits for respirable elemental carbon. The exposure limits were so high that the only level of adequate respiratory protection would have been a full-face, Self-Contained Breathing Apparatus with an assigned protection factor of 10000. There are currently no recommended exposure levels to carbon fiber. NIOSH recommends assessing exposure to carbon fiber expressed in concentrations of elemental carbon. Another result from the air sampling from tests identified that in an equal environment, the diamond-tipped saw blade contributed less to the carbon fiber/carbon nanotube exposure than the metal or concrete saw blades. This was determined based on the measured concentration of elemental carbon being equal to the measured mass concentration of carbon fiber.

Low Cost Surface Awareness:

Airports around the world, ATC Controllers, use the view from the ATCT to detect and track aircraft and other vehicles on the airport surface, and to ensure that they remain safely separated. When visibility is reduced controllers develop a mental picture of the status of the airport surface by asking pilots and airport operators to report their location. To improve situation awareness and safety, the FAA implemented surface surveillance at the Nation's largest airports to provide a map-based picture of aircraft and vehicles. These surveillance systems use a combination of advanced capabilities (e.g., multi-lateration) and cost about \$25 million to install and maintain. Unfortunately, these systems are cost prohibitive for small and medium airports, leaving over 450 U.S. towered airports without an affordable surveillance solution. A similar problem is also found in small and medium airports around the world. To address this need, the CAASD developed Low Cost Surface Awareness (LCSA). This surveillance concept and its 2015 prototype were enabled with the use of infrared cameras to monitor the movement of aircraft and vehicles across the airport surface. Algorithms are used to detect the presence of targets and to estimate their position on the airport surface. This information is then presented on a map display for use by ATC or airport operations, in figure 34 below.

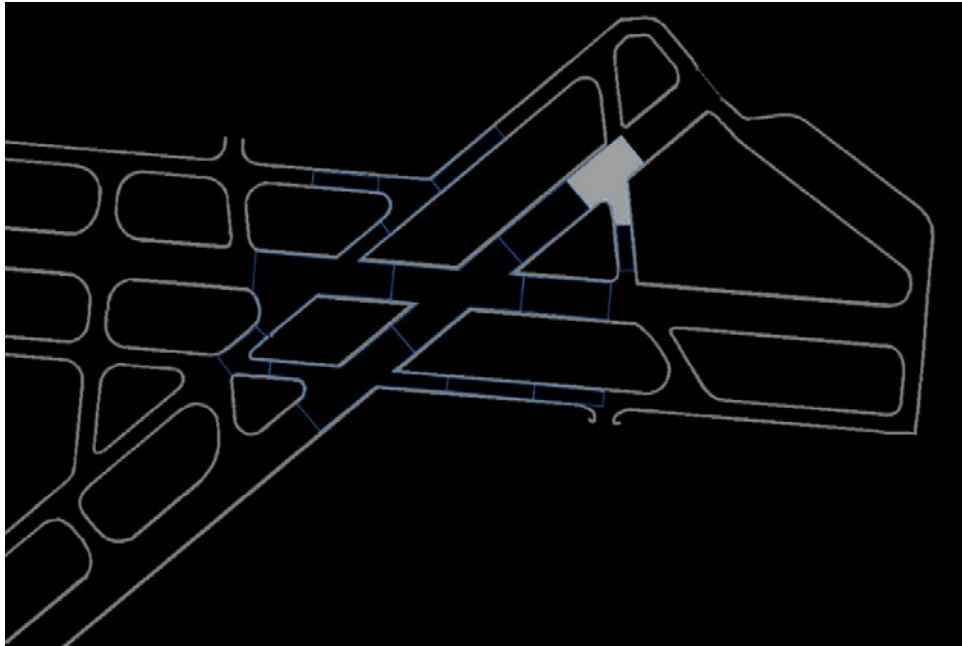


Figure 34: Low Cost Surface Awareness Prototype Display

The 2015 research culminated in the demonstration and evaluation of the end-to-end LCSA system at Teterboro Airport in Teterboro, New Jersey. The demonstration was conducted in coordination with the Port Authority of New York and New Jersey. The successful demonstration:

- Installed infrared cameras, processing hardware, and LCSA software at Teterboro Airport;
- Developed image detection algorithms which provide real-time processing of four commercial-off-the-shelf infrared camera feeds to detect the presence of aircraft and airport operations vehicles in the visual scene;
- Developed geo-referencing algorithms that map targets from the image detection software to an estimate of latitude and longitude and establish a continuous track for those targets as they move across the airport surface;
- Adapted the LCSA user interface to Teterboro Airport to display the presence of targets on a map;
- Successfully demonstrated adequate track continuity and minimal distance error in location estimation (less than or equal to about 25 ft.) See figure 35 below, and
- Collected feedback about system utility in low and high visibility. Feedback indicates that the concept provides high utility in both of these operational conditions.



Figure 35: Low Cost Surface Awareness Performance

The conclusion of the demonstration represents the end of the research phase of this project. The expected impact of LCSA is expected to help ATC controllers, pilots, and airport operations to ensure surface safety. The system is also expected to provide a low cost surveillance alternative to airport operators and the FAA, assisting in meeting budgetary constraints.

Speech Inputs to Safety Logic Systems and Decision Support Tools:

Controller-pilot voice communications contain a wealth of intent and context information. Currently this is an underutilized source of information for automation systems in live ATC operations. The hypothesis behind this research is that controller-pilot radio communications can be leveraged via automatic speech recognition to provide early indications of aircraft intent, and to improve alert performance of surface safety logic systems such as the Airport Surface Detection Equipment Model X (ASDE-X) system. The objectives of this work were to demonstrate the benefits of incorporating speech-derived controller intent information into ASDE-X as a test case, and to:

- Measure automatic speech recognition performance achievable when it is enhanced with real-time context information from ASDE-X.

- Meet these objectives CAASD established a partnership with the creators of ASDE-X, Saab Sensis.

The purpose of this collaboration was to investigate the ASDE-X safety logic algorithms and to identify how speech intent could be incorporated for optimal benefit. Simultaneously, the team experimented with different speech recognition configurations that could incorporate surveillance information for better recognition performance.

Over the course of FY2015, CAASD researchers:

- Identified three types of alert performance changes (figure 36 below) that could be beneficial to ASDE-X and could improve overall surface awareness and safety through analysis of ASDE-X tracks and current ASDE-X alert behavior;
- Designed a method to incorporate speech inputs into the ASDE-X safety logic algorithms (figure 37 below left) and collaborated with Saab Sensis to validate the design;
- Captured performance and demonstrated measurable improvement in speech recognition performance, as a result of incorporating context information available in ASDE-X (figure 37 below right). This was performed with experimentation using Sphinx, an open-source automatic speech recognition engine, and controller audio from live operations at Washington Dulles International Airport, and lastly
- Created a technology roadmap of current and future speech-based capabilities that takes into account operational need, potential benefit, application complexity and feasibility.

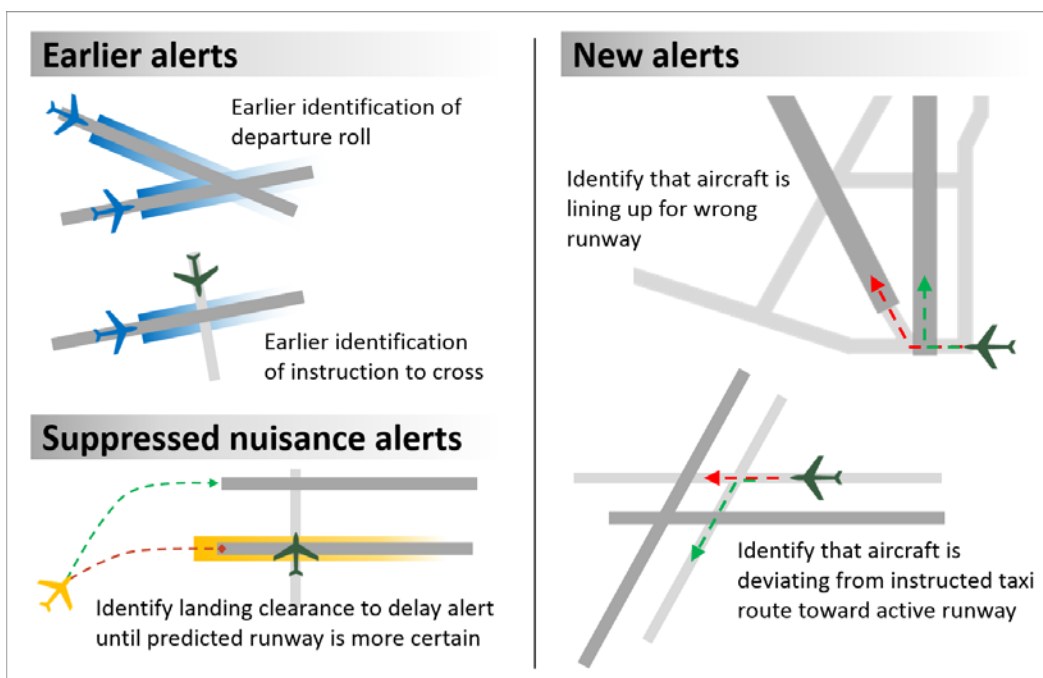
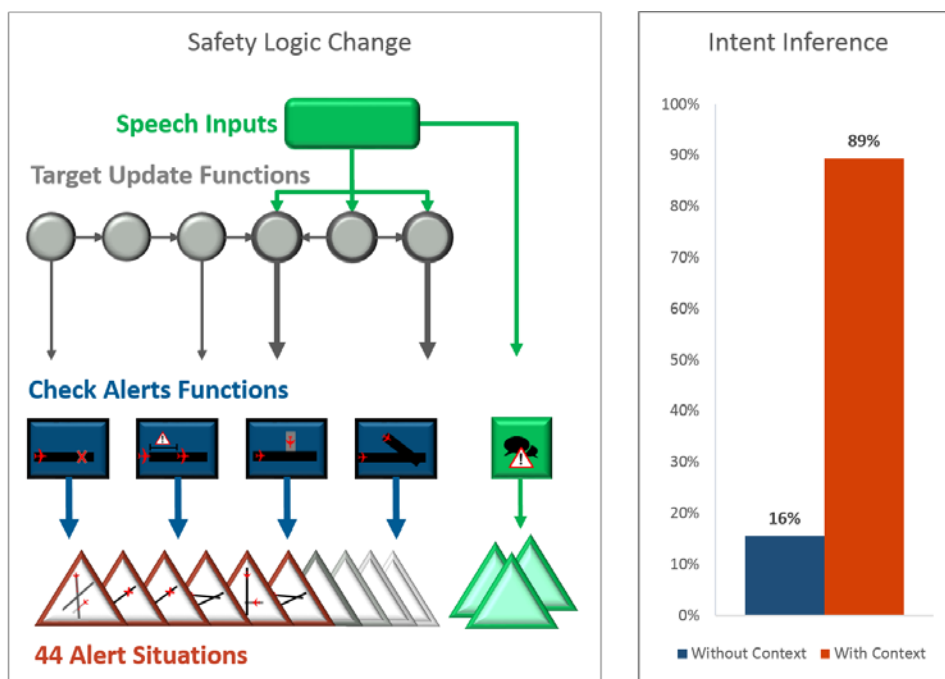


Figure 36: Types of Alert Performance Changes

Figure 37: (Left) Incorporating Speech Inputs into ASDE-X Algorithm
Automatic Speech Recognition Performance (Right)

In future research, CAASD will evaluate the feasibility of achieving sufficient speech recognition performance on pilot transmissions to drive a read-back error detection capability and to design a human interface solution that mitigates speech recognition error while still

providing benefit to the user. Research establishes a new use for speech recognition-informed applications in aviation safety, and will contribute to the development of a field prototype that leverages controller voice communications as an information source and improves runway safety on the airport surface. The particular case is also a stepping-stone for researching and developing other speech recognition-informed applications that could support aviation safety and efficiency. The roadmap informs the FAA's overall vision for deploying automatic speech recognition as an emerging technology into the NAS.

Commercial Space Research Conducted

Near-Elimination of Air Traffic Disruptions by Launch Operations Using Compact Envelopes:

The projected growth in demand for the use of the traditional airspace by commercial space transportation entities will make it increasingly hard to accommodate launches on a Special Use Airspace (SUA) basis. A better approach is required that is able to:

- Adapt to the fluctuating frequency of launches;
- Accommodate uncertainties in the timing and the ascent and descent/entry trajectories of space vehicles;
- Ensure proper separation and safety at all times, and
- Integrate with the FAA's NextGen system.

The three main objectives for this project are to:

- Develop plausible architectures for an Integrated Airspace Management System;
- Research and develop the foundation of such a system so from the outset, time-space probabilistic trajectories and safety assessments can be incorporated, and
- Create a prototype implementation for a proof-of-concept of the system that may be further developed in a follow-on project.

The impact on air traffic space operations can be significant and without approaches and procedures to minimize it, a significant negative impact on commercial space transportation will be felt.

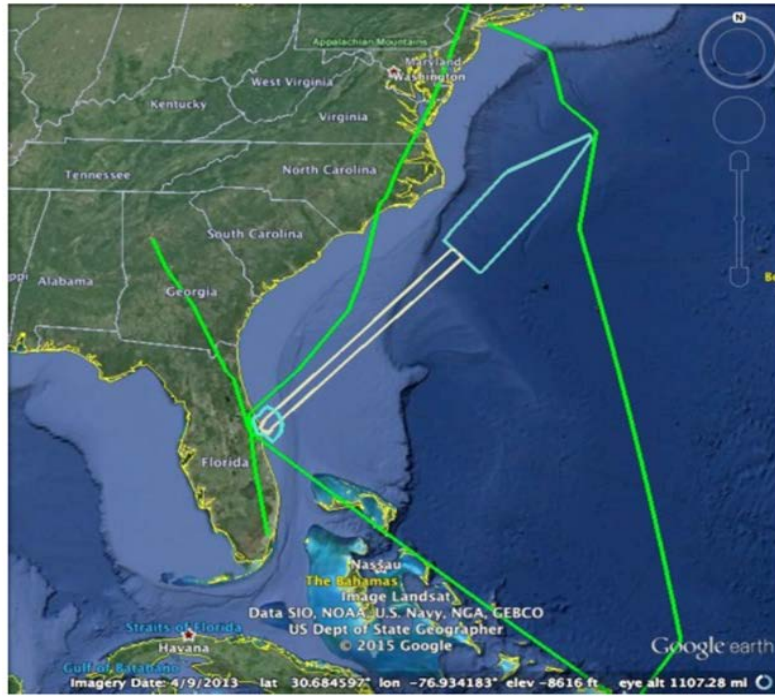


Figure 38: Space Operations Disrupt the NAS, March 1st 2013 Falcon 9 from Cape Canaveral, FL

The current subtask embodies the second phase of the research in the idea of Four Dimension (4D) compact envelopes. By now, the methodology has been established and a procedure to create the 4D envelopes for arbitrary launch and re-entry vehicles (and spaceport/location from/to where the vehicles are operating) is in place.

In Subtask I, the potential reduction in NAS impacts has been assessed in a devised preliminary set of simulations. In order to ensure that the idea can finally be transitioned to full operation (in the 2020-2025 time frame), and leveraging potential improvements in ATM derived from the phased implementation of NextGen work remains to be done in the operationalization of the ideas. This subtask addressed the methodology development as well as the necessary simulations to ensure that 4D compact envelopes can be effectively embedded into the SVO ConOps while taking into account more accurate representations of the limitations that real-life situations may impose. Such limitations include ATC controller workload, aircraft dynamic response times under various equipage situations, and operational considerations derived from fuel load of existing aircraft. The result was expected to be a section of the SVO ConOps streamlining the interface of the research team's ideas with the rest of the procedures developed, as well as a body of simulation data (using the same setup developed for Subtask I, Stanford University's own software and NASA's FACET tool) to substantiate all claims.

The Subtask II, including its final report, has been implemented by the end of the summer (September 2015) and results have been presented at the COE Commercial Space Transportation (CST) Annual Technical Meeting held in Washington, DC on October 27-28, 2015.

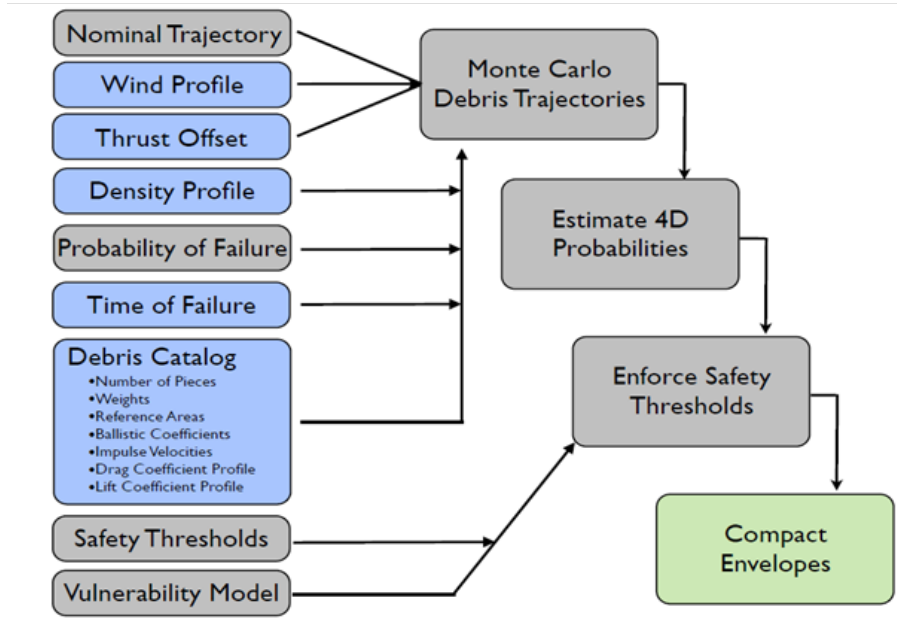


Figure 39: Stanford University Framework for Aircraft Risk Management

The project team created dynamically allocated compact envelopes to identify hazard areas in the airspace for arbitrary space vehicles flying from any spaceport. Simulated cases include seven vehicles, 10 locations, 14 mission profiles; over 90 days, and compared traditional hazard areas versus compact envelopes. The use of compact envelopes nearly eliminate (i.e., reduce by 97%) the disruption of air traffic due to launch operations as simulated using FACET tool. Some cases resulted in the complete elimination of air traffic disruption. FAA HITL simulations have been conducted and support the baseline assumptions of the model.



Figure 40: Ten Test Locations

Propellant Tank Burst Testing:

The New Mexico Institute of Technology (NMT) is performing burst tests to better understand and characterize the bursting and fragmentation of propellant tanks under research funded by the FAA COE for CST. The principal investigators of the testing include Dr. Warren Ostergren, Dr. Bin Lim, and Dr. Andrei Zagari. Student researchers include Mr. Antonio Garcio and Mr. Steven Sweeney. Mr. Meliton Flores is the test engineer from the NMT Energetic Materials Research and Testing Center.

Objectives of the research include developing an understanding of the fragmentation hazards from composite propellant tanks, and constructing hypotheses and experimental validation of how cracks form in propellant tank-test samples. Specific tasks of the current research include:

- Multiple tests of aluminum 6061 and composite material tubes to better understand the crack opening behavior;
- Developing methods to predict the crack opening behavior;
- Developing standard test procedures for composite materials under shock and high-rate pressure loading, and
- Numerically simulating and predicting the tank fragmentation.

Based on the experience of munitions where the amount of shell fragmentation is a function of the number of grains, it was hypothesized that the fragmentation of tanks would be a function of the strain-rate of over-pressurization. With low strain-rates, a rupture in a tank weak point would create a strain release wave, lowering the stress in the entire tank, resulting in a single fracture opening. High strain-rate over-pressures were hypothesized to generate a strain release wave that is not fast enough to prevent additional tank ruptures, resulting in multiple fracture openings.

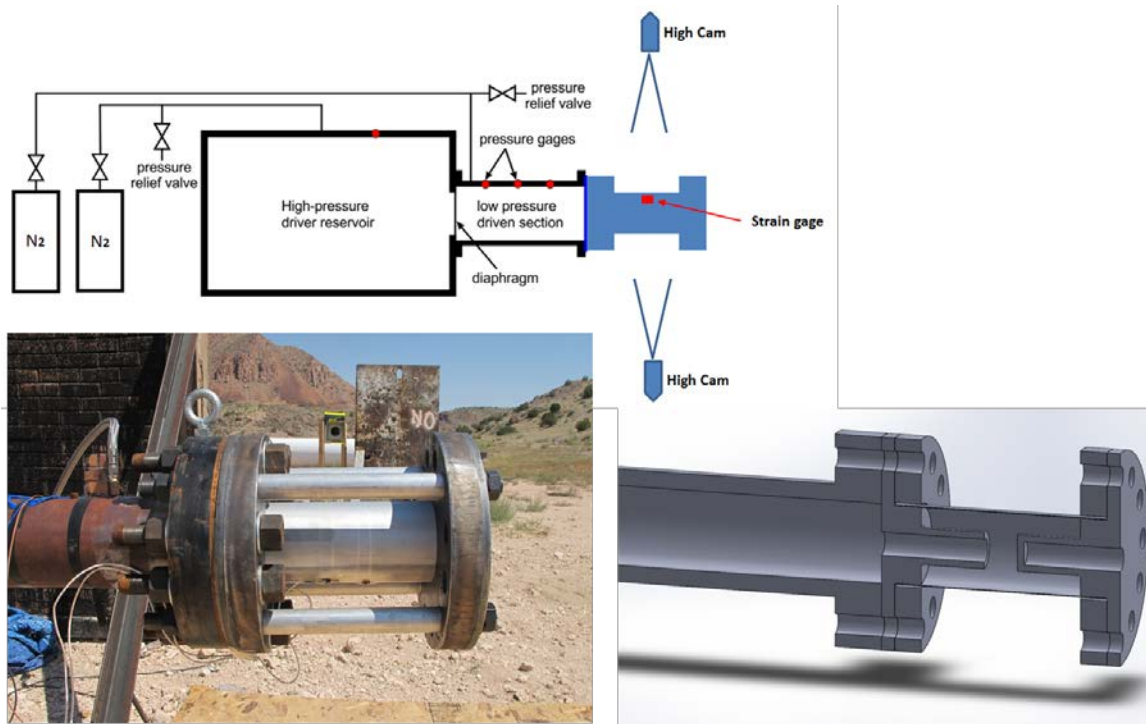


Figure 41: Experimental Test Rig

An experimental test rig was built that allowed axisymmetric simulation of tank rupturing dynamics under low and high strain-rate conditions. To date, testing has supported the hypotheses, demonstrating single fractures from low strain-rate conditions and multiple openings to the test articles under high strain-rate conditions. Further tests will be conducted to validate the experimental results collected to date and to help benchmark the numerical codes.

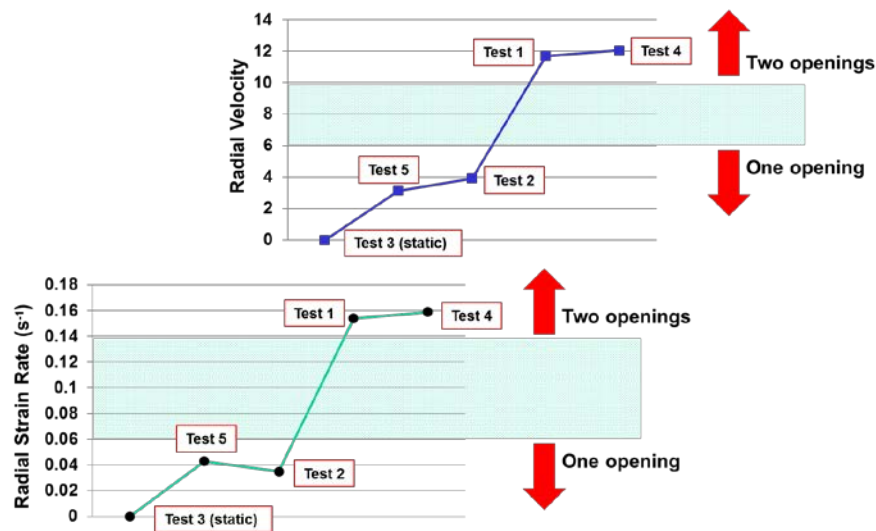


Figure 42: Radial Velocity and Radial Strain Rate Experimental Test Results

Continued Airworthiness Research Conducted

2015 Survey of Emerging Metallic Structures Technology:

New and Emerging Metallic Structural Technology (EMST) is being developed at record pace for implementation into transport category aircraft as aircraft manufacturers continually strive to reduce weight and drive down the cost of manufacturing. These technologies consist of new materials, processes and novel designs. Understanding the current state of the technology, any unique characteristics and the variations in the processes of these new materials is critical for the FAA technical specialists to efficiently assess the certification approach for each application. For this program, the FAA is working with WSU/ National Institute for Aviation Research (NIAR) to actively monitor evolving EMST through surveys, symposiums and site visits to major aerospace organizations. The major focus areas of EMST this year include the following:

- Aluminum-lithium alloys will be the predominant new material used in aerospace structure. New material qualifications have been completed and most published in MMPDS available for industrial use. New variants of the material such as thick plate are being introduced with improved performance moving into the area where the 7050 legacy material dominates the machined al plate market. These new plate materials are being developed in thicknesses and were not available before with improved properties. Material properties and performance do vary with plate thickness and may need further study. Phase I of FAA sponsored research revealed several unique behaviors of the material. Follow on research has been developed and is in the planning process.
- Hybrid structures are on the rise as designers seek traditional and non-traditional solutions to improve performance and decrease weight. Manufactured materials such as GLARE, a laminate of aluminum and fiberglass are already seeing widespread usage although the long-term service history is still evolving. Metallic coatings and flame spray applications are now evolving into structural applications.
- Computational simulation capabilities have improved tremendously due to improved tools, computer speed and efficiency. Validation techniques are evolving and are in need of oversight and standardization. Industry is already looking to the future where simulation may replace conventional processes for inspection, test and predicting material performance.
- Automation in manufacturing is changing the entire landscape of aircraft design, manufacture and assembly because of the potential in saving cost and improving quality has game changing potential. Fully automated aircraft cells that can incorporate part manufacture, from conventional to additive through installation and assembly in one station are currently being prototyped. Real time quality monitoring through physical or simulated results is also being developed. Integrated process control and IPQA techniques will need to be understood so the requisite FAA approval in the type design can be facilitated. The illustration in figure 43 below shows the prototype installation of a Multi Robotic Advanced Manufacturing Center. In this center, conventional machining, additive manufacturing, robotic fastening and assembly with metallics or composites can be performed simultaneously.

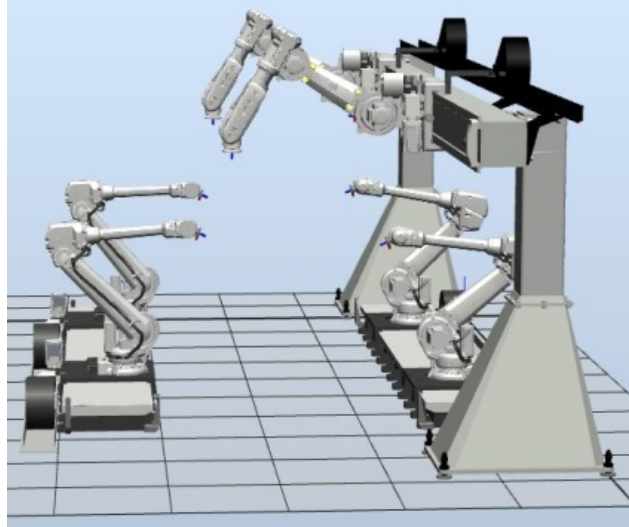


Figure 43: Automation in Manufacturing

Additive manufacturing has again surpassed all predictions for growth and investment. Much of the aerospace focus is on how to develop reliable certification standards for material properties. Multiple standards agencies have embarked on developing standards but few have proposed standards to a level that would be sufficient to manufacture and produce statistically validated product. Every major Aircraft and Engine OEM is actively assessing and pursuing AM. This year industry worked to improve process control and reduce variability while improving productivity. Much effort was spent on following industry and gathering information on technology and supporting numerous standards organizations in determining the requirements and best approach to producing specific material and process standards.

Traditional Design Basis Values

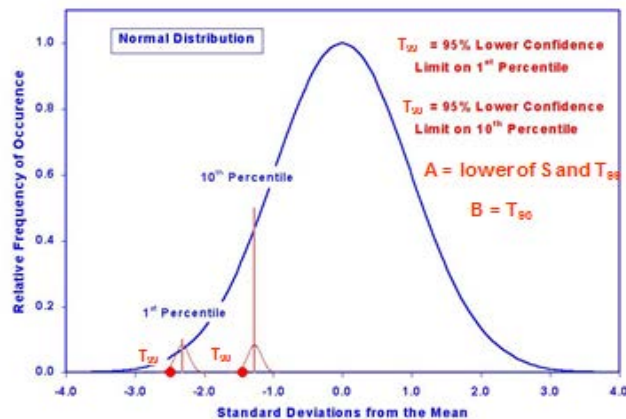


Figure 44: Traditional Design Base Values of Additive Manufacturing

EMST efforts this year include (d), (but are not limited to):

- Collaborate with Battelle on comparing MMPDS and CHM-17 relative to AM;
- Supported MMPDS Emerging Technology Working Group and prepared briefings on NCAMP;
- Collaborative efforts on outlining an equivalency process with Battelle for AM
- Meeting with Oak Ridge National Labs reviewing AM automated designs and IPQA sensing systems;
- Industry meetings with Lusk, Boeing, Airbus, Spirit, Gulfstream, and Lockheed on AM;
- Meeting with Assault and Simula on automated end-to-end AM design processes;
- Entered into a partnership with America Makes as a potential test house – Access to data;
- Joined SAE Additive Sub-Committees: Materials, Process and Data;
- Participated in a Carnegie-Mellon Workshop on Government Role on AM – Briefing on NCAMP;
- Participated on an Additive Manufacturing Technical Panel at the AA&S Conference
- Support the FAA’s committee on AM;
- Prepared outline and objectives for Phase II Al-Li R&D projects;
- Briefed Research team, Sponsors & Industry partners and aligned potential industry partners;
- Supported and prepared data for multiple meetings with project sponsors;
- Yearly update of EMST R&D Roadmap;
- Yearly update of EMST Technology Report;
- Facilitated the potential partnership with Boeing and the Technical Center on an EMST technology demonstration project;
- Created and issued Survey on Additive Manufacturing to benchmark industry, (in process), and
- Supported limited FAA projects with Fractography fracture failure analysis on multiple projects.

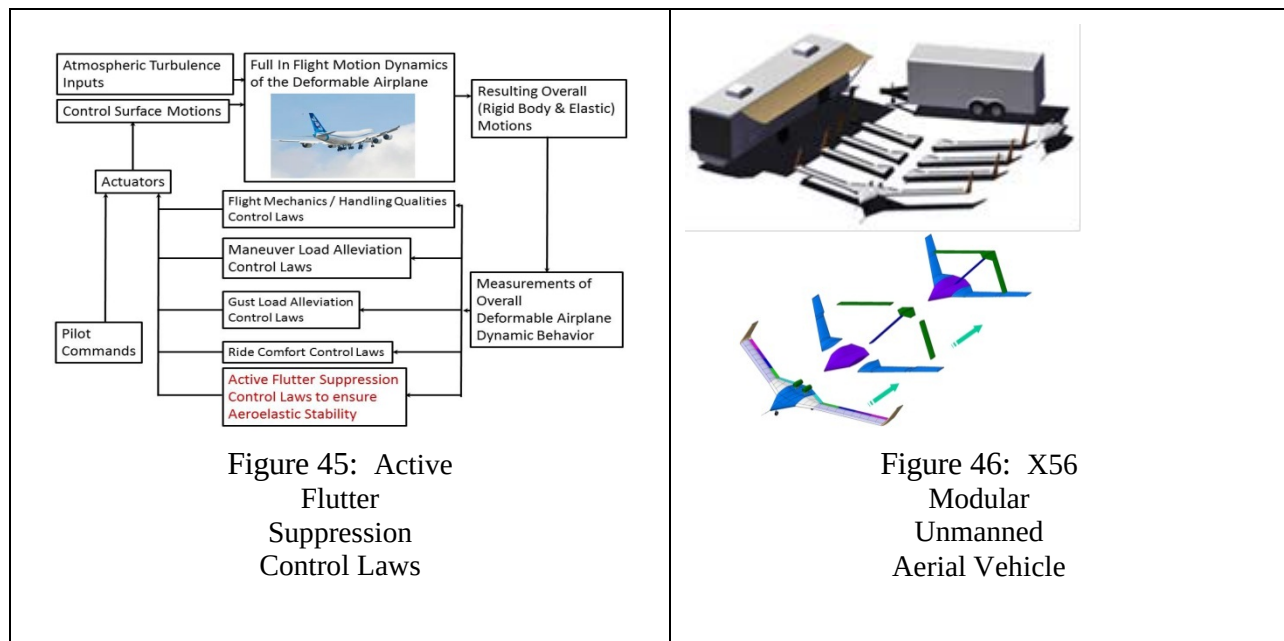
The EMST project will continue to monitor evolving technology and industry research as it may pertain to the assessment of new metallic technologies. Research identified in earlier versions of the roadmap have already been accomplished providing much insight into these new materials and has prompted further investigations and collaboration with industry and material suppliers. This study has highlighted multiple technologies where a review of FAA policy and guidance material may be necessary and has been widely praised by industry as a proactive action to improve the FAA’s technical position in this evolving technology.

Active Flutter Suppression (AFS) – The Development of a Research Plan:

Flutter is an aero-elastic instability that, once reached due to increasing flight speeds and Mach numbers, leads to airframe oscillations of magnitudes that may cause structural damage. Airplanes must be proven to be flutter-free throughout their flight envelopes, with safety margins, and manufacturers design flutter-free aircraft by building enough stiffness into the airframe, and by a corresponding distribution of structural and systems weight. The utilization of active control technology for suppressing flutter has the potential for saving overall weight, but the technology, because of the safety issues involved, is not yet allowed in general.

The next generation of transports will utilize advanced Fly-By-Wire technology that will be capable of providing AFS to reduce the impact of flutter requirements on the airplane design. OEMs are exploring AFS to optimize airplane design, improve operational safety, ensure continued airworthiness, and prevent and mitigate accidents. However, current regulations do not have provisions to address the safe application of these AFS systems and require the use of special conditions to certify airplanes with these unique features. The introduction of AFS systems requires the evaluation of relevant technical issues, certification requirements and compliance issues, and philosophical issues dealing with the application of this technology to commercial transports. This multi-phase project will provide data to allow the FAA to develop new regulations if needed and to adjust regulatory guidance as needed to preserve current aviation safety standards. This research would focus on the conventional type of Transport Category airplanes that are being designed today and in the near future. As an initial phase, an AFS Research Plan is being developed. As part of the plan, a current state of AFS in the commercial airplane sector was assessed through surveys, interviews with airplane manufacturers and operators, and discussions with technology developers. Recent accomplishments this FY include:

- The creation of a comprehensive database of AFS technical publications with emphasis on commercial and military applications;
- Numerous meetings with experts and stakeholders, including Boeing Commercial and Boeing Research & Technology, NASA, USAF, and Lockheed Martin, and
- Outreach efforts made via presentations at Conferences, such as the American Flutter and Dynamics Council (AFDC), as well as site visits such as NASA Armstrong Research Center (center for NASA flight-testing) located at Edwards Air Force base. NASA Armstrong is also the current location of the USAF-funded X-56 flight test system for aero-elastic and flutter testing of advanced aircraft configurations, developed by Lockheed Martin Skunkworks.



The results of the comprehensive review of the state of the industry include information on some history of active flutter suppression systems; a discussion of the key engineering physics involved and the technical issues associated with these systems. A review of the current state of art, directions and challenges for research in this area as well as recommendations for research was also under review. The four major research tasks identified are:

- The creation of reference test cases that would allow researchers, the flight vehicle industry, developers of simulation codes, and the FAA, to build confidence in the analysis and design capabilities they use.
- The development of consistent, universally accepted, formulations of the aero-servo elastic equations of motion of the maneuvering deformable airplane, including rigid body and elastic motion coupling, nonlinear effects, flight control actuation, and readiness for control law design, as well as the implementation of active control laws.
- A comprehensive aero-elastic and aero-servo elastic reliability and uncertainty analysis, and
- The development of control law design and implementation methods for aero-servo elastic systems modeled by high order multi degree of freedom mathematical models accounting for all aero-servo elastic phenomena, including handling qualities, stability, gust and other dynamic loads and load distributions, ride comfort, and maneuver loads.

A team of experts that would assist the AFS Research Plan development is currently being finalized.

Advanced Metallic Fuselage Structure-Start of a New Project:

The aircraft industry is striving to reduce fabrication, operational and maintenance costs by introducing advanced materials, construction methods and production technologies. In light of the B787 and A350 advanced construction and increased competition from composite materials industry, the metallic material industry has made significant strides at unprecedented rates in developing new metallic alloys and material manufacturing process that are competitive with composites in terms of cost and performance. EMST that are on the near-term horizon include advanced welding (friction stir, linear, laser and electron beam), advanced metallic alloys (aluminum-lithium) and hybrids (metallic-composite structures), fiber-metal laminates and bonded structure. Prior studies have demonstrated the potential to design and build durable and damage tolerant structures using EMST. For next generation metallic fuselage with goals of higher operating pressures, longer inspection goals, and improved corrosion resistance the critical driver for fuselage panels will be damage tolerance. However, with the introduction of new technologies, data and information is often lacking to allow for a comprehensive assessment of long-term safety concerns. Regulators and industry need to work together in preparation for their application and certification. Data is necessary to assess continued relevance of existing regulations and develop additional safety standards and regulatory guidance if needed to maintain the current level of safety afforded by the existing airworthiness standards. For this new effort, the FAA will be collaborating with industry to assess durability and damage tolerance of EMST including unitized welded structure, new metallic alloys (Aluminum Lithium), and hybrid construction, shown in figure 47 below.

Accomplishments for this fiscal year include the establishment of a new five-year Cooperative Research and Development Agreement 15-CRDA-0310 with the ALCOA Technical Center on August 2015. The purpose of this collaborative effort is to obtain full-scale fuselage panel test data to demonstrate how fuselage concepts utilizing EMST improve the durability and damage tolerance, compared to the current baseline aluminum fuselage structures. The single aisle aircraft fuselage will be used as the baseline structure. Test data will be collected utilizing the unique capabilities of the FAA's Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) facility. This data will be used to verify improved weight and structural safety performance of the EMST. It will also be used to assess the relevance of existing regulations and to inform whether additional safety standards and regulatory guidance should be developed to provide improved safety beyond that afforded by the existing airworthiness standards.

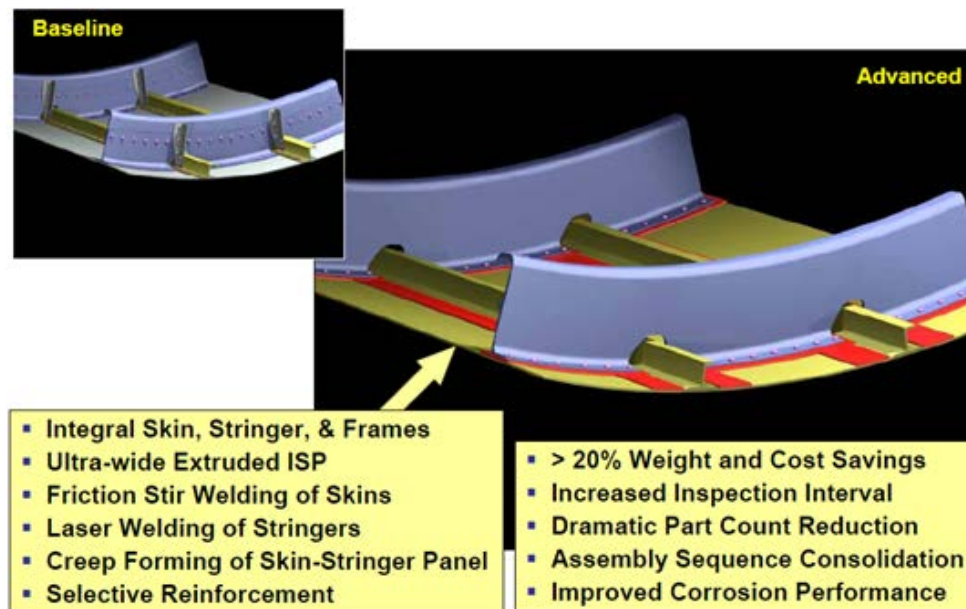


Figure 47: Advanced Metallic Fuselage Structure

Airframe Beam Structure Test (ABST) Fixture:

The development of a new structural test capability was initiated within the FAA, namely, the ABST fixture under partnership with the Boeing Company through Cooperative Research and Development Agreement 07-CRDA-0236. A system integration test program was initiated to integrate the hardware and software equipment provided by the Boeing Company that will be used in developing the ABST and demonstrated functionality. During this fiscal year, Building 245 was used as a staging area to assemble and integrate several key components in a simplified cantilever beam assembly loaded using a single 5-kip actuator shown in figure 48 below. The test set-up required interfacing the control, data acquisition, and hydraulic systems. Both static and fatigue tests were conducted under low loads and hydraulic pressure to verify full system integration, data acquisition, and data reduction capabilities. Follow-on efforts of the system integration test program, will focus on the design of a bench test-set up to exercise multiple load actuators simultaneously using a bootstrap assembly.

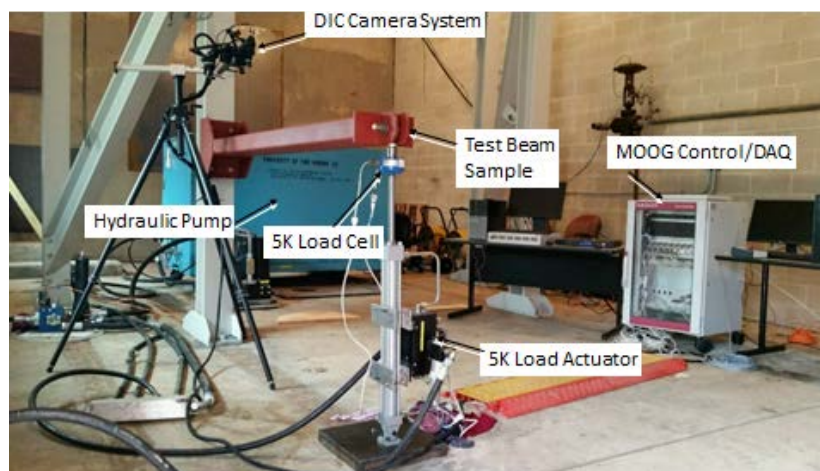


Figure 48: Preliminary Set-Up for System Integration Test Program Supporting Development of ABST Fixture

Assessment of Advanced Aluminum-Lithium (AL-Li) for Primary Structure:

This study is underway to gain a better understanding of the material properties, mechanical behavior, and unique characteristics of the typical next generation Al-Li, being used in airframe structures by comparing it with traditional aluminum alloys. The latest generation of Al-Li alloys purports to offer a significant weight savings over conventional aerospace aluminums resulting in significant use in recent aircraft and aerospace applications. The current public data provided for these alloys is very limited and does not provide a comprehensive understanding of the strengths and weaknesses of such materials. Due to previous generations of Al-Li alloys displayed material behaviors, which limited their use for aerospace applications, it is necessary to fully understand the properties and behaviors of these new alloys. Two Al-Li alloys are being considered as an initial case study, namely 2198-T8 and 2196-T8511, alloys used for skin and extrusion applications, respectively. Several properties are being assessed and compared with baseline 2024-T3 and 7075-T6 alloys, including static properties; fatigue life and Fatigue Crack Growth (FCG) behavior, as well as supplemental properties. Resources and expertise are being leveraged from several organizations, including Constellium, Bombardier, National Aeronautics and Space Administration-Johnson Space Center, Naval Air Systems Command, University of Dayton Research Institute (UDRI), NIAR, Drexel University and the Federal Aviation Administration Technical Center (FAA-TC).

In general, test results to date revealed that the static; fatigue and FCG and several supplemental properties of typical third-generation Al-Li alloys were comparable to the baseline aluminum alloys. The static properties for both the Al-Li and baseline materials tested were comparable and the values exceed all the MMPDS A and B basis values, as shown in figure 49a. below. Anisotropic behavior was observed in the Al-Li, where properties at the 45° grain direction differed from other grain directions. There was a general improvement in the FCG properties where higher crack growth resistance was measured in the instability region of the FCG curve for the Al-Li compared to the baseline.

Results from lap-joint fatigue tests using specimens configured to induce high secondary bending yielded varying results. The 2198-T8 displayed shorter fatigue lives compared to the 2024-T3

bare sheet material, shown in figure 49b. below. Examinations of the fracture surfaces revealed marked differences. The fracture surface for the 2198-T8 was much smoother with shallower striations compared to the baseline material. Additionally the 2198-T8 grain structure appeared elongated with constituents congregating along the grain boundaries. The 2198-T8 material also displayed unique cracking behavior not observed in the 2024-T3, namely, eyebrow cracking (crack path circumvents the fastener hole) and inter-laminar cracking (cracks appearing parallel to the material surface and perpendicular to fracture surface), figure 49c. below. This initial study contributes to the availability of limited information in the public domain regarding material properties of Al-Li alloys for aerospace applications. A final report was drafted covering the test results for the basic material properties. However, the associated data for component and full-scale articles subjected to in-service operational loads is lacking.

Follow-on research is intended to provide insight into how these materials perform in assemblies where complex and out-of-plane loads as well as behaviors associated with years of service and variable environments prevail. The occurrence of unique fatigue damage modes observed in the Al-Li compared to typical aluminum alloys used in airplanes today warrant further investigation into the crack growth behavior to validate the applicability of existing damage tolerance requirements. This includes testing of lap-joint configurations more representative of typical airframe structure. Additionally, the anisotropic behavior revealed that Al-Li materials might require more data to adequately describe material characteristics than typically published in MMPDS for stock aluminum material.

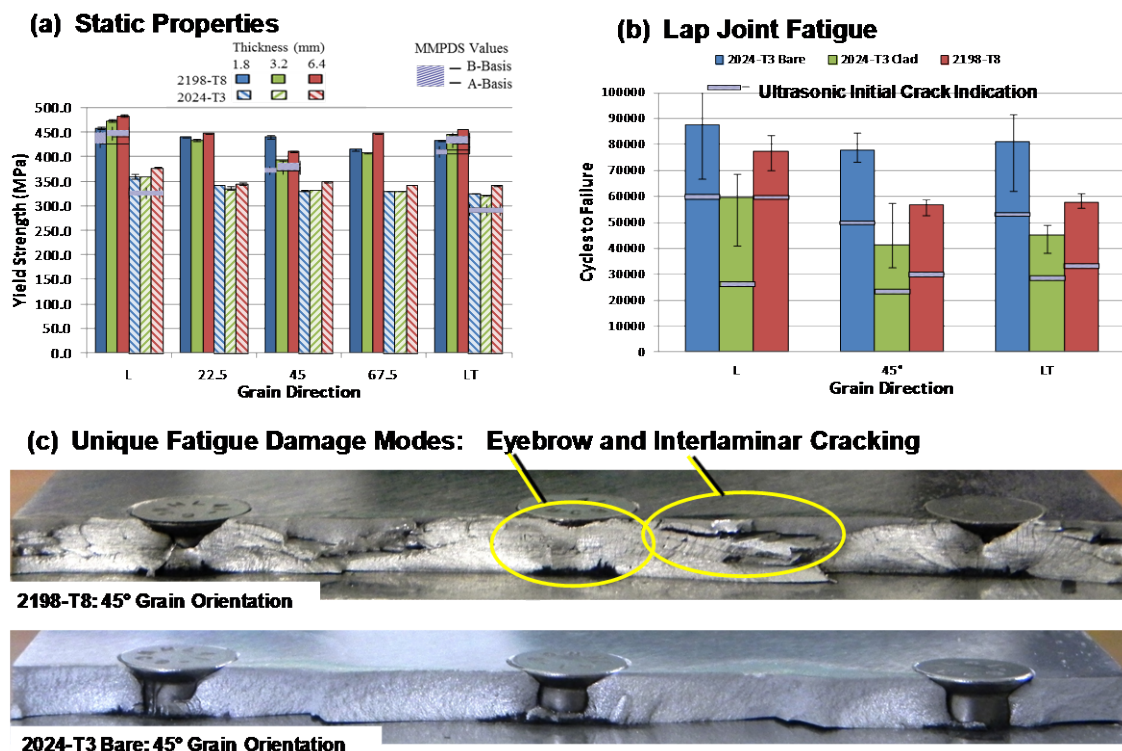


Figure 49: a-c Test Results for Aluminum Lithium

Bonded Repair Technology:

In a joint effort, the FAA and The Boeing Company are investigating the structural robustness and damage resistance capabilities of adhesively bonded repair technology through the testing and analysis of metallic B727 fuselage panels at the FASTER facility. The program objectives are to characterize the fatigue performance of bonded repairs under simulated service load conditions and to investigate tools for evaluating and monitoring the repair integrity over the life of the part. For this fiscal year, a major phase of testing has completed investigating the effects of environment on fatigue performance of boron/epoxy (B/Ep) composite and aluminum bonded repairs fatigue tested under environmental conditions (165°F and 85% humidity) up a typical design service goal of 80000 cycles.

A comparison of crack growth characteristics from a prior panel (panel 2) fatigue tested under ambient conditions reveal differences in which the environment may be a contributing factor on fatigue performance in the B/Ep composite repairs, figure 50a. below. As shown, results reveal slower crack growth under hot-wet conditions compared to those under ambient lab conditions

for which the average measured rates were 1.29×10^{-5} in/cycle and 1.47×10^{-5} in/cycle, respectively. A contributing factor to this difference is the mismatch in the thermal coefficient of expansion of the composite patch and aluminum fuselage resulting in the development of thermal residual stresses ahead of the notch from the initial patch installation curing process. At elevated temperature, these residual stresses are relaxed as illustrated in figure 50b. below. Hoop strains are shown and measured ahead of the crack tip at three locations at three different temperatures; -25°F, 80°F and 165°F. With increase in temperature, the strains ahead of the crack-tip reduce which would contribute to slower crack growth rates. Results for the aluminum repair indicted limited effect of environment on the fatigue crack growth, shown in figure 50c below. As shown, the fatigue crack growth behavior was similar for hot-wet and ambient

conditions where the measured rates were 1.18×10^{-5} in/cycle and 1.19×10^{-5} in/cycle, respectively. Because both the repair and the fuselage skin are made of aluminum, the coefficients of thermal expansion were comparable, resulting in limited thermal residual stresses after the initial patch installation curing process. As shown in figure 50d below, the hoop strains measured from three notch gages ahead of the crack-tip were similar for the three applied temperatures. Data from this program will be used to assess methods to quantify bonded repair integrity.

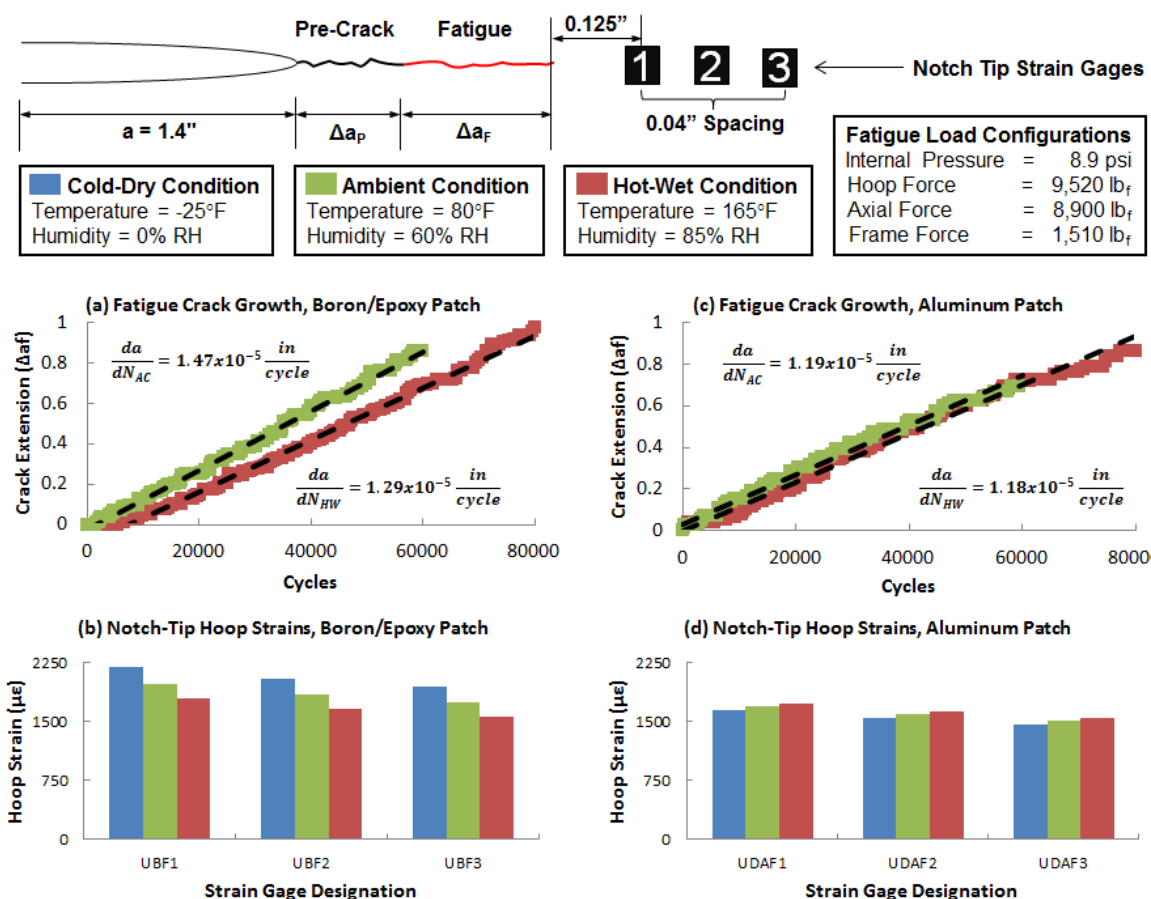


Figure 50: a-d Effect of Environment on Fatigue Performance of Bonded Boron/Epoxy Composite and Aluminum Repairs

Determine the Current State of Active Flutter Suppression in the Commercial Airplane Sector to Assess Adequacy of Existing Standards, Guidance, and Regulations:

This multi-phase AFS project will provide data as needed to allow the FAA to develop new regulations and to adjust regulatory guidance as needed to preserve current aviation safety standards. This research will be focused on the conventional type of Transport Category airplanes that are being designed today and in the near future. As an initial phase, an AFS Research Plan is being developed. As part of the plan, a current state of AFS in the commercial airplane sector was assessed through surveys, interviews with airplane manufacturers and operators, and discussions with technology developers. Recent accomplishments include the creation of a comprehensive database of AFS technical publications, with emphasis on commercial and military applications, and numerous meetings with experts and stakeholders, including Boeing Commercial and Boeing Research & Technology, NASA, USAF, and Lockheed Martin. Outreach efforts have been made via presentations at conferences such as the AFDC as well as site visits to NASA Armstrong Research Center (center for NASA flight testing) located at Edwards Air Force base. NASA Armstrong is also the current location of the USAF-funded X-56 flight test system for aero elastic and flutter testing of advanced aircraft configurations, which was developed by Lockheed Martin Skunkworks. The results of this comprehensive review of the state of the industry include:

- Information on some history of active flutter suppression systems;
- A discussion of the key engineering physics involved;
- Technical issues associated with these systems;
- A review of the current state of art, directions and challenges for research, and
- Recommendations for research.

The four major research tasks identified are the same as those listed in the Active Flutter Suppression-The Development of a Research Plan section of Continued Airworthiness.

Efficient and Accurate Computational Methods and Tools for Damage Tolerance Based Aircraft Reliability Assessment:

This project supports the development of a standardized Continued Operational Safety (COS) risk assessment method for small airplanes consistent with the AIR safety management principles. The goal is to develop a probability-based risk identification methodology and tool to assist ACO engineers; owner/operator designated engineering representatives and type certificate holders in identifying and managing the safety risks for COS as well as to assist small airplane manufacturers, modifiers, and operators in developing Fatigue Management Programs. This project considers technical issues associated with having limited available data for modeling statistically correlated strength in time-dependent reliability analysis. Additionally, it provides a methodology to be used to include a wide range of time-dependent strength scenarios such as damage degradation, aging, and repair/replacement after inspections.

While the project considers a perfect repair/replace scenario, it provides a technical platform that could assist in including the effects of imperfect repairs and imperfect inspections in risk assessment and risk management methodologies. The project was concluded in May 2015 with accomplishments documented in a draft report titled *Efficient and Accurate Computational Methods and Tools for Damage-Tolerance Based Aircraft Reliability Assessment*. In addition, the project resulted in development of a software tool called Fly Risk that uses a strength-conditioned importance sampling method, tailored to analysis of time-dependent aircraft structural reliability, shown in figure 51 below. Improved accuracy and efficiency, when compared to similar method, is an important accomplishment of this project.

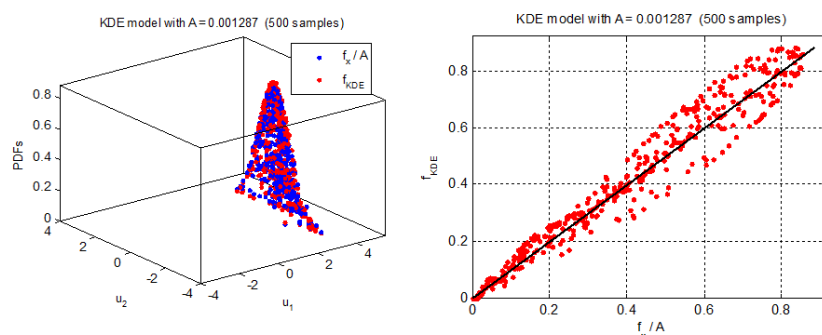


Figure 51: A Representative Analysis Performed by Fly Risk

The FAA-Drexel University Fellowship Program:

The FAA-Drexel University Fellowship Program is a collaborative effort to promote aviation safety within academia and support ongoing research activities within the FAA's Aviation Research Division. The goal of the FAA-Drexel Fellowship Program is to educate and train the next generation engineers addressing aviation and aerospace safety. The actual research and development are conducted and executed at the FAA WJHTC Structures and Materials Section, the ANG-E281 division, and the Atlantic City International Airport, NJ 08405. R&D is performed by Drexel's graduate and undergraduate students under the combined supervision of the FAA scientists and engineers, led by Dr. John B. Bakuckas, and Drexel faculty Doctors, Dr. Jonathan Awerbuch and Dr. Tein-Min Tan. Course work and academic supervising takes place at Drexel's campus as well. The FAA-Drexel Fellowship Program, established in 1997, supported 37 undergraduate students in seven senior design projects; approximately 25 undergraduate students (working part time, either for credit or for hourly pay) involved in many different research projects. There were seven co-op students (each six-month long sessions at the FAA-Technical Center), 14 Master of Science degree students (completed and current), and 10 Philosophy Doctorate students (completed and current), with some 35 of them awarded, various first place prizes within and outside Drexel. It generated over 80 conference and journal publications and FAA reports and a similar number of conference presentations. Accomplishments by the Program Fellowships during FY 2015 are summarized below:

- Numerical and Experimental Study of Adhesively Bonded Repairs of Aluminum Fuselage Structures Using Aluminum and Composite Patches by Reewanshu Chadha, Ph. D. Candidate. Mr. Chadha developed a global/local FE model, shown in figure 52a below, to study the adhesively bonded repairs of aluminum fuselage structure subjected. The model was validated by comparing the hoop strains near the patch and the fatigue crack growth rate with the experimental results shown in figure 52b. The model was then applied to a Mid-Bay 5-Ply B/Ep patch and a parametric study was conducted to study the effect of patch stiffness, in terms of ply orientation, on the fatigue crack growth, shown in figure 52c below.

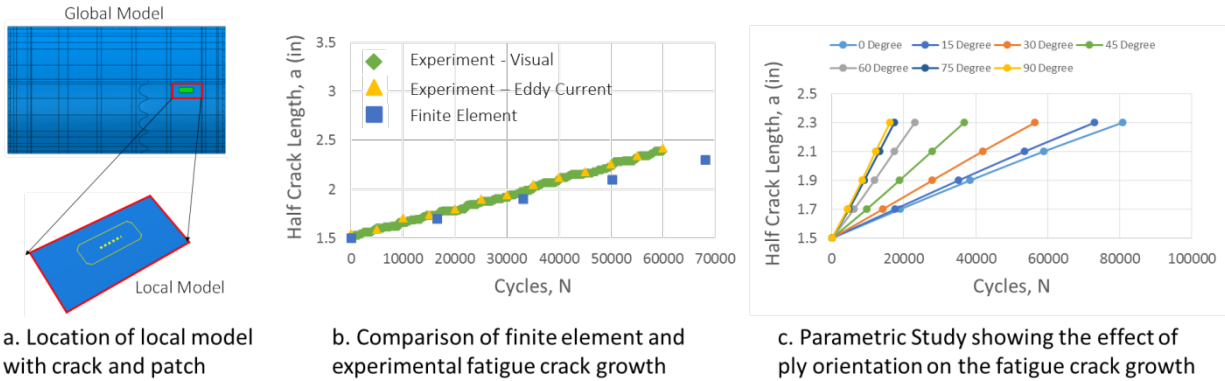


Figure 52: (a) Global/Local FE Model (b) Validation of the FE Model Comparing Fatigue Crack Growth Rate with Experiments (c) Parametric Studies on the Effect of Ply Orientation on Fatigue Crack Growth Rate

- Evaluation of Adhesively Bonded Repairs to Fuselage Structure Subjected to Environmental Conditions by Bin Lei, Ph. D. Candidate. Phase 3 testing of the third B727 fuselage panel has completed. The panel, having both B/Ep and aluminum bonded repair patches, was subjected to mechanical fatigue loads of over one design service goal (80000 cycles), under hot-wet environmental condition (165°F and 85% humidity). The effects of the environmental condition (i.e., ambient vs. hot/wet) on the fatigue crack extension and fatigue crack growth rate, under repair with bonded boron/epoxy and aluminum repair patches, was investigated. Phase 4 testing of the third B727 fuselage panel has been initiated and the panel is subjected to cold-dry environmental condition (-25°F). Strain-gage-chains capable of measuring strains at 10 locations within a half-inch distance from each crack tip were introduced to measure the strain fields near the crack tips under four different repair patches. Data obtained from the gage-train will be used to characterize panel deformation and crack growth behaviors under various temperatures.

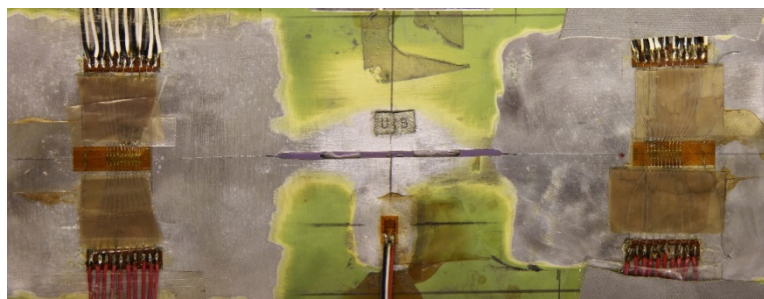


Figure 53: Strain Gage Chains Installed Near Tips of Crack at Under-Designed B/Ep Patch

- Fractographic Examinations and Reconstruction of Fatigue Crack Growth in Aluminum Lithium Riveted Lap Joints by David Stanley, M.S. (Drexel Mechanical Engineering). A detailed examination of the fatigue fracture surface morphology of two aluminum alloys, AA2024-T3 and AA2198-T8, was conducted. Three specimen directions (relative to the rolling direction), the L

(rolling), LT (transverse), and 45° directions were studied under a constant amplitude fatigue loading condition. The prior year's examination of the pattern of fatigue striations, using a Scanning Electron Microscope (SEM), shown in figure 54, below, revealed striation ridges-defined as the intersection of two neighboring striation gorges, seen by the bright segmented lines in figure 55 below. The presence of constituents, however, causes the crack to progress, locally, at different directions and rates, as shown in figure 56 below.

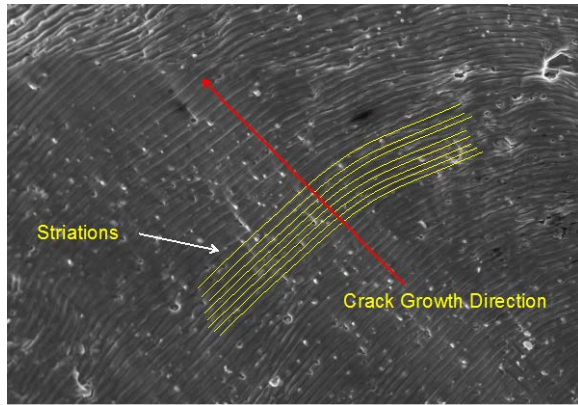


Figure 54: Fatigue Striations on Fracture Surface of AA2024-T3

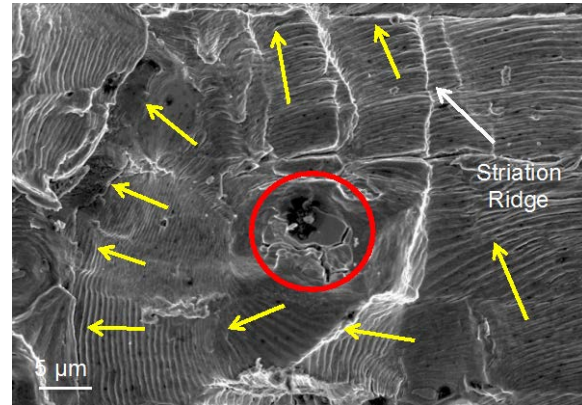


Figure 55: Varying Local Crack Growth Direction (yellow arrows) Around a Constituent (red circle)

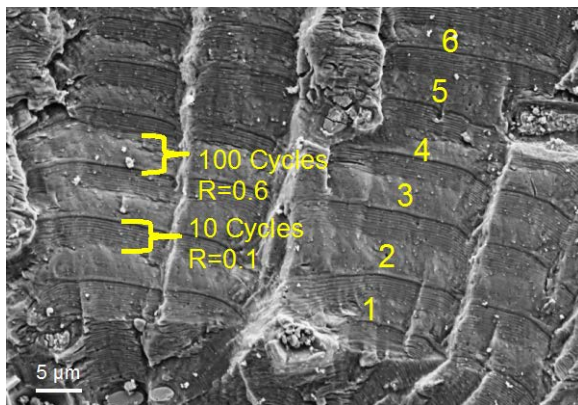


Figure 56: A 6-Segment from the 10-4-6 Marker Band Pattern in Clad AA2024C-T3

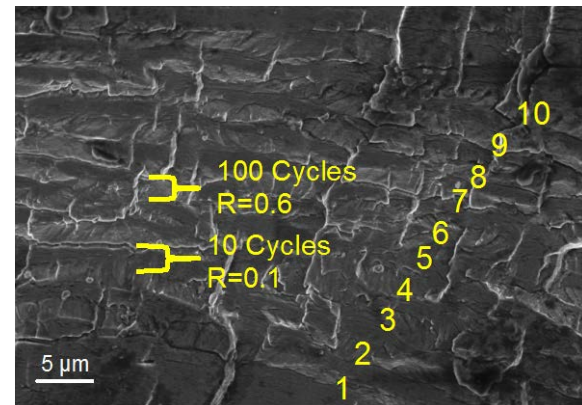


Figure 57: A 10-Segment from the 10-4-6 marker band pattern in AA2198-T8

The striation-based approach under the constant amplitude fatigue loading condition was difficult to accurately identify fatigue crack. Fatigue tests were conducted using a 10-4-6 marker band spectrum loading profile to provide easier identification of marker bands along the fracture

surface for quantitative fractography. By introducing the different R-ratios, a contrast difference could be observed via the SEM, in both alloys, shown in figure 56 and figure 57 above. The marker bands accentuate the crack front profile, enabling direct measurements of crack growth direction and rate.

- Design of an Airframe Beam Structure Test Fixture and a Beam Structure Test Article Representative of an Aircraft Wing or Stabilizer Components by Ryan Neel, B.S., Sean O'Connor, B.S., Joseph Yacono, B.S., Joseph Angelico, B.S., Aidan Jamison-Frank, B.S., Nathan Knauss, B.S., Mark Santella, B.S., William Scaggs, B.S., Dan Ehala, B.S. and Benjamin Kim, B.S. All part of Drexel Mechanical Engineering. The FAA in partnership with the Boeing Company are currently expanding structural testing capabilities to include primary beam structure representative of an aircraft wing structure or horizontal stabilizer for the initial purpose of studying the durability of bonded repairs. A 10-member Drexel University Senior Design Team was tasked with developing a preliminary design for such a system. The project entailed two sub-systems; (a) the design of a test article representative of an aircraft wing structure with stabilizer components; and (b) the design of a test fixture capable of subjecting the test article to any combination of pure bending, shear, and torsional loading configurations. Such that the skin of the test article experiences specified levels of stress and strain during fatigue loading and residual strength tests. The goal was also to ensure optimal and durable integration between the two sub-systems.

To facilitate the completion of the project, the FAA and The Boeing Company provided conceptual designs of a test fixture and test article, as shown in figures 58a. and 58b. respectively. Regular weekly three-way consultation was conducted between FAA-TC engineers and machinists, The Boeing Co. engineers, and Drexel team. The test article and the test fixture were developed within a complex iterative design process in which several methods of validation were used to evaluate each design. Validation methods included fundamental structural calculations and FEstress/deformation analyses. The collaborative effort resulted in the creation of a design that met project requirements. Solid works models of the final test fixture and test article are shown in figures 59a and 59b respectively. The preliminary design provided by the teams will be used by Boeing engineers to develop the final design of a full-scale test fixture and test article.

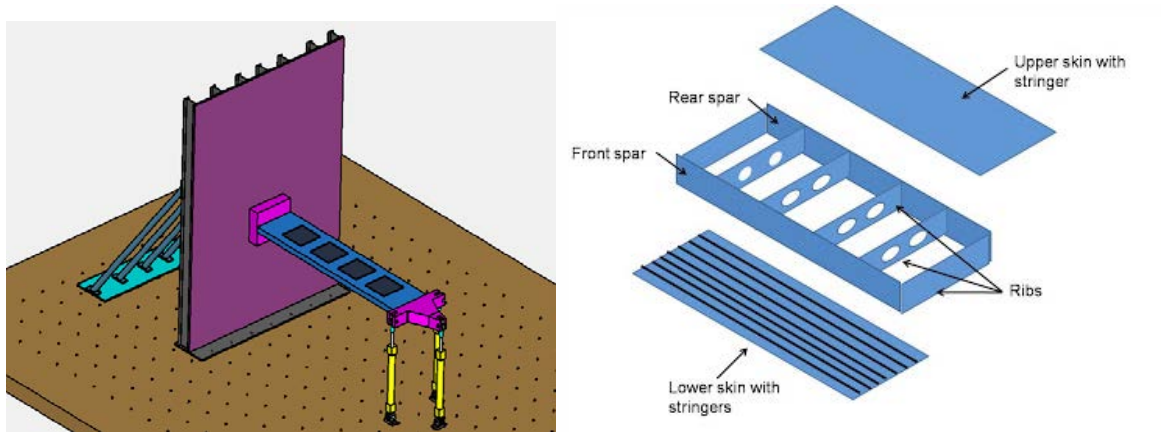


Figure 58: (a) Conceptual Designs of Beam Structure Test Fixture (b) Test Article provided by The Boeing Company

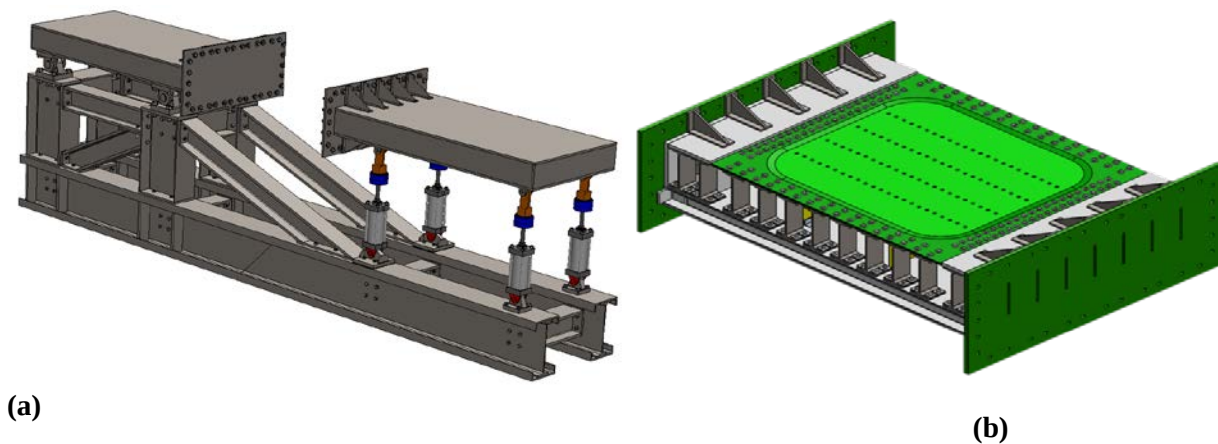


Figure 59: (a) Team designs of Beam Structure Test Fixture (b) Test Article Representative of Aircraft Wing Panel

In-Service Cracking Investigation:

This project supports the investigations of in-service cracking occurrences to help identify issues that affect the safe operation of aircraft. Recent efforts focused on in-service cracking of the wing spar on several Embraer 170 in the U.S. Fleet. Large cracks were observed in three airplanes at this location while in-service for less than 15000 flights. Working with WSU/NIAR, an assessment and fractographic examinations were performed on samples taken from two cracked wing spars designated A/C 00012 and A/C 00018. This included verification of the material (7050-T7452), identification of crack initiation sites, assessment of whole quality, determining crack shapes and sizes and reconstructing an estimated crack growth history. Major findings revealed poor hole quality with drilling marks (circumferential grooves or rifling patterns), particularly in A/C 00012. For both samples, multiple crack initiation sites were observed along the whole bore surface, with cracks propagating along many different planes. No evidence was gathered to indicate that the initiation sites were due to the drilling marks. Crack

growth reconstruction from striation counts along the crack surfaces indicates crack initiation occurring early in the service of both airplanes. For A/C 00012, cracks were estimated to initiate 8000 to 9000 flights prior to crack discovery at 14943 ft. For A/C 00018, cracks were estimated to initiate 6320 flights prior to crack discovery at 14712 ft. Evidence of earlier crack initiation in A/C 00012 could be attributed to the poor whole quality observed.

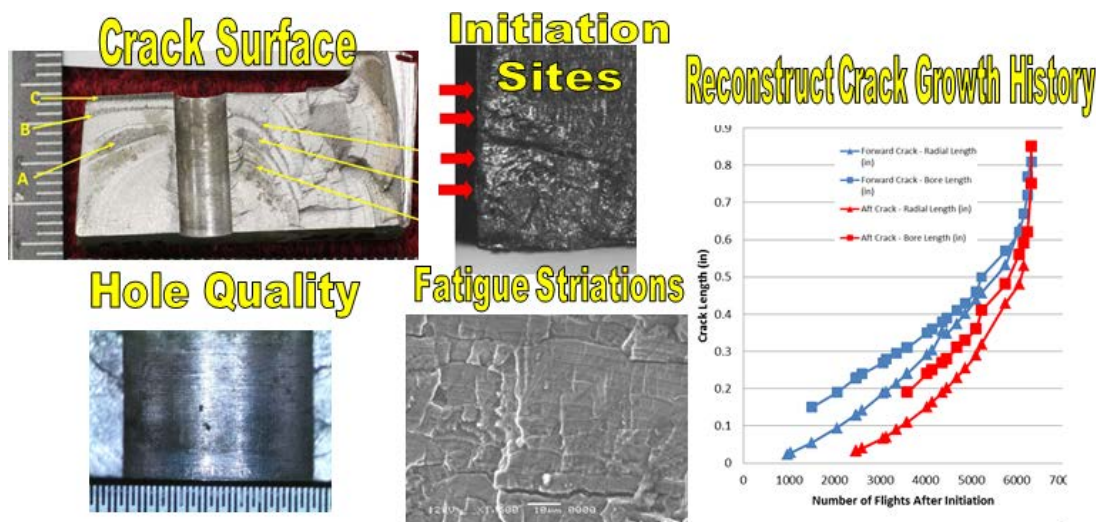


Figure 60: Support of In-Service Cracking Investigations

Metallic Materials Properties Development and Standardization (MMPDS):

The MMPDS is an effort led by the FAA to continue the handbook process titled *Metallic Materials and Elements for Aerospace Vehicle Structures*, (MIL-HDBK-5). The 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. Consistent and reliable methods are used to collect, analyze, and present statistically based aircraft and aerospace material and fastener properties. The objective of the MMPDS is to maintain and improve the standardized process for establishing statistically based allowables that comply with the regulations, which is consistent with the MIL-HDBK-5 heritage, by obtaining more equitable and sustainable funding sources. This includes support from government agencies in the Government Steering Group (GSG), from industry stakeholders in the Industry Steering Group (ISG) and from profits selling the handbook and derivative products. Towards this goal, the commercial version of the MMPDS-10 was released in April 2015, shown in figure 61 below. Significant changes to the handbook include the addition of five new metallic alloys, updated guidelines for analysis of small samples and fatigue data and updated specifications per AMS revisions. In addition, equitable and sustainable funding sources were secured in FY15 where 60% to 70% was funded by the ISG and GSG and 10% was funded from commercialization efforts.

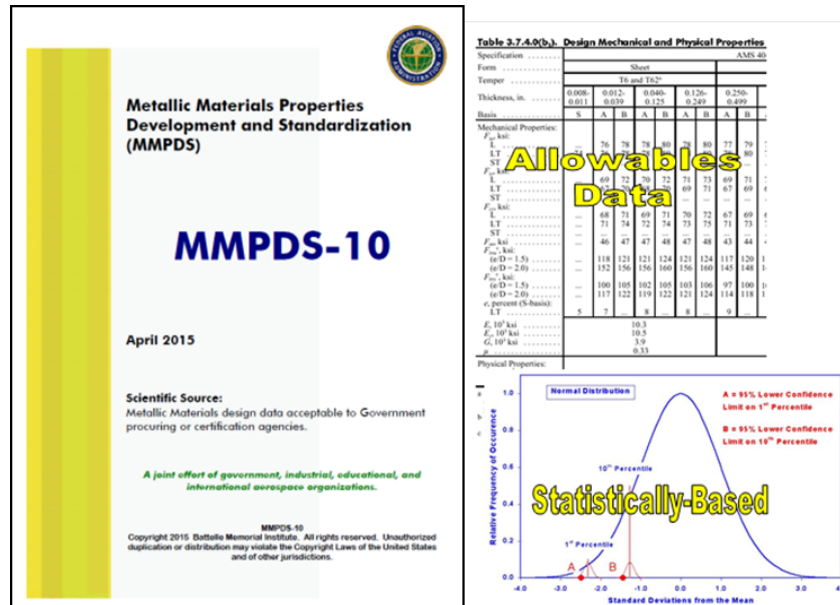


Figure 61: Cover of MMPDS-10

NASGRO® Fracture Mechanics and Fatigue Crack Growth Software and Database:

Structural failure due to the consequences of naturally occurring and service-induced flaws, damage, or cracks in a structural component is the primary threat to the integrity, safety, and performance of nearly all highly stressed mechanical structures. Consequences of such failures include serious injury or loss of life, severe environmental damage, and substantial economic loss. Fracture-based damage tolerance analysis is a means to comply with FAA regulations in reduction of structural-related accidents. Such analysis tools require unique material behavior data to readily available from other sources. NASGRO® is a NASA-developed software package capable of performing state-of-the-art fracture and fatigue crack growth analysis. Under continued active development for over 25 years at NASA's Johnson Space Center (JSC), NASGRO®'s initial use was for damage tolerance assessments on NASA hardware. However, with significant support and guidance from the FAA, developments in recent years have made NASGRO® so powerful and versatile that it is now the de facto standard fracture analysis tool in the aircraft industry. Features that make NASGRO unique among fracture mechanics analysis tools include:

- A large library of more than 70 crack geometry solutions;
- A material property database containing data for hundreds of metallic materials;
- A unique crack growth equation (and seven legacy equations) able to model onset of crack growth, small-crack behavior, retardation, and instability, and
- Capabilities to model elastic-plastic loading, failure of glass or glass-like materials under constant loading, and critical crack size.



Figure 62: NASGRO ® -NASA-Developed Software Package Capable of Performing State-of-the-Art Fracture and Fatigue Crack Growth Analysis

In order to facilitate technical development, information exchange, and software distribution with the wider aerospace industry, NASA initiated a Space Act Agreement with Southwest Research Institute (SwRI) in 2000 to form and manage the NASGRO® Industrial Consortium that is currently composed of 20 members, most of which are major global aircraft companies, and NASA and the FAA. Within the framework of this consortium, JSC and SwRI release a major version of NASGRO® every year. Major milestones in FY15 have been the release of major version 8.0 in August 2015, as well as release of version 7.11; a bug fix release to the previous version (v7.1), in January 2015. Version 8.0 contains important new technology and improvements including:

- New K solution for single corner crack and through crack at an offset hole in a plate (HC01);
- New K solutions for a crack at a rectangular cutout with rounded corners (TC25 & TC26);
- Addition of K solution to TC02 (through crack at edge of plate) for bending restrained boundary conditions;
- Addition of capability to handle pin load to TC13 (uni-variant weight-function for through crack at a hole in an offset plate);
- New capability to input K as a function of crack size via data table models (KTxx);
- New CC16 finite width correction factors for pin loading;

- New Rigorous K-analogy in NASGRO STRIPY Strip-Yield Module;
- New High Cycle Fatigue (HCF) Threshold Failure Criterion;
- Addition of Alternative Failure Criteria FAD and Transient Power Fuel Control (TPFC) to SC04 and SC05 models (surface cracks in cylinders), and
- New capability to plot FAD and TPFC results from the NASFLA GUI

Transport Airplane Risk Assessment Methodology (TARAM):

This project supports the implementation of FAA Order 8110.107A prescribing the use of the Monitor Safety/Analyze Data (MSAD) process to make COS decisions and for issuing Airworthiness Directives (AD) based on risk analysis methodologies. The MSAD compliant process for transport category airplanes is the Transport Airplane Risk Assessment Methodology (TARAM). An important parameter used in TARAM analysis is ND-Not be Detected. The conditional probability is that an occurrence of a defect (fatigue crack) will Not be Detected (ND) before it leads to an unsafe outcome (airplane accident). Currently, there is a lack of data to provide sound estimates of ND, which can lead to large errors in the calculated risk used to make safety decisions and to determine acceptable compliance times. Excessively conservative values for ND could lead to unnecessary ADs or with unnecessarily aggressive compliance times. The scope of this project is limited to obtaining data that can be used in the estimation and development of guidance material for ND for airplane structure fatigue problems in metallic Fatigue Critical Baseline Structures (FCBS) items of transport category airplanes. The FAA is currently working with Sandia National Labs in this multiyear effort and is planned to be conducted in four phases:

1. In-service damage survey: Gather planning information through site surveys, record reviews, and interviews with operators and repair stations to assess the available of data on structural cracking observed in the fleet. This data will be used for the development of a detailed research plan. The plan will support FAA in assessing the probability of not detecting fatigue damage of a given size/geometry, in a given structure and aircraft, by various methods of inspection/detection, including incidental discoveries, FY14-15.
2. Sponsor will conduct analysis of Phase I planning information and develop a detailed plan for the life-cycle of the research effort, FY15.
3. Execute plan developed in first two phases and obtain and deliver data necessary to support development of initial ND guidance, FY16-18.
4. Prepare final report and database for use in updating TARAM, FY19.

In this fiscal year, Phase I and II were completed. For Phase I, the FAA's Service Difficulty Reports (SDR) was identified as the best source of information for this project. Data from the SDR database was cross-referenced and verified with data submittals provided by several operators. In addition, a search protocol and collection tool was developed to gather crack

findings from the SDR database using common spreadsheet software, Excel, as shown in figure 63, below. The approach and data collection tool was used to develop the structure of an ND database starting with a single aircraft; Boeing 737-3H4 with a serial number of 22940 with the date of manufacture, 1984, from which there were 247 crack findings entered. For Phase II, a detailed plan was developed by the FAA based on the Phase I findings from Sandia. Emphasis is placed on streamlining data mining activities and increasing data capture by developing an automated tool to process/extract information from the FAA SDR database. Once validated, the automated data mining tool will be used to gather information and populate the ND-TARAM database. Currently, the kick-off meeting for the Phase III of this activity is set for October 2015.

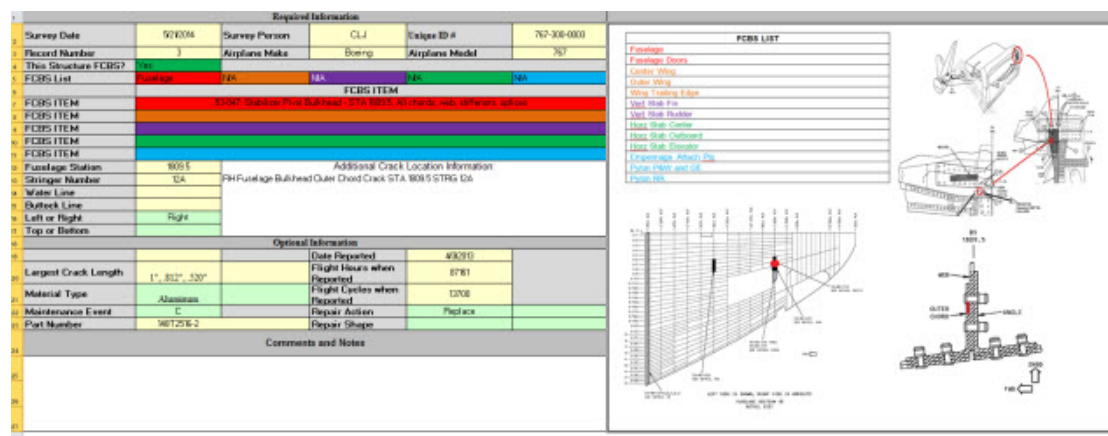


Figure 63: ND Data Gathering Tool User Interface

Structural Health Monitoring (SHM):

Industry is promoting new technologies such as SHM to reduce long-term maintenance costs, improve safety, and reduce labor cost and human error. However, to enable the insertion of SHM in commercial transport airplanes for current and future applications, including fatigue monitoring & condition based maintenance; data is needed to assist the FAA in developing SHM certification and continued airworthiness requirements. For this multi-year project, the FAA is partnering with Sandia National Labs, Delta Air Lines and Boeing to conduct trial SHM certification & integration activity using embedded Comparative Vacuum Monitoring (CVM) sensors to detect the formation of cracks in a critical load-bearing structure. The goal is to integrate SHM into the regulatory framework and transition the use of the technology from its prototype status into mainstream maintenance.

The application chosen was a remote hot-spot sensing of the center wing box front spar shear fittings, at Body Station (STA) 540, on seven of Delta Air Lines Boeing 737-700s, shown in figure 64a. below. After 21000 flights, it is known that this area of the aircraft is prone to high stress levels, and has known cracking issues as indicated by a Boeing service bulletin requiring inspections. Designed as a passive system, the CVM sensors have an array of embedded galleries to which a vacuum is applied, shown in figure 64b. below. Any leaking path of atmospheric pressure detected produces a measurable change in vacuum level, indicating the

presence of a crack. If no crack is present, a vacuum is achieved. The data is downloaded from the CVM sensors on a 90-day repetitive schedule by Delta Air Lines. The objective is to produce the data package within 12-18 months of monitoring, consisting of five to six readings following installation on the aircraft. In total, 70 installed sensors are installed, as shown in figure 64c. below. This results in the generation of 350 data points, based on five checks. The data from the sensors is monitored and tracked in conjunction with performance tests at Sandia National Laboratories, to identify aircraft structural maintenance items earlier and more efficiently. The goal is to collect flight-test data and work with the FAA and Boeing for possible certification by FY16, and serve as a pathway for the future implementation of SHM on commercial aircraft.

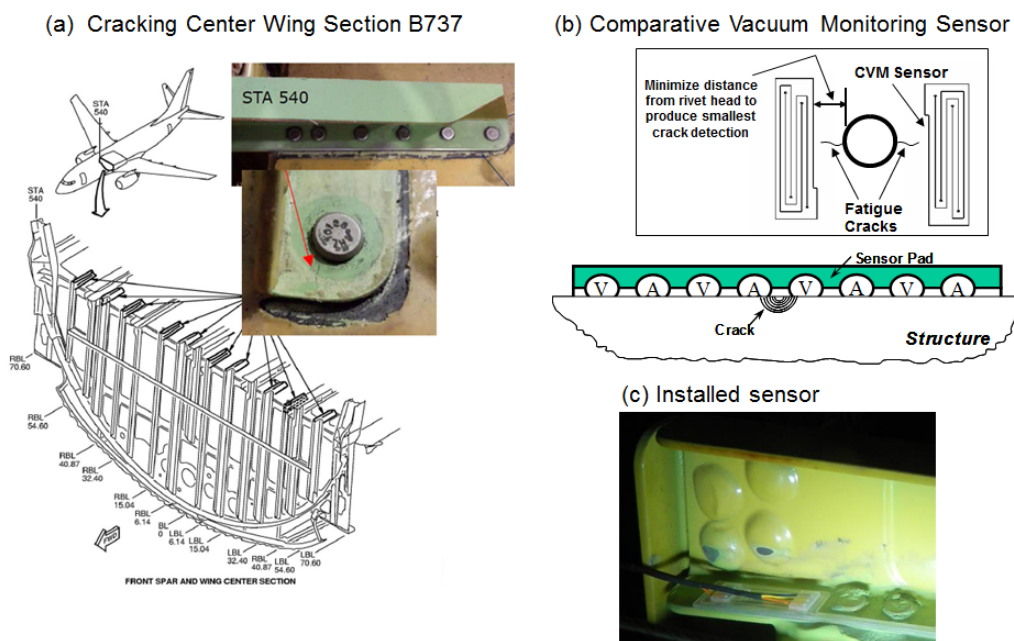


Figure 64: a-c Structural Health Monitoring Certification and Integration Activity

Upgrades to the FAA's FASTER Fixture:

A major modification of the FAA's FASTER fixture was completed, which included replacing the original control and data acquisition unit and converting the load actuators to an air-based system, shown in figure 65 below. The new MTS control and data acquisition unit updates the older obsolete system to current standards used in the aerospace industry for structural testing. In addition, the conversion to air-based system load actuators replaces the original water-based units, which reduce maintenance costs, eliminate testing down time due to valve equipment failures, and improve loading performance of the actuators. This modification was done as a cost-share joint effort under a Cooperative Research and Development Agreement (07-CRDA-0236) with The Boeing Company.

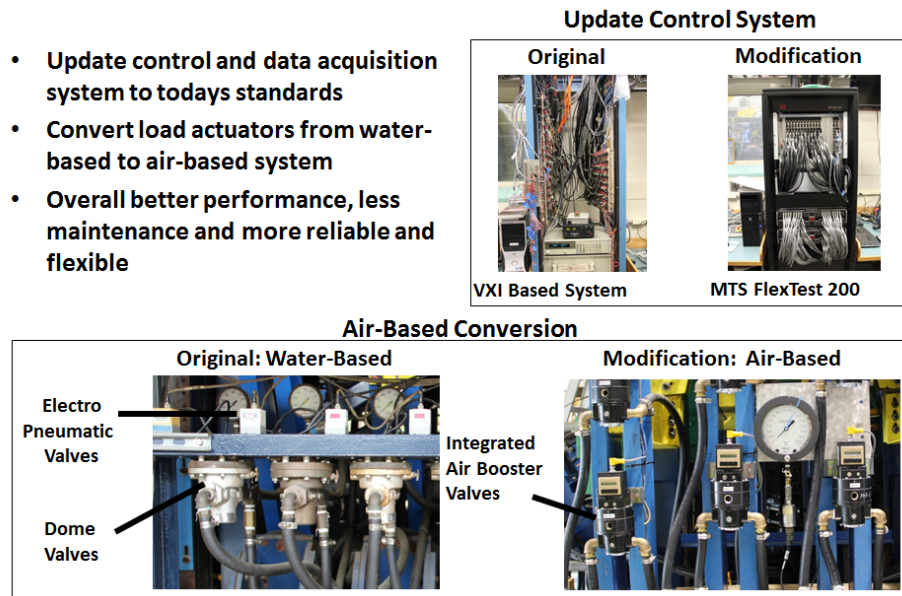


Figure 65: FASTER Fixture Upgrade

Digital System Safety Research Conducted

System Complexity Impacts on Safety:

The growing complexity of aircraft systems and software may make it difficult to assess compliance to air-worthiness standards and regulations. Systems are increasingly digitally reliant (software/electronic hardware) and interconnected, making design, analysis, and evaluation potentially more difficult than in the past. While new capabilities are welcome, they may require increased effort in system validation and verification. Complexity could mean that design errors or faults could lead to unsafe conditions that are undiscovered and/or unresolved. The goal of this research is to investigate the nature of complexity; study the impacts on safety and how it manifests in digitally reliant systems, such as avionics, along with how to measure it, and how to tell when a level of complexity might lead to safety problems and assurance complications. After performing a systematic literature search, it was found that complexity is often blamed for problems. As a result, the literature search was broadened from simply collecting definitions to describing taxonomy of issues and general observations associated with complexity. The review revealed that complexity is a state associated with causes that produce effects. A larger taxonomy of different kinds of causes and taxonomy of different kinds of effects was developed. To prevent the impacts that complexity creates, one must reduce the causes of complexity, which typically include:

- Causes related to system design (the largest group of causes);
- Causes that make a system seem complex (reasons for cognitive complexity);
- Causes related to external stakeholders;
- Causes related to system requirements;
- Causes related to the pace of technological change, and
- Causes related to teams.

After a system is deemed complex due to any combination of causes, it is important to examine the problems or benefits of that complexity. Complexity has direct bearing on safety, apart from performance, usability, and cost. While addressing critical quality attributes (e.g., safety versus performance and usability) in a system, or achieving a desired tradeoff between conflicting quality attributes, often results in additional design complexity. For example, to reduce the probability of a hardware failure causing an unsafe condition, redundant units are frequently designed into a system. The system then not only has two units instead of one, but it also has a switching mechanism between the two units and a way to tell whether each one is working. This functionality is often supported by software and the system is now considerably more complex than when there was just one unit. Further investigation into the impacts of complexity reveals that complexity can impact human planning, design, and troubleshooting activities in the following ways:

- Software planning may be more difficult including software lifecycle definition and selection);
- The design process may be problematic. For example, existing design and analysis techniques may fail to provide adequate safety coverage of high performance, real-time systems as they become more complex. Also, it may be hard to make a safety case just from design and test data, making it necessary to wait for operational data to strengthen the safety case;
- Complexity may make people less able to predict system properties from the properties of the components;
- Complexity may make problem definition, reporting, and diagnosis difficult;
- Complexity may make it harder for people to follow required processes;
- Complexity may increase verification and assurance efforts and reduce confidence in the results of verification and assurance, and
- Complexity may make change implementation more difficult (e.g., in software maintenance and sustainment).

Fire Safety and Research, Research Conducted

Analysis of the Gases Vented from Lithium Batteries and Their Effect on Cargo Compartment Fire Protection:

Lithium-ion and lithium-metal cells are known to undergo a process called thermal runaway during failure conditions. Thermal runaway results in a rapid increase in temperature of the battery cells accompanied by the release of flammable gas. These flammable gases will often times be ignited by the high temperature of the battery and result in a fire. In addition to the combustion of these gases as they vent, the accumulation and potential explosion of the gases is

of concern. Thermal runaway events of lithium-metal and lithium-ion cells have resulted in numerous fires. Some of the notable fire events within the aircraft environment include an aircraft Auxiliary Power Unit (APU) battery, an aircraft main battery and one aircraft ELT battery. In addition to lithium batteries installed on the aircraft, hundreds of millions of them are shipped every year as cargo. The Class C cargo compartment in a passenger airplane is equipped with a fire suppression system, designed to have an initial concentration of five percent Halon 1301 fire suppressing agent, followed by a residual concentration of three percent for the remainder of a flight. These Halon concentrations are effective at mitigating fires involving typical cargo; however, there is a concern regarding whether these concentrations are sufficient to suppress a cargo fire involving lithium batteries and to mitigate the risks of a potential explosion of the accumulated vented battery gases.

Tests were conducted to analyze the various gases vented from lithium cells in thermal runaway and evaluate the risk of the build-up and ignition of these flammable gases within an aircraft cargo compartment environment. Small scale tests were carried out in a 21.7 liter combustion sphere where a gas chromatograph, Non-Dispersive Infrared (NDIR), paramagnetic analyzer, and pressure transducer were used to quantify the individual gases released from lithium batteries. After the gas constituents were quantified, tests were performed to measure the pressure increase from combustion. Later, large scale tests were conducted in a 10.8m³ combustion chamber, a volume comparable to the volume of a loaded cargo compartment, to validate the small scale tests and evaluate the effect of Halon 1301 on preventing an explosion of the battery vent gas mixture. Results of the small scale tests showed the volume of gas emitted from cells increased with battery State-Of-Charge as shown in figure 66, below. Combustion of the gases showed a lower flammability limit of 10% and an upper flammability limit that varied from about 35% to 45%, depending on SOC. The combustion tests also showed a maximum pressure rise at altitude that equated to over 100 pounds per square inch absolute at sea level. Tests conducted at approximately five percent Halon concentration, which is the design extinguishment concentration for aircraft cargo compartments, resulted in little change to the resulting pressure rise. Tests at approximately 10% Halon concentration were required in order to inert the cargo compartment to prevent the battery gases from exploding, as shown in figure 67 below.

In summary, the results of these tests showed that a variation in SOC affected the volume of flammable gases substantially and that a combustion event could compromise the safety of an aircraft. The Halon 1301 fire suppression system showed minimal effectiveness against preventing an explosion of the battery gases at current design concentrations of five percent.

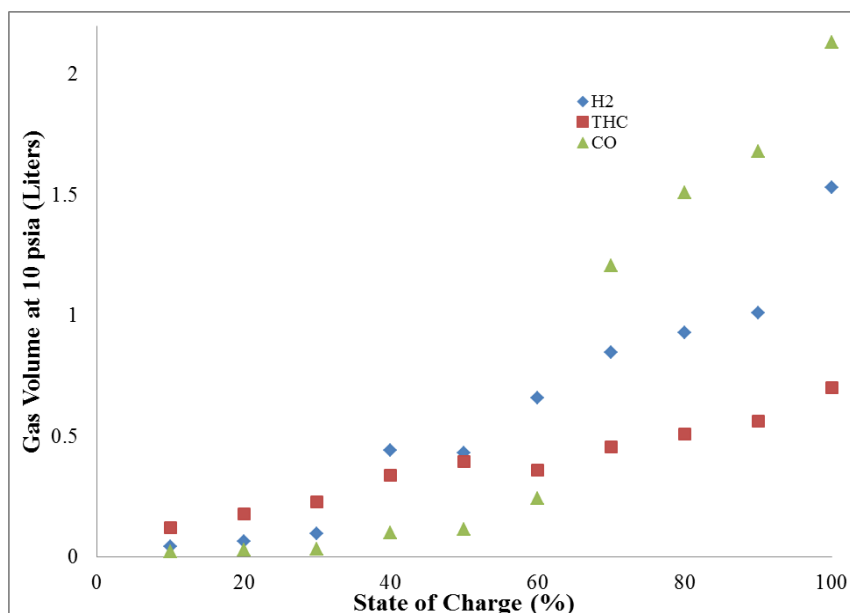


Figure 66: Variation of Flammable Gases with State of Charge

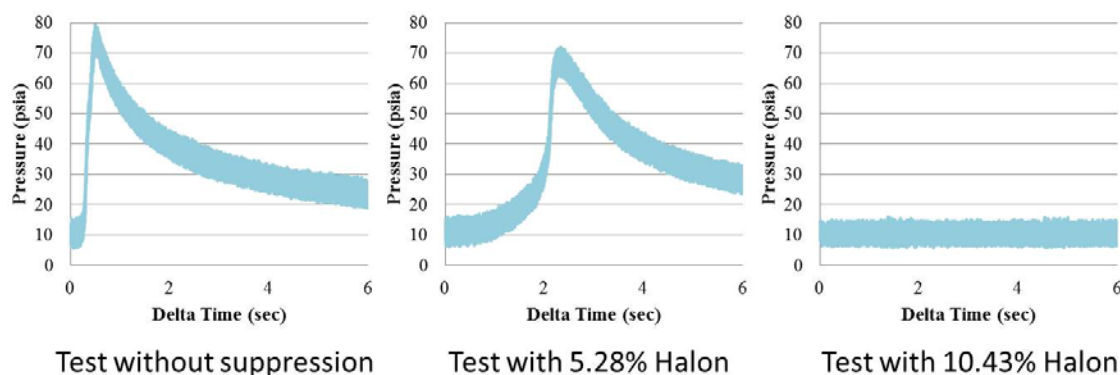


Figure 67: Combustion of Lithium Battery Vent Gases with Various Quantities of Halon 1301

The Development of a Flame Propagation Test Method for Composite Fuselage Structure:

The increasing use of composite materials as primary and secondary structures in commercial airplanes presents unique certification challenges for the FAA. Traditional metallic structures do not react with fires and have not been required to meet any of the FAA's cabin interior fire test requirements. These requirements have increased in severity in recent years to protect against fires in inaccessible areas after the fatal in-flight fire of Swissair 111 in September 1998. A composite airplane introduces large surface areas of composite materials into the inaccessible areas, potentially introducing flammability hazards into an area where fire detection and extinguishment is difficult. By mandating that the composite structural materials must be resistant to propagating flames and self-extinguishing when exposed to a moderately sized fire, the FAA can ensure that a fire in an inaccessible area will be localized and short-lived, allowing for continued safe flight and landing of the airplane.

To date, the FAA has imposed special conditions to certify composite fuselage airplanes for flame propagation resistance. These special conditions are typically met by placing a moderately sized fire adjacent to a representative composite skin and structure test article. After the fire source is completely burned, the test article is inspected for visible evidence of flame propagation along its surface, which is evidenced by regions of delamination and exposed carbon fibers. If the fire remained in a localized area and did not travel extensively along the composite, then the material is considered safe for use in inaccessible areas. Although special conditions are an adequate safety determination means, a more standardized and universally-applicable, evaluation method was developed to use for future composite fuselage certification applications.

Initially, a test rig was developed to perform multiple intermediate-scale composite flame propagation tests in a controlled environment. The rig, displayed in figure 68, below, is a variable-angle composite panel holder, which simulates the effects of a confined inaccessible area near a composite fuselage skin. The fire source—a urethane foam block, provided uniform burning. A variety of aerospace and non-aerospace grade composite materials were tested and assessed for post-test flame propagation length and width. The results from these initial tests were used to correlate a new laboratory-scale test to performance of the same materials in tests similar to the special conditions tests. These tests also confirmed the flame propagation resistance of typical aerospace-grade composites that was observed during testing for special conditions certification of composite airplanes.

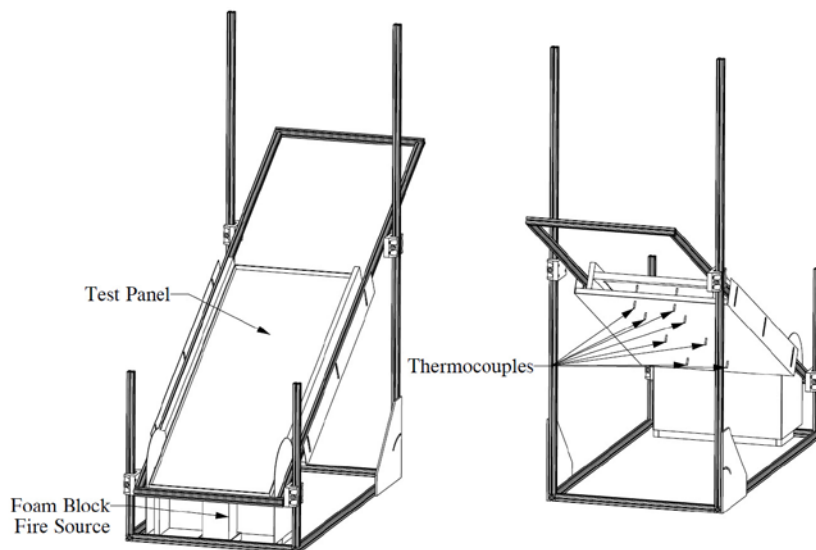


Figure 68: Composite Test Rig

A laboratory-scale test method, known as the Vertical Flame Propagation (VFP) test apparatus, was developed for evaluating the flame propagation potential of composite materials in structural applications for aircraft fuselage skin and structure. The VFP displayed in figure 69 below, consists of a 710-watt radiant coil furnace mounted vertically and opposite the composite test sample. A pilot burner impinges on the lower portion of the test sample for 50 seconds, at which point it is translated away. The burn time beyond pilot flame removal is recorded as well as post-test measurements of burn length and burn width. Three test apparatuses were constructed

and validated with a machine-to-machine comparative test series. Reproducibility was confirmed by testing all machines in different laboratories at the FAA Technical Center, as well as shipping one device each to Boeing and Airbus, repeating the same test series. Feasibility testing has also confirmed that the VFP can be used to assess flame propagation on air ducting and wire insulation; also located in the same inaccessible areas as composite structure and therefore should meet the same flammability requirements.

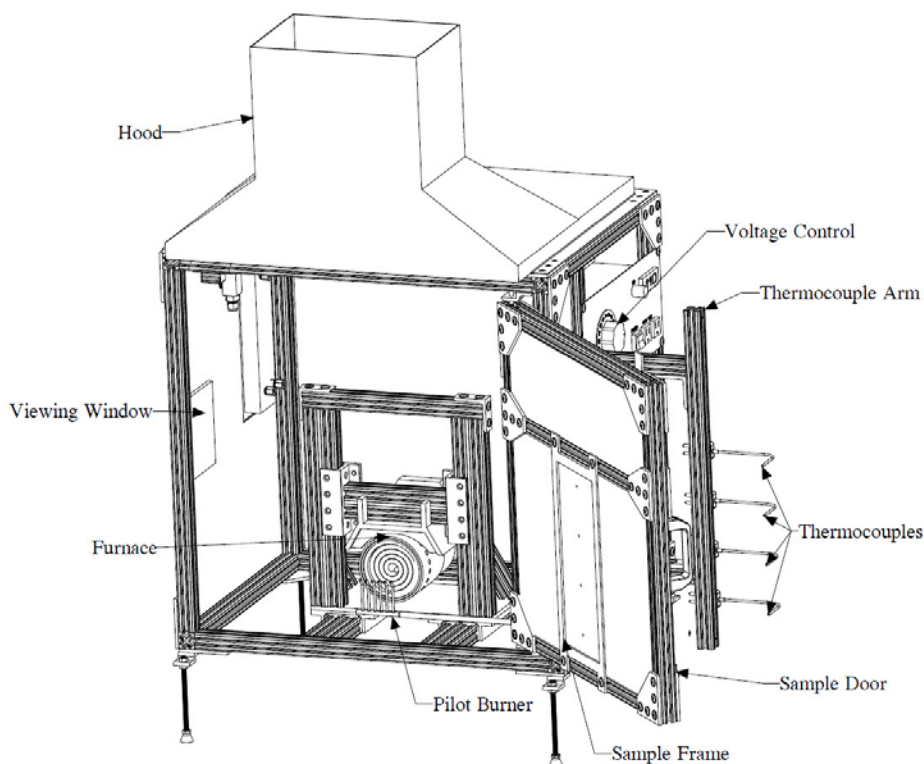


Figure 69: Drawing of a Composite Vertical Flame Propagation

Although the lab-scale test method has been developed and refined for use in certification, the intermediate-scale test rig is still useful to evaluate other factors that may influence the flame propagation of a composite structure while the aircraft is in-flight. A recent study, detailed in FAA report DOT/FAA/TC-TN15/1, evaluated the effect of the composite panel thickness and external ambient conditions on inboard surface flame propagation. A variety of composite samples were evaluated, all produced from the same unidirectional carbon epoxy pre-pregs with toughened 350°F epoxy system, ranging in thickness from 0.044 inch to 0.3675 inch for the solid laminates and a honeycomb panel with four plies of carbon epoxy bonded to a one inch thick aramid honeycomb core. The results from this test series indicate that the relative flammability of a composite material is dependent on the rate of heat dissipation from the flame-impinged surface. This varies depending on several factors, including the panel thickness and the heat dissipation rate at the outboard surface. As displayed in figure 70 below, thin

panels were found to propagate flames under static ambient conditions, and more heavily influenced by the heat transfer at the outboard surface.

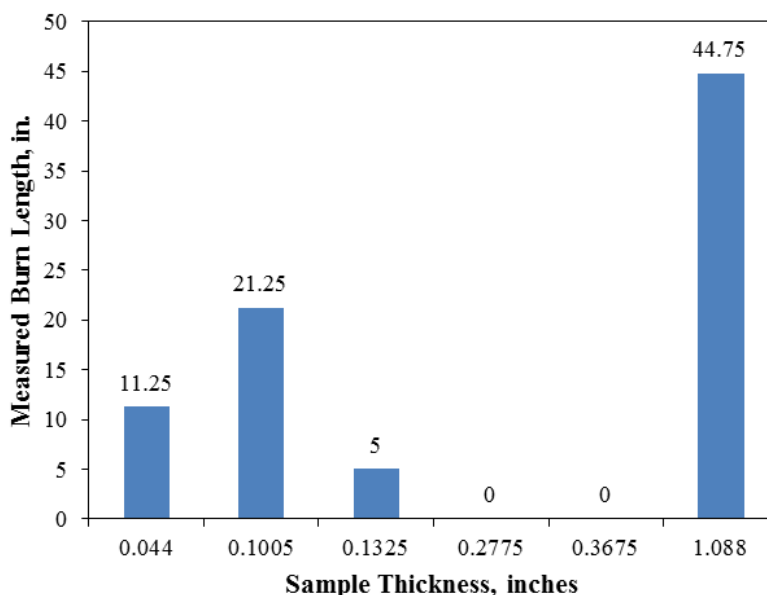


Figure 70: Graph of Composite Sample Thickness

Thicker panels were found to have enough thermal mass between the flame-impinged surface and the outboard surface to not propagate flames under static ambient conditions, and were relatively unaffected by the heat transfer at the outboard surface. The sandwich panel was found to behave like a thin composite panel with an insulated outboard surface, and was entirely unaffected by the heat dissipation rate at the outboard surface.

Controlled Fuel-Oxygen Ratios in the Micro Scale Combustion Calorimeter:

The toxicity of smoke from polymeric materials when they burn is a concern. The most toxic decomposition products are generated when fires are under-ventilated (fuel-rich) and there is not enough oxygen present to completely burn them. The problem is worsened when a fire occurs in a confined space, such as behind the ceiling or walls in an aircraft cabin where the availability of air/oxygen is limited. Inherently fire-resistant materials and materials loaded with flame retardants inhibit the combustion process, potentially creating smoke containing toxic combustion products, including carbon monoxide. These products, in high enough concentrations, can cause incapacitation and death. The FAA Micro Scale Combustion Calorimeter (MCC) has been adapted to provide a way to measure the toxicity of burning plastics. This patented test method was originally developed to accurately measure the heat release rate from a burning material in excess air. The MCC method was modified to control a stoichiometric (an ideal reaction in which the fuel and oxygen in air are completely consumed) amount of oxygen with no knowledge of a samples chemical composition. This is achieved by running a preliminary test where the sample is degraded and its decomposition products completely reacted in an excess of oxygen. This is used to calculate the exact amount of oxygen required to completely burn the products. Subsequent tests use this information and oxygen is

controlled and normalized for sample weight to produce desired fuel to oxygen ratio during a material's decomposition. Carbon monoxide and carbon dioxide analyzers measure how much of each gas is generated during the combustion, providing a simple way to measure smoke toxicity. Fourier-Transform Infrared Spectroscopy (FTIR) is also used to measure these gases as well as identify other hazardous components (see figure 71 below). In addition, the FTIR has been calibrated for several other toxic gases of interest to provide quantitative yields of those products (if present).

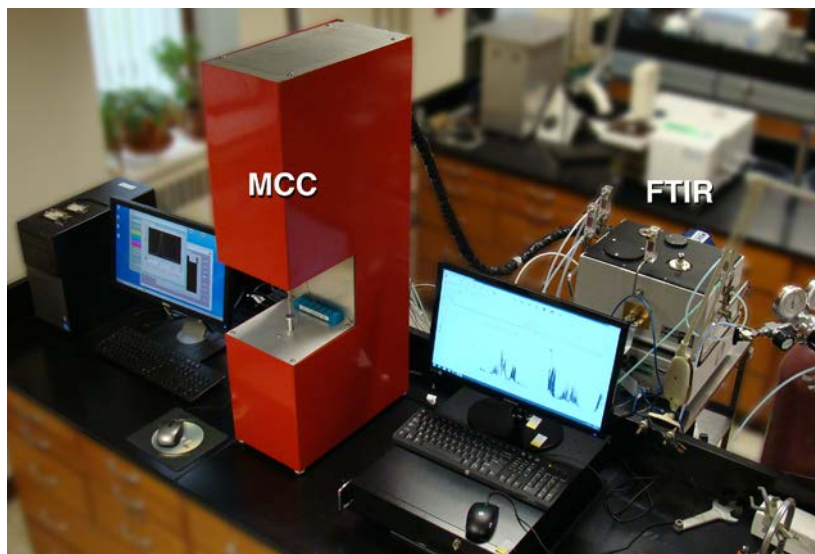


Figure 71: Microscale Combustion Calorimeter

The modified MCC has been used to examine the combustion gases produced by common polymers over a wide range of oxygen concentrations. The ratio of the amount of material (fuel) to the amount of air (oxygen) is called the Fuel to Air ratio (F/A), and the F/A divided by the stoichiometric F/A is called the equivalence ratio. Figure 72 below, shows the strong dependency of the production of CO and CO₂ to the Equivalency Ratio (ER) for seven pure polymers (e.g., PA66, nylon; PE, polyethylene, etc.). As the equivalency ratio increases, the amount of CO and the resultant toxicity also increases. At a fuel rich ER of 2.0 the amount of CO is greater than the amount of CO₂.

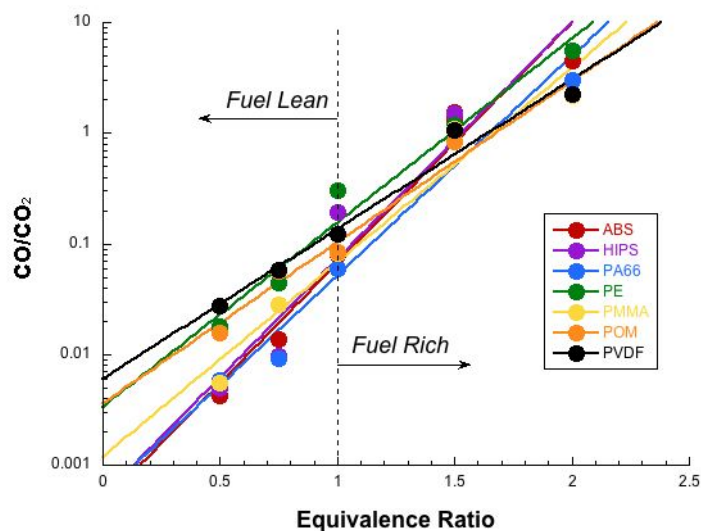


Figure 72: MCC Fuel Air Graph

This research provides a new method of quickly evaluating materials toxic gas production under different ventilation scenarios. Ultimately, this method will help identify safer, non-halogenated flame retarded materials for use in passenger aircraft, cabin interiors.

Effect of Moisture on the Ignition Time of Polymers:

Moisture has been shown to be an important factor on the measurement of the ignitability of combustible solids. In the case of wood, moisture increases the time to ignition. However, a previous study of high temperature engineering plastic Poly (arylether-ether-ketone) showed that moisture decreases the time to ignition of samples, which was a surprising find. Therefore, five additional engineering plastics, Polycarbonate, Polyoximethylene, Polymethylmethacrylate, Polyphenylsulfone and Polyhexamethyleneadipamide were used or under consideration for aircraft interior applications, and were studied to extend the previous work. It was determined that emersion of these polymers in water or by exposure to a relative humidity of 50% also caused the polymers to ignite earlier. Prior to the testing, the polymer samples were conditioned at three different environments; emersion in water, 50% relative humidity and dry atmosphere. Conditioned samples were subjected to a series of experiments with different external heat flux to measure the time to ignition of samples in a cone calorimeter. In some cases, times to ignition varied by a few hundred of seconds between wet and dry samples. Conditioned samples were also examined by micro scale combustion calorimetry to determine the effect of moisture on the thermal and decomposition properties. It was found that the absorbed moisture did not change ignition or decomposition temperatures significantly. However, close examination of the surface of the burnt samples revealed steam bubbles, as shown in figure 73 below that changed the surface density and heating at the surface.

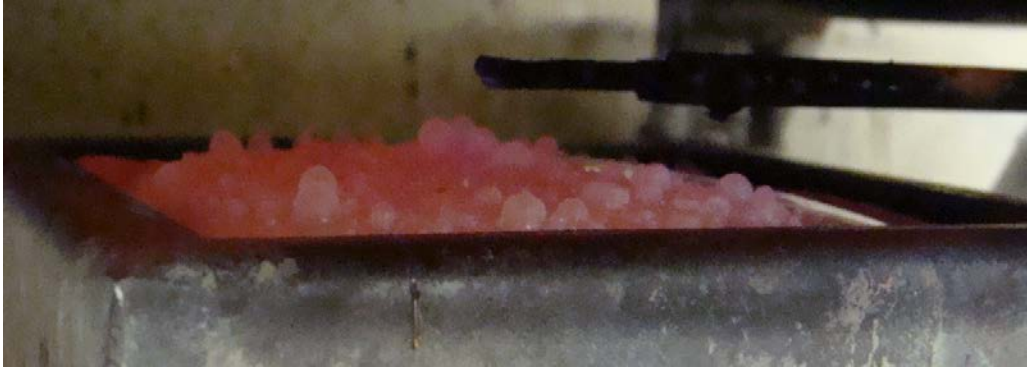


Figure 73: Photograph of Surface of Wet PA66 Sample

The experimental findings were confirmed by the numerical pyrolysis modeling tool ThermaKin, which predicts the thermal decomposition of polymers subjected to a fire condition. The two-phase solid-to-foam model qualitatively captured the premature ignition of moisture-containing samples. Based on the results of the study, it was recommended that samples be exposed to prescribed standard conditioning procedures that include relative humidity to ensure the reproducibility of standardized fire test data.

Evaluate the Effectiveness of a Water Spray System in a Freighter Main Deck Cargo Compartment:

Testing was conducted with an industry partner using ordinary combustible materials and lithium-ion battery fire loads. The system was able to control but not extinguish the ordinary combustible material fires. This was the desired objective because the water quantity required to achieve fire extinguishment would be too heavy to be a practical solution. Initial testing was also conducted on lithium-ion batteries that were directly exposed to the water mist nozzles. The propagation of fire from cell to cell was stopped by the water mist system. While direct exposure of batteries is not a likely scenario for the bulk shipments of batteries as currently transported by aircraft, the testing objective was intended to determine if there was any practical effectiveness of the water mist system to determine if further testing was warranted. The results of this testing will be presented at the International Aircraft Systems Fire Protection Working Group meeting and industry feedback will be evaluated.



Figure 74: Water Mist Nozzle

Evaluating a Novel Halon-Replacement Fire Extinguishing Agent in an Engine Nacelle Fire Simulator:

Testing was completed in an engine Nacelle Fire Simulator (NFS) to evaluate a blended fire extinguishing agent intended to replace Halon 1301 in the fire zones of a large transport aircraft's engine nacelle and APU compartments. The testing was in accordance with the fourth revision of the *Minimum Performance Standards for Halon 1301 Replacement in the Fire Extinguishing Agents/Systems of Civil Aircraft Engine and Auxiliary Power Unit Compartments* (MPSHRe). The NFS is operated by the Fire Safety Branch at the FAA's William J. Hughes Technical Center (FAATC). Personnel supporting this testing activity were from FAA, an aviation industry team, and the European Aviation Safety Agency. The MPSHRe is a two part process, including issues relating to the end-use of a Halon-replacement candidate must be shown acceptable and the Halon-replacement candidate is subject to testing to prove acceptable fire extinguishment capabilities.

The testing component occurs in the full-scale NFS test fixture capable of providing forced ventilation flows, fire threats, and fire extinguishing agent storage and delivery, which is wholly analogous to a fire and its extinguishment in an engine fire zone, although the article is not actually an aircraft engine. The FAATC NFS satisfies the requirements of MPSHRe revision four. Evaluations to effect Halon 1301 replacement occur in the FAATC NFS test section, which has an annular cross section, based on an inside diameter of 0.6 m and a 1.2 m exterior. The fixture is primarily made of 6.4 mm thick mild steel. The fire threats are located 1.8 m downstream from the front, constant cross-sectional plane of the test section. A spray fire threat resides at 12:00 and a pool at 06:00. Fire extinguishing agent is injected near the test section inlet. Figure 75 below shows detail imagery of the FAATC NFS.

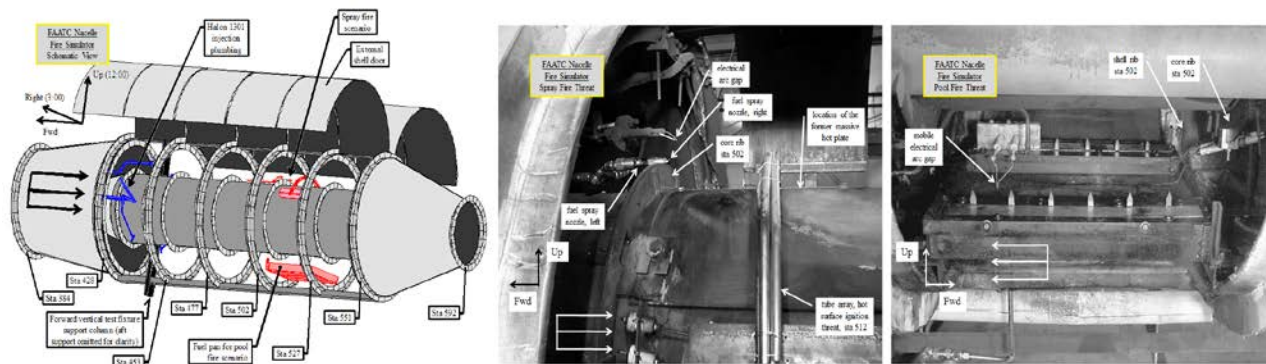


Figure 75: Engine Halon Replacement Test Article-Detail Imagery of the FAATC NFS

Halon 1301 fire extinguishment behavior is determined for a protected volume inside the FAATC NFS. The concentration of agent is measured with a gas analyzer at 12 points within the volume. The Halon 1301 delivered to the protected volume is within concentration-time envelope described by volume concentration and a resident duration of half a second, which is analogous in form to the FAA certification criteria for Halon 1301.

The air-based ventilation flows internal to the FAATC NFS are prescribed. The spray fire threat is based upon an Aviation Turbine Fuel, lubricating oil or hydraulic fluid. It is ignited electrically and persistently interacts with the electrical ignition source while simultaneously heating a collection of stainless steel tubes that pose an auto-ignition (hot surface) threat by the time of agent interaction. Aviation turbine fuel fires the pool fire threat. The pool fire is electrically ignited and interacts persistently with the electrical ignition source. Per the MPSHRe, evaluating a replacement candidate for Halon 1301 parity requires testing in at least four conditions. These conditions result from combining two forced ventilation flows and two fire threats. The fire threat is either pool or spray-based.

A blended fire extinguishing agent, comprised of two gases at fixed ratios, was assessed per MPSHRe revision four. During the completion of this project, more than 100 tests were completed to acceptably progress through the MPSHRe-indicated test process. The tests were accomplished to perform measurements of the replacement candidate's concentration field, as it migrated through the NFS in the internal forced ventilation flow. It also assessed the candidate's ability to extinguish fire, as compared to Halon 1301. See figure 76 below for imagery representative of the progression through a pool fire extinguishment test.



Figure 76: Engine Halon Replacement Pool Fire Detail Imagery of the FAATC NFS

The project outcomes were the recommendation of a concentration value for the candidate blend considered equal to that of Halon 1301, as specified for this application by the FAA. It also affirmed that a gas analyzer used for a single gas agent can be used to measure the distribution of the candidate blend in a forced ventilation flow within a given envelope of test conditions, as well as an extended duration of work contributable to additional experience and knowledge to better understand the candidate. The recommendation of the candidate's concentration for future certification action is in review.

Thermal Hazard of Lithium-Ion:

The fire hazard of lithium cells/batteries carried on airplanes in passenger electronics and shipped as cargo includes the thermal energy generated by individual cell failure and subsequent self-heating (thermal runaway) and the energy released by burning or explosion of the volatile cell components. In this study, the thermal energy released at cell failure was measured for four rechargeable lithium ion (secondary) cells having nominal cell potential $\varepsilon = 3.7$ Volts and measuring 18 mm in diameter by 65 mm in length (18650). This is similar to those shown in figure 77 below. The table lists the cathode material for these carbon anode cells, the advertised (nominal) and measured capacities (Q), the nominal and measured voltages at full charge (ε), and the mass of each cell.

Cathode	Capacity, $Q_{\max}$ (A-s)		ε (V)		Mass (g)
	Nominal	Measured	Nominal	Measured	
$\text{LiMn}_2\text{O}_4\text{-LiNiCoO}_2$	11,700	11,200	3.6	4.1	42
LiCoO_2	9,400	8,300	3.7	4.1	48
LiNiCoAlO_2	5,400	5,000	3.7	4.1	42
Unknown	18,000	3,600	3.7	4.0	40

Figure 77: Lithium Ion 18650 Cells

These 18650 lithium ion batteries were charged to various capacities Q to obtain a range of stored electrochemical (free) energy from $\varepsilon Q = 0$ to $\varepsilon Q_{\max}$. The thermal energy ΔH_{total} released during thermal runaway was measured in a bomb calorimeter under an inert atmosphere (nitrogen) to prevent burning of the cell contents. A thermodynamic analysis of battery failure

showed the total heat released by the cell during thermal runaway in the bomb calorimeter ΔH_{total} is the sum of the chemical energy of mixing, reaction and decomposition of the electrodes and electrolytes ΔH_{rxn} , and the stored electrochemical (free) energy, εQ ,

$$\Delta H_{\text{total}} = \Delta H_{\text{rxn}} + \varepsilon Q$$

Figure 78: Total Heat (ΔH_{total}) and Heat from Chemical Reactions (ΔH_{rxn}) Released by 18650 Lithium Ion Cells of Different Chemistry and Rated Capacity Versus Stored Electrochemical (Free) Energy (εQ)

Figure 78 above, shows the total energy released during cell failure ΔH_{total} measured in the bomb calorimeter versus the electrochemical (free) energy of the tested cell, εQ . The heat of mixing, reaction and thermal decomposition of the cell components, ΔH_{rxn} , obtained by difference, is also plotted in figure 80 below. What is clear from figure 80 below is that all of the energy released at low electrochemical energy (state of charge) is due to the chemical reactions of the cell components, which depends strongly on the cell chemistry (see figure 77 above). At higher states of charge about one-third of the total energy comes from chemical reactions and two-thirds comes from stored electrochemical energy.



Figure 79: Lithium Batteries Heat Release

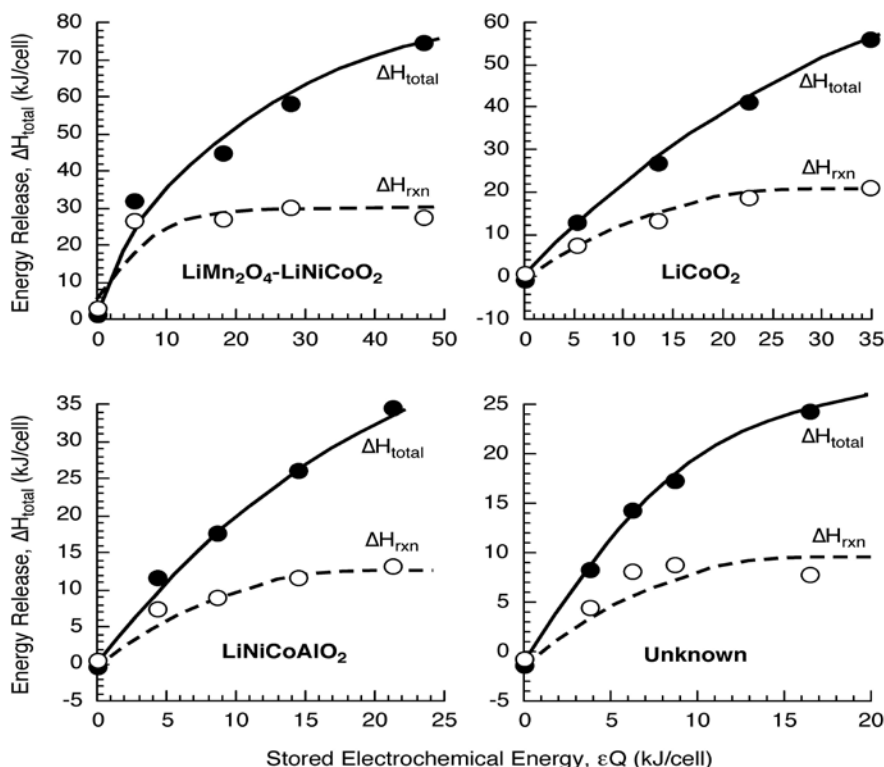


Figure 80: Lithium Batteries Heat Release Graphs

This work clearly demonstrates the safety benefits from shipping batteries at reduced SOC. At low SOC the risk of a fire (ignition) and propagation of thermal runaway to the remaining batteries in a bulk shipment package is reduced, and at a SOC below some threshold value the risk of ignition and propagation will be eliminated. However, from the difference in measurement of nominal and actual battery capacity shown above, the metric for determining the safe SOC of a battery should be based on a clear definition of SOC or the actual measured capacity.

Flightdeck/Maintenance/System Integration Human Factors Research Conducted

Report Best Practices for Maintenance and Ramp Line Operations Safety Assessment (LOSA):

Data-driven modifications to risk management are needed for maintenance operations to assist the FAA in the development of adequate tools/systems that increase safety by aiding the identification of hazards and managing the associated risks. Proactive and predictive approaches, as opposed to reactive changes based on post-accident/event investigation, align with the principles of risk management and fundamental concepts of SMSs. An LOSA is a formal but voluntary process that uses trained observers to monitor normal operations and to record their observations. This process is directly aligned with the principles of SMS. Preliminary Maintenance LOSA data from an earlier study showed the value of proactively managing risk.



Figure 81: Line Operations Safety Assessment Characteristics

Given the voluntary nature of LOSA, there is no common database, which shares information from participating carriers or companies. Therefore, a survey was distributed to evaluate the utility of Maintenance LOSA and Ramp LOSA programs across the industry and to identify lessons learned and best practices for implementing a program. We examined Maintenance LOSA and Ramp LOSA programs that either have been implemented, or are in the process of being implemented at airlines, Maintenance Repair Organization (MRO) service companies, and other aviation service organizations. Respondents included aviation professionals from commercial and cargo airlines; helicopter service providers and MROs who were involved with planning, implementing, or participating in a Maintenance or Ramp LOSA program. Twelve respondents had current or previous involvement with a Maintenance LOSA or a Ramp LOSA program, or both. The majority of respondents reported the status of their most recent program as currently active; however, some reported that their most recent Maintenance LOSA program had gone dormant prior to completing all five phases of LOSA implementation:

1. Preparation;
2. Development;
3. Training;
4. Implementation, and
5. Reporting and feedback.

The progress rate of phase completion for the most recent LOSA programs overall was higher for Ramp than Maintenance respondents. All Ramp respondents reported completion of all phases of the LOSA program. In contrast, Maintenance respondents reported varied states of completion for the phases, with only one respondent reporting all phases as complete. Most other Maintenance respondents indicated completion of the preparation, development, and training phases, and fewer still had finalized the Implementation phase. The majority of Ramp LOSA respondents reported that the focus of data collection was the entire operation, while responses were split equally among Maintenance LOSA respondents who reported entire operation, identified/known problems, specific aircraft types, and specific facility as the focus.

Ramp LOSA respondents represented organizations with more active observers conducting between 200 and 11000 observations during the implementation period, while Maintenance LOSA organizations had fewer observers by comparison and had conducted between five and 30 observations during the implementation period. Therefore, conclusions from the survey are limited by these factors. Nonetheless, the feedback from the respondents is of value as they are users of the LOSA program and described their experiences.

When asked about senior management's support for LOSA within their organization, the majority of respondents felt that management was very or completely supportive initially, and that their support either did not change or increased over time. Union groups, workers, and employee groups were perceived as less supportive initially, with increased support over time. When challenges in gaining support did occur, respondents indicated that there was concern about the program's impact on operations, return on investment, and protection of information and employees.

At least half of the respondents indicated that their organization used the FAA's database software tool for generating LOSA reports. Challenges with the FAA LOSA software interfacing with existing company IT platforms were reported. For those that did not use the database tool for generating reports, respondents reported development of an in-house program for communicating and generating reports. The results are limited by the small sample; nonetheless, the feedback and information are vital as companies explore using proactive, voluntary programs as part of their safety management systems. As noted previously, there is not a common database used by participating carriers or companies to share information. Thus, the most optimal method for identifying challenges, best practices, and lessons learned is to solicit feedback from users. The challenges noted can be shared with the airline maintenance community to assist as other companies consider implementing a LOSA program. A complete item report of results and summary article were provided to the FAA sponsor.

NextGen – Air Ground Integration Human Factors Research Conducted

Complete Human Factors Research and Identify Information Requirements for FlightDeck-based Interval Management in the Terminal Area and Closely Spaced Parallel Approaches:

Implementing the NextGen Air Transportation System includes the application of Automatic Dependent Surveillance-Broadcast (ADS-B) technologies and procedures to improve air traffic safety and efficiency. The current project involved the analysis of flight deck technologies and procedures using ADS-B for Interval Management (IM) operations and Closely-Spaced Parallel Approach (CSPA) operations in the existing airspace and in NextGen airspace. The use of IM procedures may permit increased capacity in the terminal area, particularly surrounding busy airports. With the use of ADS-B, IM may allow flight crews and ATC to effectively achieve and maintain spacing between aircraft in en route and terminal airspace. This technique will require new ATC and flight deck procedures and tools to allow for safe and efficient flight following. Controllers determine and assign intervals between aircraft whose flight crews then are required to keep these intervals using IM procedures. The flight crews need to get the right information to conduct IM operations. This information should be in a location on the flight deck that permits

easy identification and validation. Currently, tools and procedures are being developed for both Ground Interval Management (GIM) and Flight Deck Interval Management (FIM).

CSPA applications are also considered part of future airspace operations. CSPA can increase the efficiency of airports in IMC by allowing independent, parallel approaches to runways with a lateral separation of at least 2500 ft. The use of IM and CSPA offers the potential for increased capacity in the terminal area; however, each will require new display features, alerting technologies, and flight deck procedures. The project addressed findings from a focus group interview with six commercial pilots who had simulation experience with the use of a candidate IM technology. In the interviews, the research team addressed information requirements for the various tasks and procedures associated with IM and CSPA, including alerting/notification, target acquisition, maintaining position, aircraft performance awareness and modification, and responses to off-nominal events.

**Navigation Display (ND)
with Closely Spaced Parallel Approach Indications**

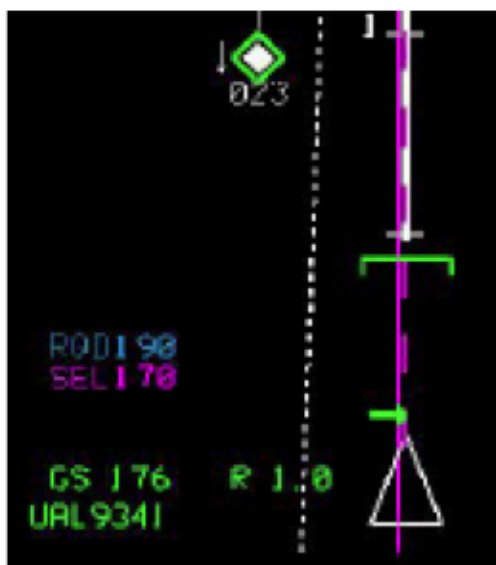


Figure 82: Navigation Display with Closely Spaced Parallel Approach Indications

NextGen – Weather Technology in the Cockpit Research Conducted

Develop NextGen Part 121, 135, and Part 91 Concepts of Operation and User Requirements for the Provision, Integration, and Use of Weather Information in the Cockpit:

The Weather Technology in the Cockpit (WTIC) Program developed a ConOps to describe the operational concept for the application of data link weather in U.S. NAS in the NextGen mid-term time frame with emphasis on the pilot flight and flight deck perspectives for Part 121/135 (commercial) aircraft and Part 91 (General Aviation) aircraft. The ConOps provides a detailed examination of the current methods of operations and the potential problems and opportunities

presented by enhanced weather information in the cockpit. It also summarizes the NextGen enhancements expected to be enabled by the availability of data link weather in NAS operations. In order to illustrate specific operational applications of data link weather to cockpits, the ConOps presents scenarios in NAS operations.

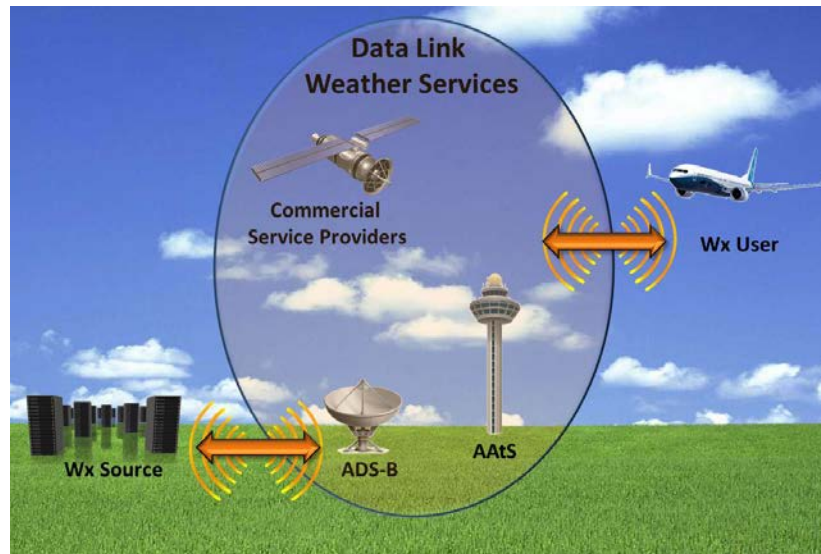


Figure 83: Data Link Weather Service Context

Using the Part 121/135 WTIC ConOps and the Part 91 ConOps as the primary input for a detailed functional analysis, the WTIC program developed a Functional Architecture Document (FAD) to detail the set of functions, requirements, and architecture that describes the necessary data-link weather capabilities necessary to achieve planned NextGen benefits in various adverse weather conditions. In addition to detailing the results of the functional analysis, the WTIC FAD contains sections on requirements and a physical architecture. Since the functional analysis is solution agnostic, the FAD describes a physical implementation of the functional model.

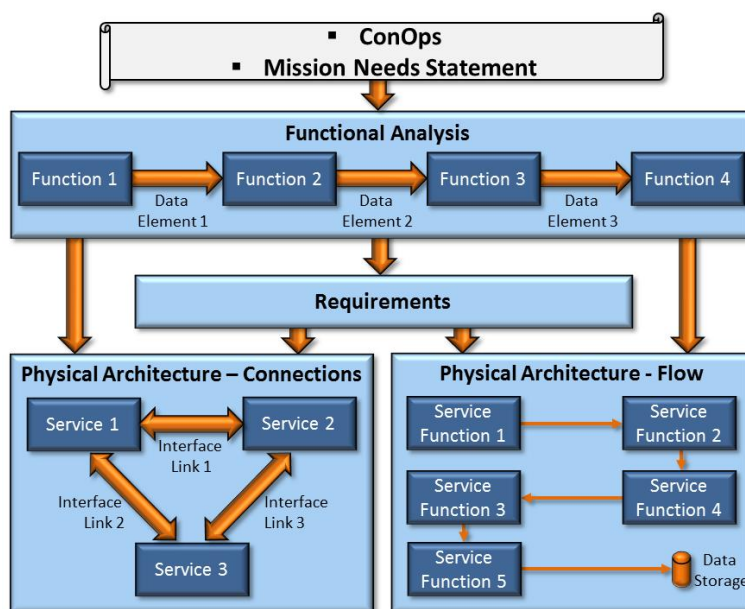


Figure 84: Functional Analysis and Architecture Relationship

The WTIC FAD will primarily be used by the WTIC program office to assist in the identification of minimum required data link weather services, identification of internal and external interfaces for data link weather, assistance with assessing gaps in existing functions and data, and the derivation of service level requirements that can be allocated to enabling systems.

Quantify the Impacts to the NAS of Uplinking Graphical Turbulence Guidance and Eddy Dissipation Rate to the Cockpit:

The WTIC program conducted a demonstration to assess the feasibility, benefits, and human factors considerations of using a low cost device to display Eddy Dissipation Rate (EDR), an objective measure of turbulence, and Graphical Turbulence Guidance (GTG), which provides a forecast of turbulence in cockpits. The motivation for this demonstration was to resolve the Meteorological (MET) information gap of the lack of spatially and temporally relevant turbulence information, for use in flight operations to mitigate the associated operational shortfalls of inefficient requests for altitude changes and reduced capacity due to unnecessary airspace avoidance relative to turbulence. In addition, the potential of improving crew management and associated safety benefits was also evaluated.

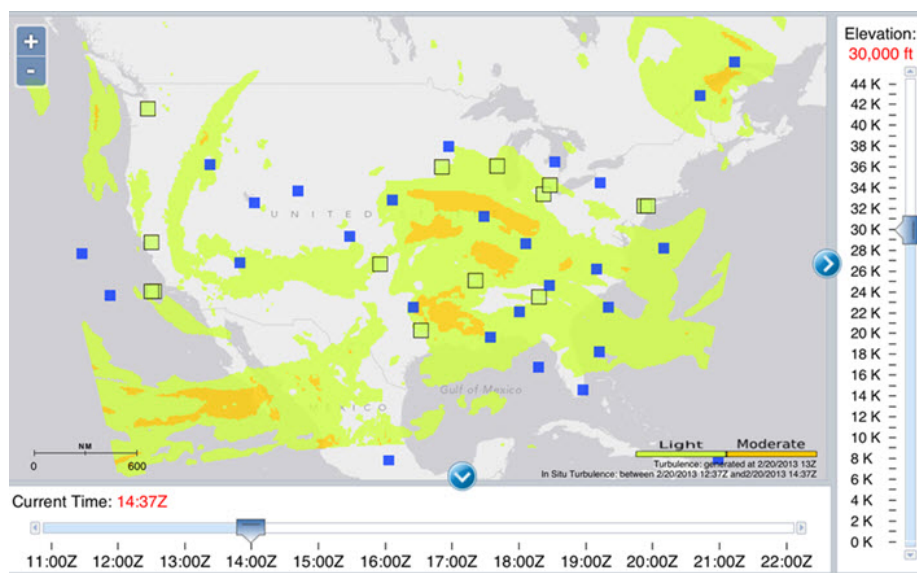


Figure 85: Display of Eddy Dissipation Rate and Graphical Turbulence Guidance on Cockpit Based Viewer

The demonstration results showed a positive change in pilot behavior of aircraft equipped with the EDR/GTG viewer. Benefits included reduction in altitude changes and less radio calls to ATC. Objective data indicates 400 plus, less flights changing altitudes NAS wide on low turbulence days with 100% of representative aircraft equipped with viewer. Using simulations, projected NAS benefits based on demonstrated aircraft benefits, assuming a 50% sector usage, were calculated to be \$1.1 million daily cost savings and \$414 million annual savings resulting from savings in fuel, increased capacity and efficiency, reduced workloads, and passenger time value. In addition, passenger comfort was ranked highest in terms of turbulence decisions and subjective feedback indicated that crew management decisions and communication were enhanced. Subjective evaluations of the EDR/GTG viewer were positive.

Propulsion and Fuel Systems Research Conducted

Recent Developments in Turbine Engine Component Risk Assessment Software:

High-energy rotating components in aircraft gas turbine engines may contain inherent or induced anomalies that can lead to rare but potentially catastrophic failures. The FAA ACs address specific types of inherent and induced anomalies (AC 33.14-1 and AC 33.70-2, respectively) and establish a general framework for all life-limited engine parts (AC 33.70-1). The associated risk of fracture can be predicted using DARWIN®, an award-winning probabilistic fracture mechanics software code developed by Southwest Research Institute® under FAA funding. Previous versions of DARWIN® provided auto-zoning capabilities for risk assessment, involving inherent anomalies in components modeled using 2D and 3D FE geometries. These techniques automatically build DARWIN® zones based on user-defined property regions that consider anomaly size and occurrence rate, material properties, and other parameters.

Auto-zoning leads to consistent results among users and reduces the human time required for zone definition. However, the computation time associated with auto-zoning may be significant for component models with large numbers of FEs. DARWIN® 9.0 provides a new optimal Gaussian Process pre-zoning capability for the efficient automatic creation of zones in large complex 2D and 3D FE geometries with inherent anomalies (see figure 86 below). It defines pre-zones as groups of FEs arranged based on similar stress ranges, temperatures, and distance-to-surface values. It then identifies the risk limiting location within each pre-zone via an approximate risk surface based on risk values at training points within the pre-zone. The previously developed optimal auto-zoning methodology is then used to determine the optimal zone break-up of the model. For large models where the number of pre-zones is significantly smaller than the number of FEs, the optimal pre-zoning capability can significantly reduce the computation time associated with risk assessment. Initial studies indicate that the new pre-zoning algorithm is up to two to three orders of magnitude faster than the previous optimal auto-zoning algorithm and up to four to five orders of magnitude faster than the previous exhaustive algorithm. Furthermore, the pre-zoning method requires less memory than either the exhaustive or the optimal methods. This feature enables the pre-zoning method to solve much larger models than either previous method.

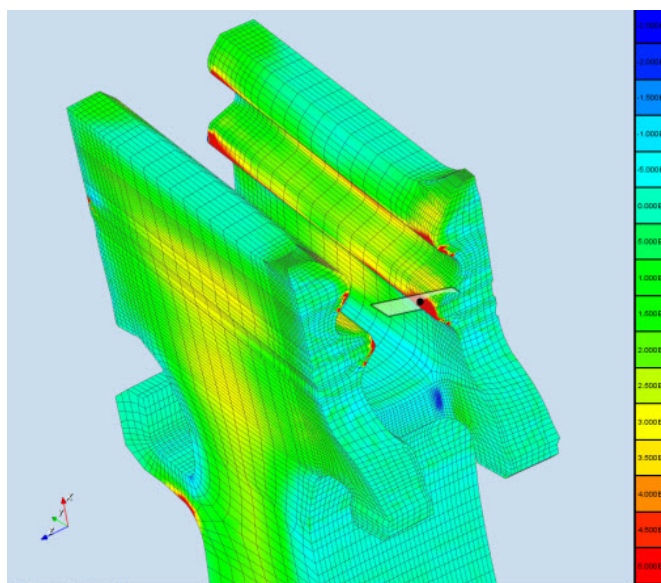


Figure 86: DARWIN ® 9.0

Rotating engine components often have 3D geometric features that repeat cyclically around an axis. For example, a rotor might have eight sectors where the geometry remains identical between any two rays separated by 45° that originate from the axis of rotation. Previously, DARWIN® only supported full 3D models or 2D axisymmetric models where the cross section was constant about the axis of rotation. DARWIN® 9.0 provides a new capability for risk assessment of components that are defined via 3D sector FE model geometries. When the sector model option is selected, DARWIN® displays the original sector model and the exterior component boundaries based on cyclically repeating sectors. For life and risk assessments, fracture models are based on the full FE model geometry. This new capability is available for both manually and automatically zoned models.

DARWIN® 9.0 includes a new Stress Intensity Factor (SIF) solution (CC18) for part-elliptical cracks that originate at corners with a 135° angle, such as one corner of a chamfered edge. Cracks modeled using the CC18 SIF solution are capable of transitioning to the CC12 SIF solution, which is the bi-variant SIF model for a crack that spans the entire length of a chamfered corner. DARWIN® 9.0 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® 9.0 will be released for production use in industry.

System Safety Management Research Conducted

Angle of Attack in General Aviation Operations Research:

Unlike in the commercial aviation sector, the rate of fatal accidents in GA has remained steady for the last decade. The FAA and aviation industry have proposed a data-driven approach to identifying high priority safety initiatives for GA and worked jointly to mitigate accident causal factors. Some of the recommended safety enhancements reference the use of Angle of Attack (AOA) systems in GA aircraft.

The System Safety Section (ANG-E272) conducted research to determine if the use of an AOA display in the GA cockpit can provide a pilot with the appropriate information to increase the stability of an approach. Through a cooperative agreement with the FAA PEGASAS, ANG-E272 worked with Purdue University, The Ohio State University, and Florida Institute of Technology to conduct the research.



Figure 87: Angle of Attack Cockpit Display

Six AOA systems were procured, installed, and calibrated in six GA aircraft (two from each university) to form a fleet to determine the effectiveness of AOA system in GA operations. Pilots with 50 to 200 total flight hours were recruited from flight schools, each having experience

within a highly structured curriculum and a consistent degree of proficiency. Once selected, participants were placed randomly in one of four groups as outlined below:

- Group 1 received training and had access to the AOA display;
- Group 2 received training but did not have access to the AOA display;
- Group 3 did not receive training but had access to the AOA display, and
- Group 4 did not receive training and did not have access to the AOA display.

During the experiment, the participants were trained and instructed to fly certain maneuvers as designed by the experiment.

Based on final analysis of collected data, it was determined that AOA systems were helpful in certain complex situations. For example, use of AOA systems contributed to approach stability during operations at airports lacking a visual guidance system. AOA information also supported more stable approaches in situations where the pilot had a lower level of familiarity with the aircraft in use. In addition, an AOA training video developed during the research to train the test pilots was determined to be highly effective in providing information on the AOA concepts and benefits, as well as demonstrating the different AOA device installations. The FAA GA and Commercial Division and the FAA Office of Accident Investigation and Prevention requested further development of the training video for use in outreach activities promoting safety to the GA community. The revised AOA training video was completed and delivered in April 2015.

Integrated Domain Assessment (IDA):

An Integrated Domain Assessment IDA proof of concept prototype supports the FAA Air Traffic Safety Oversight Service (AOV) decision-making process in the approval of controls for high-risk hazards in the NAS. IDA provides integrated assessment of safety risk associated with multiple changes in the NAS. While the existing SRM approach focuses on the individual system, IDA conducts holistic safety evaluation of NAS system changes by considering the interactions and/or interdependencies among the systems and safety elements in the dynamic environment of NAS evolution towards the NextGen. As the NextGen matures, the NAS is becoming a more complicated and integrated system of systems. Any change to a system may lead to unrecognized and unmanaged safety risk to other systems in the NAS. IDA identifies those potential inter-related safety hazards prior to the implementation of the change to improve the SRM process. The IDA prototype built on a system model that integrates the NAS architecture and system safety data, has four major functions:

- System impact analysis;
- Safety Risk Management Document (SRMD) Evaluation;
- Control effectiveness evaluation, and
- SRMD and NAS data tracking.

The results from the IDA tool will support AOV's oversight of the Air Traffic Organization (ATO) through its Approval, Acceptance, and Concurrence process, Safety Management Action Review Team activities, audit, and compliance processes.

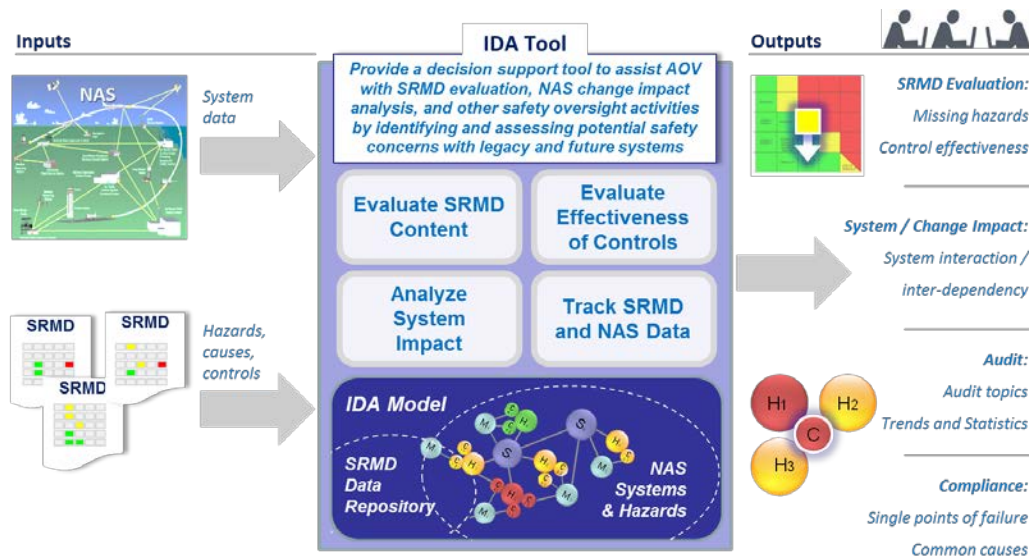


Figure 88: Concept overview of Integrated Domain Assessment

IDA uses a set of safety indicators including:

- System impact;
- Control effectiveness;
- System safety influence;
- System instability;
- System unavailability, and
- System anomaly rate to characterize the NAS safety status.

A rule-based methodology was developed to evaluate the effectiveness of controls for reducing the safety risks proposed in the SRMDs. IDA provides a quantified measure of the NAS impact of a potential system change, based on its structural interactions with other systems, safety dependencies, and exposure to the air traffic.

The current version of the IDA prototype focuses on eight NAS systems:

- Standard Terminal Automation Replacement System (STARS);
- Common Automated Radar Terminal System (CARTS);
- En Route Automation Modernization (ERAM);
- Advanced Technologies & Oceanic Procedures (ATOP);
- Airport Surface Detection Equipment – Model X (ASDE-X);
- Enhanced Terminal Voice Switch (ETVS);
- Airport Surveillance Radar Model 11 (ASR-11), and
- Runway Status Lights (RWSL).

National General Aviation Flight Database Research:

An SMS is a standardized approach to managing safety that establishes a formalized, risk based approach. One component of SMS is safety assurance, which may include activities such as operational reporting and aviation Flight Data Monitoring (FDM). While FDM programs are well established by commercial aviation carriers, and flight data has been collected and used to improve safety, the adoption of FDM programs in the GA sector has remained limited. Barriers include financial challenges associated with Flight Data Recorders (FDR), a lack of available tools to collect, archive, and disseminate data; as well as the lack of required expertise to analyze the flight data. With advances in technology, avionics manufacturers have recently developed and commercialized low-cost FDRs. Some GA aircraft are sold with factory-installed integrated flight instrument systems such as the Garmin 1000, which is capable of recording up to 64 flight parameters (airspeed, altitude, angle-of-bank, etc.). However, the lack of accessible systems to process and analyze FDR data makes many GA pilots and operators reluctant to adopt FDM.

The FAA System Safety Section worked with the University of North Dakota, under an FAA COE for GA Research cooperative agreement, to design and develop the National General Aviation Flight Data Information (NGAFID). It is a prototype information system capable of accepting, archiving, analyzing, and disseminating de-identified flight data and aggregate analysis to NGAFID participants and aviation safety analysts. NGAFID research supports the FAA.

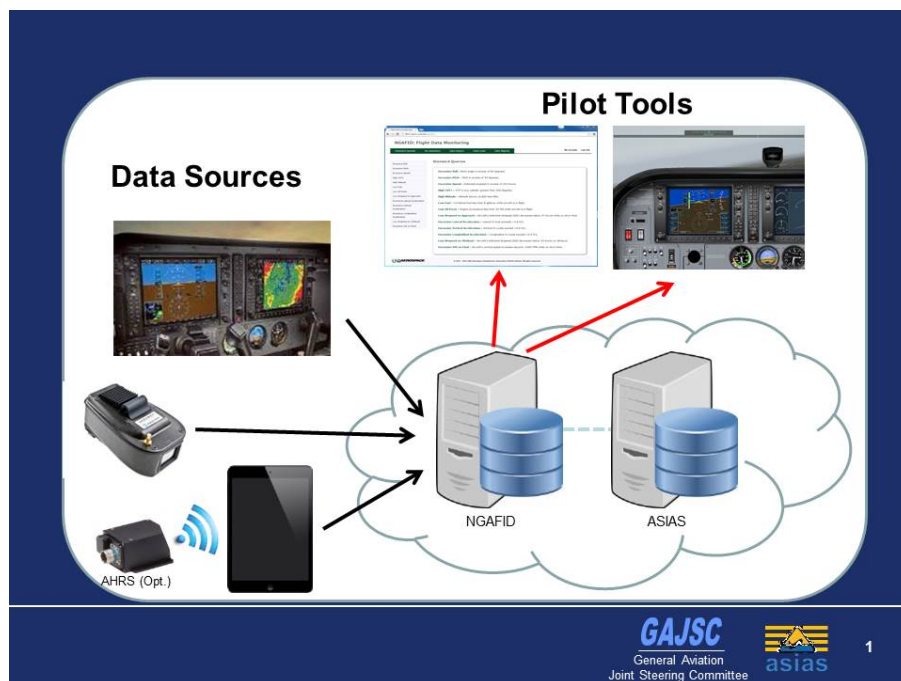


Figure 89: National General Aviation Flight Data Information

NGAFID was designed as a central database and data repository with the ability to accept more than 220 different flight parameters as recorded by a flight data recording device. Issues such as user interface, data security and access authentication, and the ability to accept a variety of disparate data formats were considered and addressed during development of NGAFID. It also

has a number of useful data analytical tools, including exceedance tools developed to detect and perform trend analysis on situations such as excessive roll/pitch/speed, low fuel, low oil pressure, and others. In addition, the research team collected more than 200000 flight hours from the fleet of Cessna 172 aircraft at University of North Dakota and Embry-Riddle Aeronautical University, and imported this data into the NGAFID.

Unmanned Aircraft System Research Conducted

Sense and Avoid (SAA) Certification Obstacles Research:

The SAA Certification Obstacles research takes an engineering view of a complete SAA system, and analyzes all aspects for obstacles to integrating Unmanned Aircraft Systems (UAS) into the NAS. The SAA Certification Obstacles task supports the work previously completed by the FAA SAA Workshop. The guiding question the committee focused on was what are the approval obstacles (issues) in having SAA systems and equipment provide a means of compliance to 14 CFR 91, by replacing pilot functions currently certificated through knowledge testing, practical test standards, and airman certification, and how such obstacles can be addressed. This research also addressed the UAS inability to visually comply with regulations and with ATC clearances and instructions and the resulting impacts to the NAS in the TRACON environment.

There are four phases to this research activity. The first two phases focus on development of a representative model for SAA that captures key operational, functional and physical characteristics associated to the proposed system. The next phase of research then uses the model to create a comprehensive list of certification obstacles that identify challenges to the airworthiness and operational approval of such a system. The fourth and final phase of the task then identifies examples of existing research, technologies and concepts to be used as evidence to address any of the previously identified obstacles. The research identified a comprehensive list that includes 24 operational and airworthiness obstacles with mitigations toward integrating UAS into the NAS. Research continues to refine the obstacles and investigate potential mitigations looking into what other new and novel systems have done to achieve certification.

Unmanned Aircraft Systems (UAS) Center of Excellence for (COE):

The FAA selected a Mississippi State University team as the FAA's COE for UAS. The COE will focus on research, education and training in areas critical to safe and successful integration of UAS into the nation's airspace. The team brings together 21 of the Nation's leading UAS and aviation universities that have a proven commitment to UAS research and development and the necessary resources to provide the matching contribution to the government's investment. The COE research areas are expected to evolve over time, but will initially include:

- Detect and Avoid (DAA) technology;
- Low-altitude operations safety;
- Control and communications;
- Spectrum management;
- Human factors;

- Compatibility with ATC operations, and
- Training and certification of UAS pilots and other crew members.



Figure 90: Alliance for System Safety of UAS through Research Excellence

The FAA's Alliance for System Safety of UAS through Research Excellence began conducting initial high priority FAA research studies in September, 2015 in order to evaluate the sufficiency of existing airborne surveillance equipment for manned aircraft (e.g. transponders and/or ADS-B). As well as providing separation and collision avoidance functions for UAS supporting the establishment of maintenance data requirements for UAS, in order to include the collection and analysis of maintenance and repair data from multiple UAS platforms. It also supports the development of a Beyond Visual Line of Sight operational framework, minimum performance standards for DAA systems, and the proposed operating rules, limitations, and guidelines for small UAS. It informs airworthiness requirements for UAS by using analytical computer modeling to examine hazard severity thresholds for UAS collisions, with property and people on the ground as well as UAS collisions with other aircraft in the NAS.

In addition, it supports the development of UAS industry consensus standards for UAS airworthiness, maintenance, and flight proficiency requirements; along with examining human factors considerations for UAS control station design, pilot training/certification requirements, and visual observer requirements to inform the development of standards. Also supported is the collection of noise measurements of UAS using current noise standards, to begin the initial assessment of whether noise certification procedures designed for manned aircraft are appropriate for unmanned aircraft.

The COE is comprised of a core team of 15 of the Nation's leading UAS and aviation universities as well as an affiliate team of six domestic and international universities that have a proven commitment to UAS research and development, and the necessary resources to provide the matching contribution to the government's investment making tax-payer funds a wise investment. In addition to Mississippi State University, the other core team members include:

- Drexel University,
- Embry Riddle Aeronautical University;
- Kansas State University;
- Kansas University;
- Montana State University;
- New Mexico State University;
- North Carolina State University;

- Oregon State University;
- University of Alabama – Huntsville;
- University of Alaska – Fairbanks;
- University of North Dakota, and
- Wichita State University.

The affiliate members include:

- Auburn University;
- Concordia University (Canada);
- Louisiana Tech University;
- Tuskegee University;
- Indiana State University, and
- The University of Southampton (UK).

The UAS COE has established a relationship with the UAS test sites the FAA announced last year through two of its core members; University of North Dakota and University of Alaska – Fairbanks. The FAA expects COE flight-testing to occur at one or more of the existing test sites to UAS research and development and the necessary resources to provide the matching contribution to the government’s investment. The COE research areas are expected to evolve over time, but initially will include:

- DAA technology;
- Low-altitude operations safety;
- Control and communications;
- Spectrum management;
- Human factors;
- Compatibility with ATC operations, and
- Training and certification of UAS pilots and other crewmembers, in addition to other areas.

Weather Program Research Conducted

Avoiding In-Flight Icing Conditions:

During the period from 2000 thru 2013, in-flight icing was a cause or factor in 140 GA aircraft accidents according to National Transportation Safety Board (NTSB) data. To address this problem, the Weather Program developed the Current and Forecast Icing Products (CIP and FIP) for the CONUS, which provides more accurate and timely diagnoses and forecasts of atmospheric conditions leading to ice accretion on aircraft during flight. After transitioning to the National Oceanic and Atmospheric Administration (NOAA), the CIP and FIP were operationally implemented in the NOAA Aviation Weather Center (AWC) in Kansas City and on the web-based Aviation Digital Data Service (ADDS) (<http://aviationweather.gov>). The Weather Program upgraded the CIP and FIP algorithms to meet NextGen requirements of a high-

resolution diagnoses and forecast of atmospheric conditions conducive to aircraft icing in FY14. These upgraded algorithms, also known as CIP/FIP High Resolution (HiRes) improved the horizontal and vertical resolution and extended the forecast from 12 hours out to 18 hours. CIP/FIP HiRes was implemented operationally on ADDS in FY14.

Currently under development is an Icing Forecast and Diagnosis product for Alaska (Icing Product Alaska (IPA) to meet NextGen requirements for expansion of weather products outside the CONUS. Aircraft accident rates with in-flight icing as a cause are significantly higher in Alaska than the CONUS due to the state's many hazardous micro-climates and the paucity of weather observations. In-flight icing significantly affects GA aircraft safety, as aviation in Alaska is the lifeblood to provide outlying villages and remote areas where there are no roads, daily supplies and provisions to exist. In FY15, a Technical Review Panel (TRP) assessed the scientific validity of the forecast portion of IPA. This capability will be implemented onto NOAA's Aviation Weather Testbed for evaluation by National Weather Service (NWS) Alaska forecasters. The diagnosis portion is under development with a scientific assessment and TRP scheduled in FY16. The IPA and Diagnosis product when completed in FY17, will be transitioned to NOAA to be run operationally on both the ADDS and Alaska Aviation Weather Unit (AAWU) websites. These automated algorithms are programmed to gather real-time information from numerous data sources including satellites, radars, weather models, surface stations, and pilot reports, as well as determine the probability of encountering icing, its expected severity, and the likelihood of super-cooled large droplet icing conditions. These capabilities are especially beneficial to commuter and GA aircraft without ice protection and those that fly at relatively low altitudes, less than 24000 feet, where they are more likely to encounter atmospheric conditions conducive to icing. In addition to availability on ADDS for NAS users, CIP, FIP, and IPA (when it becomes operational) will be used by NWS forecasters in preparation of FAA mandated forecast products.

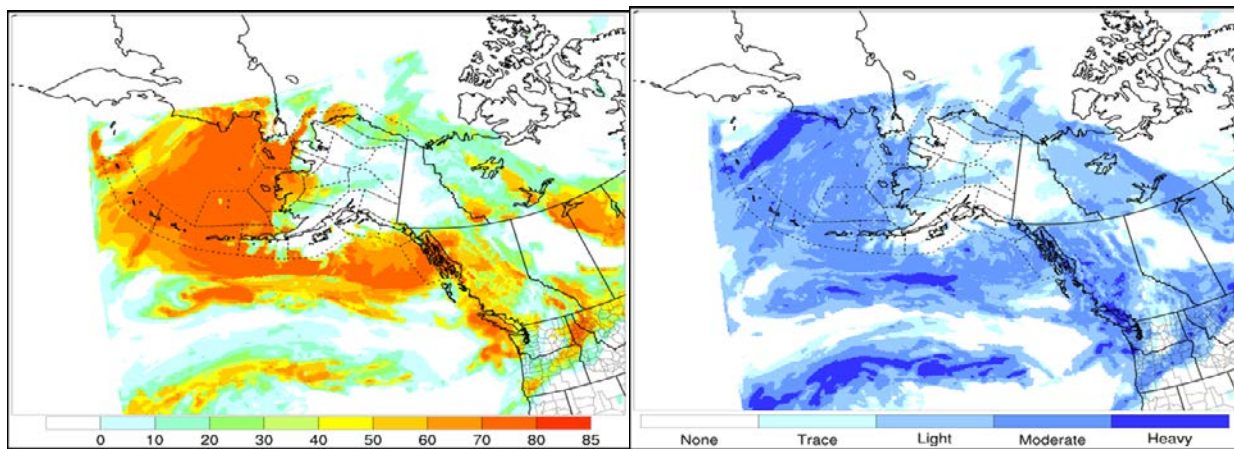


Figure 91: Icing Product Alaska Probability Forecast (Experimental)

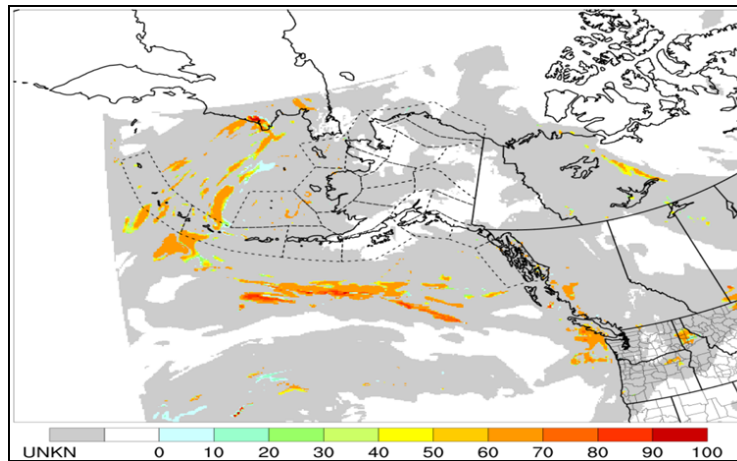


Figure 92: Icing Product Alaska Super Cooled Large Drop Conditions Potential Probability Forecast (Experimental)

Avoiding Turbulence:

Commercial and GA aircraft frequently encounter unexpected atmospheric turbulence. Though rarely fatal, these encounters often result in serious injuries to aircraft occupants or rerouting of flights. During the period of 2000-2011, turbulence accounted for 71% of all weather-related accidents for Part 121 aircraft (source taken from the NTSB briefing to Turbulence Workshop, Washington DC on September 3, 2014). In addition, according to the FAA website found at (http://www.faa.gov/passengers/fly_safe/turbulence/), turbulence is the leading cause of injuries to passengers and flight attendants in non-fatal accidents. During 2002-2013, 430 people were injured during turbulence events. In addition, the cost to air carriers of these injuries (medical attention and lawsuits), equipment damage and maintenance/inspection, or rerouting is substantial. Moreover, rerouting of flights due to reported or forecast turbulence reduces NAS capacity.

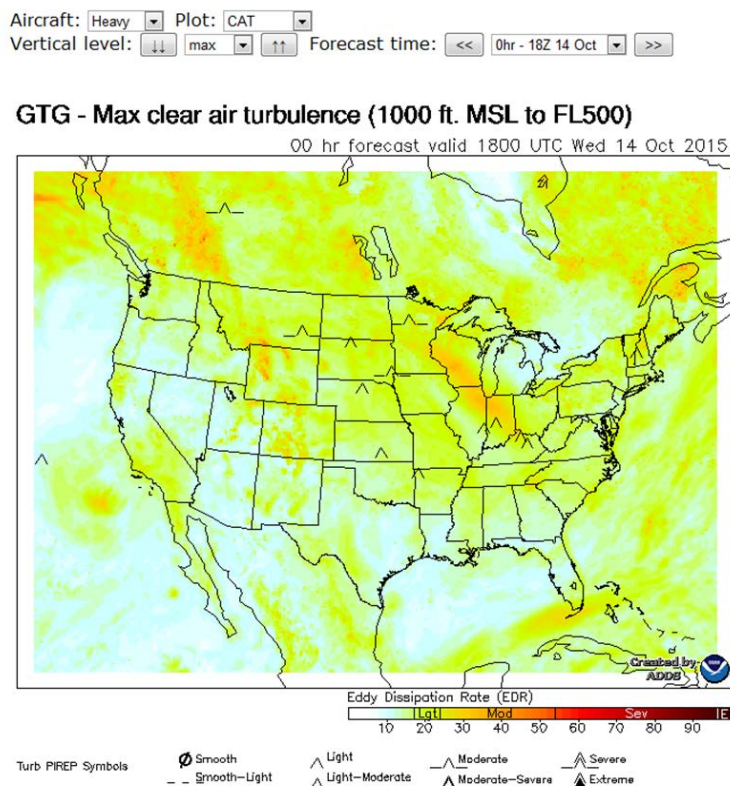


Figure 93: Graphical Turbulence Guidance Maximum Clear Air Turbulence Display

To address this problem, the Weather Program developed the GTG; a fully automated turbulence forecast capability providing quantitative analyses and forecasts of atmospheric turbulence over the contiguous U.S., parts of Mexico and Canada, the western Atlantic Ocean, and eastern Pacific Ocean. GTG can be viewed at selected flight levels on the NOAA ADDS website, found at (<http://aviationweather.gov>). In FY15, the Weather Program upgraded GTG to include all flight levels, surface to flight level 45000 feet (FL450), expanding the user base to include the GA community (the previous version did not include forecasts below 10000 feet (FL100)). Explicit Mountain-Wave Turbulence forecasts were added in addition to the already available Clear-Air Turbulence (CAT) forecasts. GTG was extended out to 18 hours forecast length, with hourly updates. A Quality Assessment, Technical Review Panel, and Safety Risk Management Panel were conducted to assess the scientific validity and effectiveness of the upgraded GTG. It is scheduled for operational implementation at NOAA by the end of FY15.

Improving Safety for Helicopter Emergency Medical Services (HEMS):

Since 1983, the U.S. has experienced more than 200 medical helicopter crashes, which have resulted in a fatality rate of about 1.18 deaths per 100000 hours. In an in-depth review of HEMS accidents occurring between January 1998 and December 2004, the FAA found that Controlled Flight Into Terrain, inadvertent flight into IMC, and lack of operational control were the predominant factors in these accidents. To meet this need, the NextGen Portfolio Management and Technology Development Directorate's Aviation Weather Division (ANG-C6) sponsored

development, and this year's transition to NWS operations of the HEMS Tool, which provides improved weather analysis and forecast information to help HEMS operators make better decisions in providing safe emergency medical services and transportation. The HEMS tool can overlay multiple fields of interest to pilots, including ceiling, visibility, flight category, winds, relative humidity, temperature, icing, satellite, and radar, G-AIRMETs, SIGMETs, METARs, TAFs, and PIREPs. All 3D data are interpolated to Great Lakes Region altitudes and can be sliced horizontally on 1000 foot intervals up to 5000 feet. The tool itself is not a weather product. Rather, a tool aggregates a number of existing weather products into a single, quick-glance, automated display. Data are time synchronized to go back up to six hours and forward up to six hours.

The HEMS tool was developed by the National Center for Atmospheric Research (NCAR) in 2007 and has been running in experimental mode at NCAR since its launch. This year's transition to operations at the NWS AWCr specifically focuses on moving the product to the well-recognized website, found at (<http://www.aviationweather.gov/aviationweather.gov>). This brings about significant improvements in product monitoring and availability. In addition, the HEMS tool is now an interactive OpenLayers tool displaying multiple weather parameters on a single website and offers more core functionality and support for mobile devices.

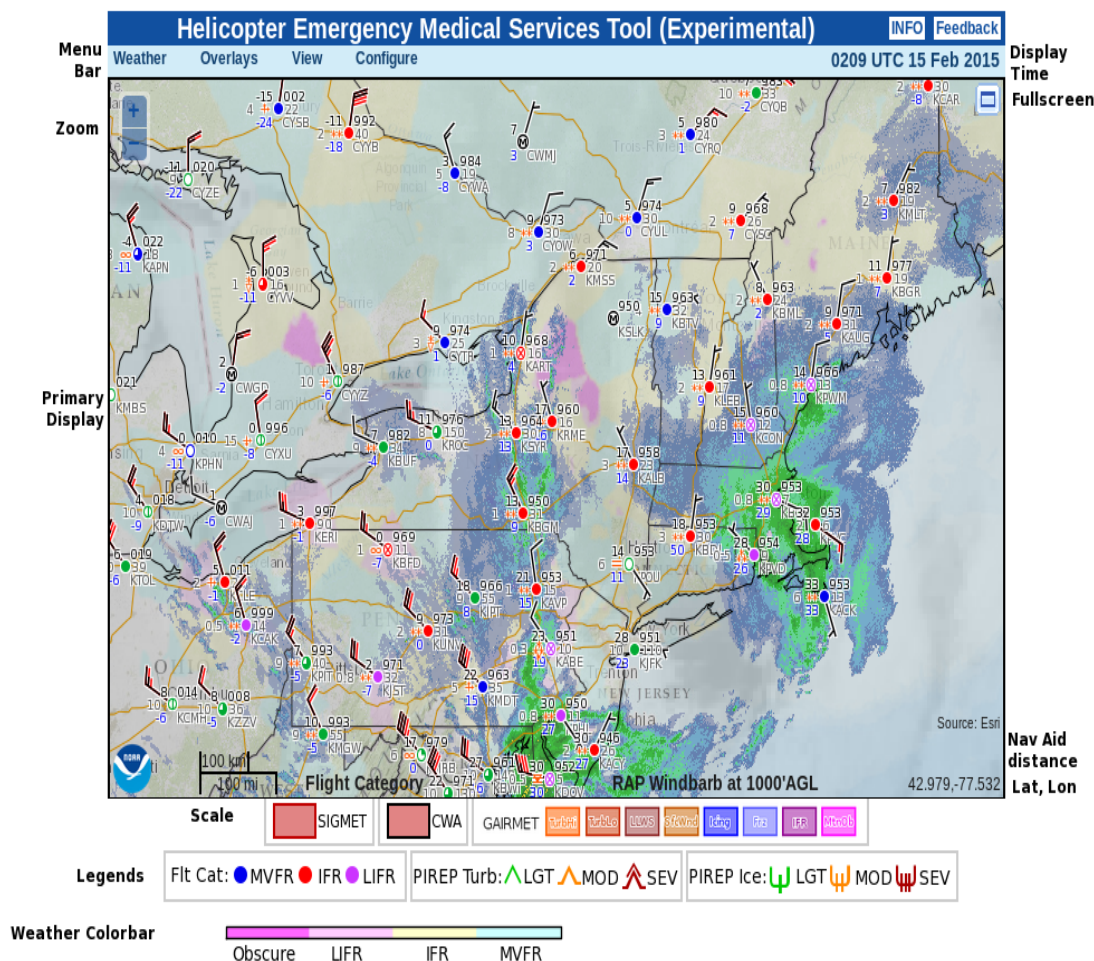


Figure 94: HEMS Tool Overlay with Multiple Weather Analysis Fields

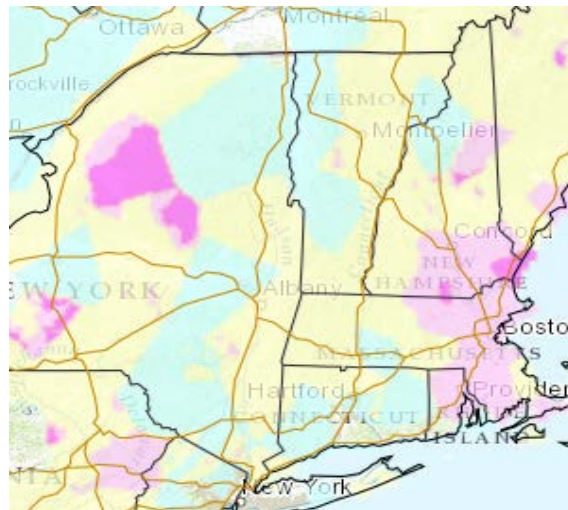
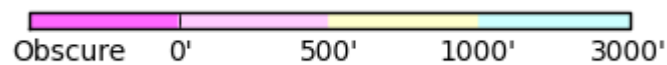
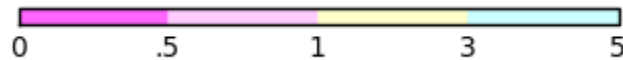


Figure 95: Sample Flight Category Plot

Ceiling: The ceiling is colored blue for 1000 feet to 3000 feet Marginal Visual Flight Rules (MVFR) conditions, yellow for 500 feet to 1000 feet (Instrument Flight Rules (IFR) conditions) and light magenta for zero feet to 500 feet (LIFR conditions). Terrain obscuration is denoted in a dark magenta. Ceilings above 3000 feet (VFR) are transparent.



Visibility: The visibility is colored blue for 3-5 miles (MVFR), yellow for 1-3 miles (IFR), light magenta for 0.5 to one mile (LIFR) and dark magenta for under half a mile. Visibilities above five miles (VFR) are transparent.



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

Develop Guidelines for Air Cargo Facility Planning and Development at Airports:

Air cargo is a significant component of the world's manufacturing and retail supply distribution chain in general, and an important revenue source for the airport industry in particular. As a result, making long-term investment decisions regarding air cargo facilities at our Nation's airports is exceedingly important. However, these decisions can often be difficult given the complex and dynamic nature of the business of air cargo. Over time, these complexities have grown as a function of modal shift, airport access, regulatory and security compliance issues, changing economic conditions, increased sensitivity to environmental issues, changing aircraft configurations and size, and other challenges. What often complicates the issue is that many airports use antiquated air cargo facilities that no longer meet demand or service requirements, nor accommodate changes to cargo handling procedures and evolving security requirements.

As airports develop, redevelop, expand, and modernize their cargo facilities, they are finding incomplete and inconsistent air cargo activity data, as well as a lack of generally accepted air cargo planning standards and design guidelines. For example, some carriers include trucked tonnage in monthly reports while others do not. Variations in reporting can affect how airports plan for and allocate space for priority on-airport cargo activity that must consider many factors, including:

- Facility throughput area;
- Storage/sorting space;
- Aircraft parking;
- Cargo tug lanes;
- Ground handling equipment storage areas;
- Landside truck docks, and
- Overall traffic circulation.

Given this complex environment, airport management requires current and accurate information coupled with effective planning and development guidelines to ensure that future airport cargo needs will be accommodated.

The objective of the research is to develop guidelines for air cargo facility planning and development at airports, including collection of necessary data in support of this effort. These

guidelines should assist airport operators in creating effective business policies and development decisions that meet the industry's current and future technological, operational, and security challenges in a cost-effective, efficient, and environmentally compatible manner. They should also include updated metrics to help guide the overall air cargo development planning process. The potential beneficiaries of these guidelines would include airport owners and operators, airlines, integrated cargo carriers, developers, financial institutions, and others linked to the airport community. Currently, the cargo models have been prepared and reviewed and full documentation for guide and final report is now underway.

Develop a Primer on the Benefits of a Whole-Building Systems Lifecycle Approach to Airport Operations and Maintenance Optimization and Recommissioning:

Airports are increasingly concerned with improving efficiency and reliability as well as reducing costs. Since an airport's Operations and Maintenance (O&M) budget constitutes a significant portion of its overall budget, many airports have begun exploring ways to optimize O&M and improve overall building system performance through recommissioning. Although significant financial and environmental benefits can be realized through O&M optimization and recommissioning, the complexity of airport building systems and the lack of a whole-building systems lifecycle approach to decision-making can lead to conflicting priorities and less-than-optimal improvements. Research is needed to help airports understand and apply a whole-building systems lifecycle approach to O&M optimization and recommissioning.

The objective of research is to develop a primer for airports that provides an overview of the benefits of a whole-building systems lifecycle approach to O&M optimization and recommissioning, as well as guidance for preparing a building systems optimization and recommissioning plan to suit their unique needs. The results are published in ACRP report #139, found at website (<http://www.trb.org/ACRP/Blurbs/172739.aspx>).

Estimate the Economic Impact of Air Cargo at Airports:

Air cargo services are part of a complex network of diverse economic production and distribution activities carried out across a wide spectrum of airport configurations. In response to this diversity, approaches employed by airports must account for differing operational roles with a variety of facilities located in many locales. Adding to the complexity, the air cargo industry is under continuing pressure to implement additional oversight measures (e.g., security) for moving cargo on passenger aircraft and, to a lesser extent, on freighter aircraft. There is every indication that demand for these measures will continue to evolve and grow over time with increased costs to the industry and to the nation's economy as a result. The principal industry stakeholders concerned with and affected by these measures include:

- Airports;
- Airlines;
- Cargo forwarders;
- Air cargo truckers;
- Independent ground handlers, and
- Commercial shippers and consignees.

The objective of research is to develop a guidebook for use by airport operators and other air cargo industry stakeholders that provide tools and techniques for measuring existing and future economic impacts of air cargo activities at a national, regional, and local airport level in the context of changing market, financial, security, and other conditions. Critical issues in measuring economic impacts of air cargo activity at a given airport should include but not be limited to the following:

- Size of air cargo market;
- Source and purpose of air cargo activity;
- Effect of changing fuel prices;
- Understanding complex linkages to changing economic conditions;
- Effect of increasing security requirements, and
- Availability and comparative cost of alternate cargo shipment modes.

The final report has been published as a web-only document.

Prepare Guidance to Assist Airports in Using Benefit-Cost Analysis and other Analytical Techniques to Make Airport Capital Investment Decisions:

Airports invest billions of dollars to enhance the passenger experience, yet they often lack specific knowledge of their customers' valuation of the physical improvements. Other major stakeholders, including the FAA and the Transportation Security Administration have limited knowledge of the value that passengers, shippers, meet and greeters, and the companies that pay for air travel, place on efficient and cost-effective air transportation services. The FAA is now using recently updated passenger time values, per DOT's 2015 "Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis". It is now available at (<https://www.transportation.gov/administrations/office-policy/2015-value-travel-time-guidance>).

The Office of Management and Budget requires use of benefit-cost studies, and the FAA has incorporated this requirement in the evaluation of their discretionary grants for capacity projects. In too many cases, however, the data are neither current nor consistent. Airports have relied on past planning practices, or more subjective surveys of passenger satisfaction that do not yield information useful for rigorous investment evaluations. The estimation of capacity benefits relies principally on the service (value of time as a function of more reliable and efficient schedule and service patterns), efficiency gains (reduced airline or operator costs), as well as the informational value of understanding when the travel sequence will be accomplished, and in what steps. Airline operational and service practices have undergone major changes over the past two decades. Technology is now available to passengers to enhance productivity, but little research has focused on how these changes affect air passengers and their decisions.

The objective of the research is to prepare a guidebook that assists airport planners, managers, and operators in using benefit-cost analysis and other analytical techniques to make airport capital investment decisions. The final report has been published in three volumes as *ACRP WOD 22: Passenger Value of Time, Benefit-Cost Analysis and Airport Capital Investment Decisions*. Volume I is the guidebook for valuing user time savings in airport capital investment

decision analysis. Volume II is the final report, while Volume III includes the appendices covering background research and the stated preference survey.

Quantify the National Aggregate Value of Airports to Communities and to Aviation Stakeholders:

The economic impact of airports is typically assessed at a local or regional level to educate communities about how their airport(s) contribute to the area's economy and to support airport infrastructure investments and ongoing expenditures to policy makers. Various entities have published reports quantifying the impact of the civil aviation industry, but not the specific economic impact of airports to the national economy. A need exists at the national level to educate policy makers and the public about the economic impact and the importance of airports and the airport system to the U.S.

To quantify the economic role of U.S. public use airports and the national airport system (airports) to the national economy in order to communicate the national aggregate value of airports to communities and to aviation stakeholders. This research includes total direct, national economic impacts of U.S. airports and multiplier effects, as well as national average on-airport economic impact by different types of airports characterized as primary (large, medium, small, and non-hub), non-primary and reliever and GA. The research has been published as Report 132. In addition to this report, there is a PowerPoint presentation and brochure that describes the key features of the report as well as the technical appendices that provide all the underlying data associated with this research effort available on the TRB website found at (www.TRB.org/main/blurbs/172111.aspx).

Airport Technology Research Program, Research Conducted

Perform Economic Analysis of Heated Pavements at Selected Airports:

A study was performed to determine the financial viability of heated pavements. There are three objectives to perform this research:

- Assess the amount of energy required to heat a slab to above freezing and compare it with the energy consumed using conventional approaches;
- Investigate the economic advantages of a heated pavement which included factors such as operational savings, and improved safety along with staffing needed to operate snow removal equipment, and
- Appraise the initial installation costs of a heating system and ascertain how they may be absorbed over a period under operation.

Some of the key findings of the research were:

- Heated Pavement Systems (HPS) are expected to have maximum benefits in the ramps and parking apron areas;
- HPS application is a viable option from an energy or financial perspective for achieving pavement surfaces free of ice and snow without using mechanical or chemical methods, and
- HPS have the potential to reduce the dependency on deicing chemicals, minimize the use of snow removal equipment and reduce labor requirements.

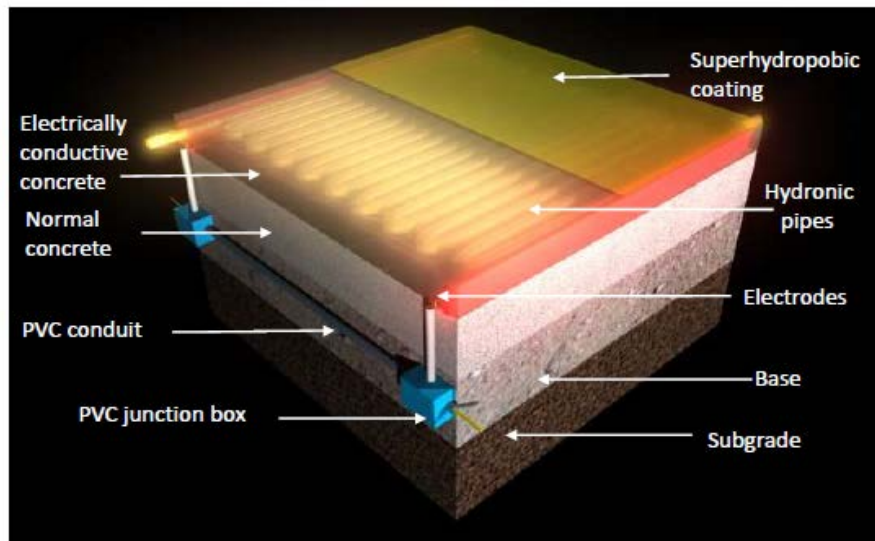


Figure 96: Heated Pavement Concept Cross Section Draft Exonomic Analysis

Center for Advanced Aviation System Development (CAASD) Research Conducted

Evaluating Space Traffic Separation Concepts:

Since the 1960's, the approach used for safely accommodating Launch Vehicle/Reentry Vehicle (LV/RV) operations has been to segregate large amounts of airspace during launch operations. This increases costs for NAS users and is not a scalable approach to handling future anticipated LV/RV needs. The FAA is working to develop new and more efficient separation concepts/standards for a variety of LV/RV operations to minimize their impact on other NAS users. However, the safety of those concepts/standards is unknown. CAASD is developing fast-time modeling and simulation capabilities that provide measures of safety of LV/RV operations with different separation concepts/standards. These modeling and simulation capabilities output several metrics that the FAA uses to determine which separation concepts/standards meet a target level of safety for each type of LV/RV operation. CAASD's capabilities examine operational risks of new separation concepts/standards and provide insight into the required

surveillance performance, ATC response times, and traffic limits to enable them. They also support the FAA's SMS process.

In FY15 CAASD developed an initial capability that can run and generate metrics for LV/RV scenarios using two separation concepts; dynamic hazard areas (or space transition corridors) and four-dimensional de-confliction. Developed modelling capabilities include:

- Calculation of measures of safety for several operational risk metrics;
- Ability to run LV/RV scenarios throughout a day of traffic;
- Algorithms for at-risk aircraft to exit hazard areas or reroute around hazard areas;
- Trajectory models for a simple rocket' first stage re-entry, and parachute;
- Debris model (developed leveraging Stanford University's debris propagator and Range Safety Assessment Tool) and hazard area generator;
- Updated surveillance model that allows for varying surveillance performance by altitude;
- Probabilistic controller and pilot response times, and
- Google Earth visualization generator for scenarios.

CAASD collaborated extensively with stakeholders, including the FAA's offices of NextGen (ANG), Commercial Space Transportation, ATO, Stanford University, NASA, and the FAA's COE for CST.

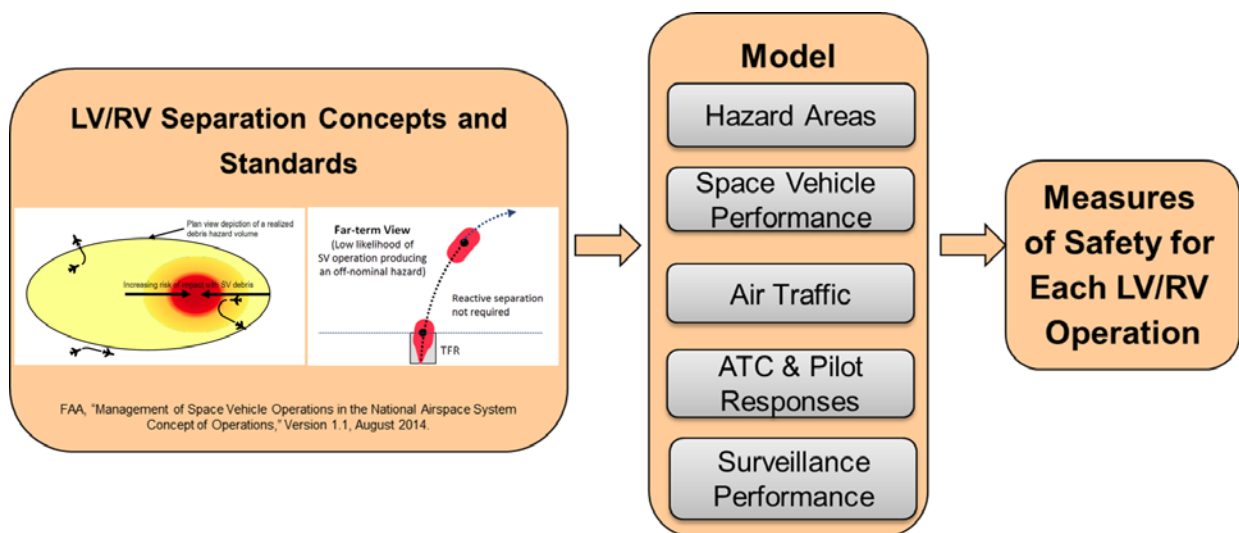


Figure 97: High Level Modeling Approach for Evaluating Separation Concepts

New, more efficient separation concepts/standards are needed to minimize the impact of LV/RV operations on the NAS and help facilitate the growth of the growing commercial space industry. The results of this research will provide the FAA and the commercial space community with a fast-time capability to evaluate separation concepts and standards in order to determine if they meet a target level of safety for each type of LV/RV operation. Additionally, this research provides insight into the required performance of surveillance and ATC response times. For FY16, research will focus on confirming and assessing the new modeling capabilities performance; improving space vehicle trajectory models; further enhancing algorithms; and performing further evaluations.

Operational Intelligence: Real-Time Feedback and Prediction – Lab Demonstration and Evaluation:

Between 2014 and 2015, the FAA tasked CAASD to develop a web-based evaluation capability displaying real-time NAS status and alerts of current and predicted constraints. In response, CAASD developed the NAS Operations Dashboard (NOD). NOD is a proof-of-concept that integrates real-time data from multiple decision support capabilities and information sources. NOD continuously monitors NAS performance areas (airborne holding, diversions, arrival performance, airport throughput, taxi times, and equipment outages) and provides alerts when user-specified thresholds have been exceeded. NOD's drill-down capabilities allow Traffic Managers to trace an event down to the level of individual flights. CAASD worked closely with National Operations Managers (NOMs) at the ATC System Command Center (ATCSCC) to identify their monitoring and alerting needs. NOD evolved significantly in FY 2015 through continued end-user engagement.

The NOD provides a series of visualizations, including the NAS Alert Map. The NAS Alert Map graphically depicts both weather and the alerting status for the Core 30 airports (see figure 98 below). Each airport is colored to indicate the highest alert status currently reported for that airport. Clicking on an airport provides a quick view of the underlying alerts. The alert table on the left of the map summarizes all current alerts by airport and performance area.

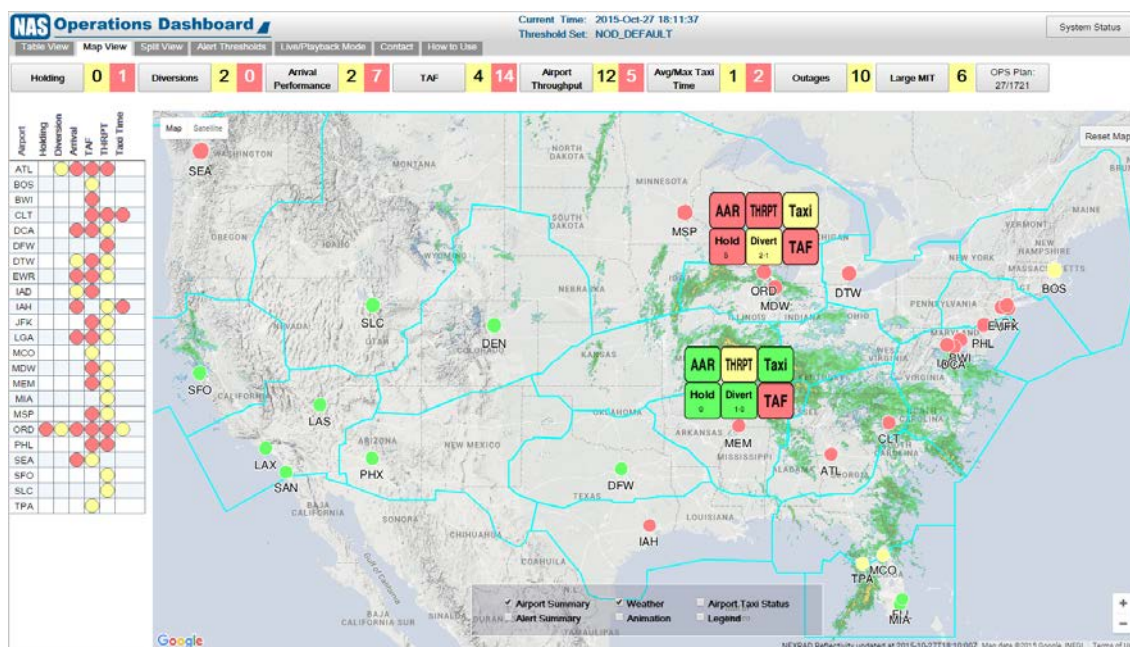


Figure 98: NAS Alert Map with Drill-Down Capabilities

NOD's map display can alternatively show surface activities at a single airport; enabling Traffic Managers to identify where queues are developing and monitor potential congestion (see figure 99). Aircraft surface positions are updated once per minute. Traffic Managers can look at detailed flight information on the right of the display while keeping an eye on NAS alerts at other airports using the summary table on the left.

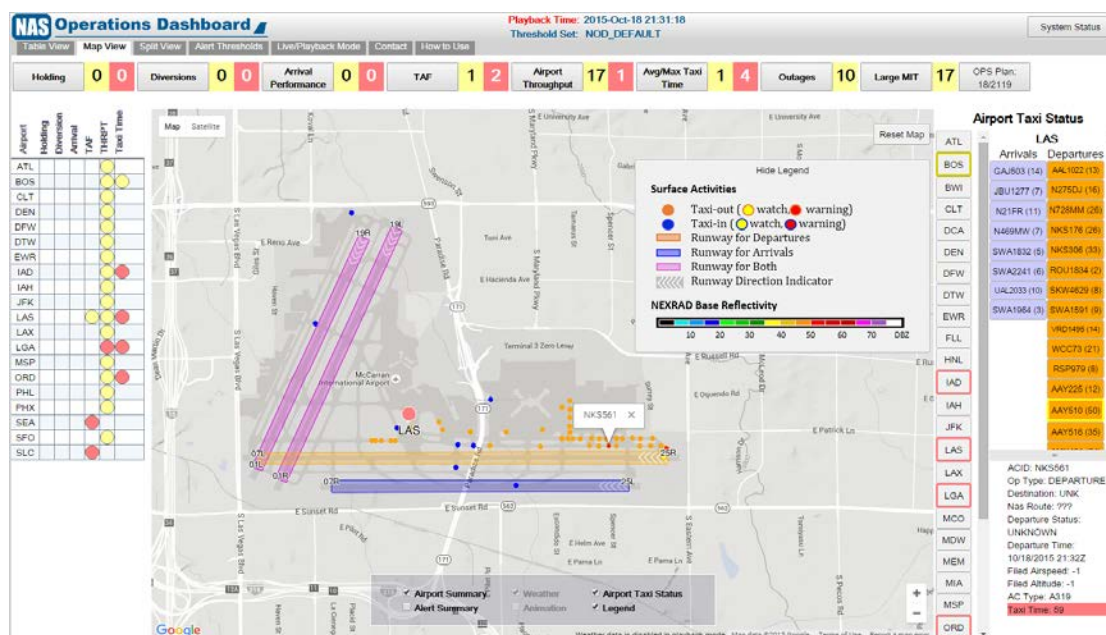


Figure 99: Airport Taxi Status with Situational Awareness of Other NAS Alerts

Field evaluations were conducted at the ATCSCC NOM position from April to September 2015. Users provided feedback on both the concept of use and proposed enhancements to the computer-human interface. The following benefits were observed during these evaluations:

- By integrating multiple performance metrics in a single display, NOD allows traffic managers to spend less time searching for data using multiple decision support tools;
- NOD's alerting capability reduces the time needed for traffic managers to scan for events requiring attention;
- NOD enables Traffic Managers to maintain situational awareness of the NAS while engaged in resolving a problem at a particular airport, and
- NOD facilitates the quick resolution of incoming questions from NAS customers via phone calls.

NOD was designed to be lightweight and portable to simplify the technology transfer and engineering processes required for implementation by the FAA. CAASD is currently collaborating with the FAA to refine NOD by enhancing visualization and alerting capabilities and expanding evaluations and benefits study to other traffic management positions, along with exploring options to expedite technology transfer.

Time-Based Flow Management Operational Integration Analysis and Simulation:

The FAA is defining concepts and requirements that further assist enroute controllers (via ground-based automation) with time-based metering of operations in order to improve their ability to accurately and efficiently meet metering schedule times. To meet this goal, a path stretch capability was proposed to provide the controller with a solution (lateral path change and an accompanying speed advisory) that absorbs the delay needed to meet an assigned metering time. Goals include the support of improved delivery accuracy to the enroute meter point and improved flight intent data to increase trajectory accuracy. This improved delivery and trajectory accuracy will support effectiveness of other time-based metering capabilities such as that defined by the Terminal Sequencing and Spacing concept, and will increase the likelihood that a flight can fly an Optimized Profile Descent by accurately absorbing the needed delay at level cruise altitudes. The improved trajectory accuracy will also improve ERAM platform's conflict probe detection accuracy and Time-Based Flow Management (TBFM) system's scheduling functionality.

In FY 2014, FAA Operational SMEs identified a number of operational concerns with the path stretch concept, around maintaining situational awareness (i.e., path stretch routes should align with controller practices and plan for a sector) and operational suitability of the solution (i.e., path stretch routes should comply with sector preferences and constraints).

In FY 2015, the FAA asked CAASD to identify and prototype mitigations to the operational concerns and to facilitate resolution of the concerns with FAA operational SMEs. Building upon

the research and requirements for a path stretch capability developed by the NASA Ames Research Center, and the requirements identified for path stretch as part of TBFM Work Package 3; CAASD identified several new design features and enhancements. The design features and enhancements addressed:

- Operational concerns raised;
- Integrated path stretch's automated advisory generation design and Computer Human Interface (CHI) with Ground Based Interval Management Spacing (GIM-S) speed advisories;
- Employed updates to reflect the context of GIM-S extended metering;
- Integrated path stretch with ERAM's conflict probe design, and
- Accounted for performance based navigation speed and altitude constraints published along the arrival procedure.

This revised path stretch design was prototyped in CAASD's Integration Demonstration and Experimentation for Aeronautics Laboratory using an ERAM emulation as well as Release 4.2.2 of the fielded TBFM system. A summary of the enhancements included in the revised path stretch design that addresses situational awareness and operational suitability are:

- Situational Awareness – Graphic display of proposed route and key information (shown figure 100 below, in the green box) identifying route turn points, initial heading, speed, and remaining delay after the maneuver is cleared.

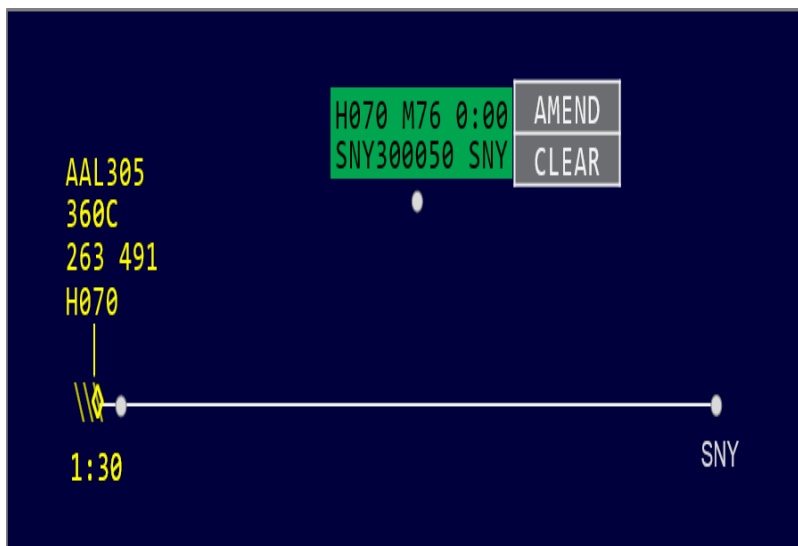


Figure 100: Graphic Display of Proposed Path Stretch Route

- Automatic updates of information in data block including assigned heading and speed in the fourth line and upcoming turn-back point reminder (shown in figure 101 below, R3 in light purple) indicating rights turn in 30 seconds.

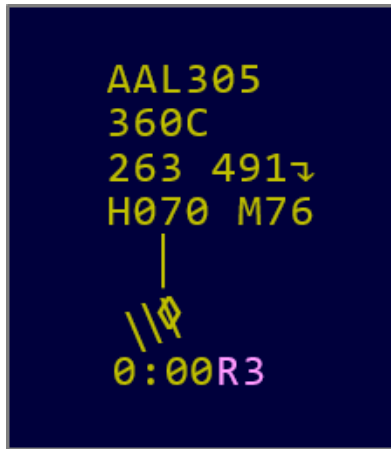


Figure 101: Full Data Block updated with Path Stretch Information

- Automatic updates of information on the Meter Reference Point (MRP) view including assigned heading and speed and upcoming turn-back point reminder (as shown in figure 102 below).

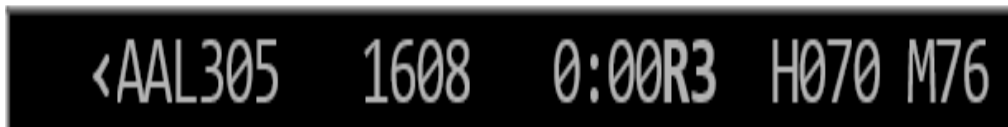


Figure 102: Meter Reference Point View updated with Path Stretch Information

- Operational Acceptability – CHI integrated into the existing ERAM and GIM-S CHI, extending similar menus and options to fit path stretch needs. Along with quick and easy adjustments of input parameters (e.g., heading, turn angle) to allow the controller to tailor the resulting path stretch to meet operational needs. In order to accommodate the preferences of individuals, the CHI also allows controllers to either use the trackball, menus and keyboard, or use the keyboard exclusively. The path stretch capabilities are available for any metered aircraft displayed on the MRP View.

Because of the research success in mitigating operational concerns, the FAA is defining the next steps for pursuing a path stretch capability through the acquisition investment decision-making process.

NextGen – Air Ground Integration Human Factors Research Conducted

Develop a Report that Identifies Information Requirements for Flight Deck Based Interval Management (FIM) Addressing the Content, Form, and Location of Information Necessary for IM Applications:

FIM is one of the NextGen operational concepts expected to help achieve NAS goals for enhanced efficiency and capacity. FIM is a flow management concept that will achieve efficiencies in terminal airspace by reducing spacing typically applied by controllers – resulting in higher arrival rates, and more efficient operations. In FIM operations, the flight crew maintains spacing behind an aircraft that they are designated to follow. When the FIM clearance is received, the flight crew enters it into an onboard system, and monitors the aircraft's adherence to speeds and progress relative to the assigned spacing interval. Flight deck avionics must display the target speed, the spacing interval, and the aircraft to follow.

This research project assessed the effects of different FIM avionics configurations and notification methods on flight crew performance, workload, and situation awareness. The avionics configurations tested were defined by an avionics condition (four different display devices and three locations) and a notification method (whether indications of events were presented only visually, or were augmented with aural indications). The results provide human factors information for the design, operation, and evaluation of FIM avionics and procedures, as well as the speed target and a Fast/Slow indicator on a modified Electronic Attitude Director Indicator.

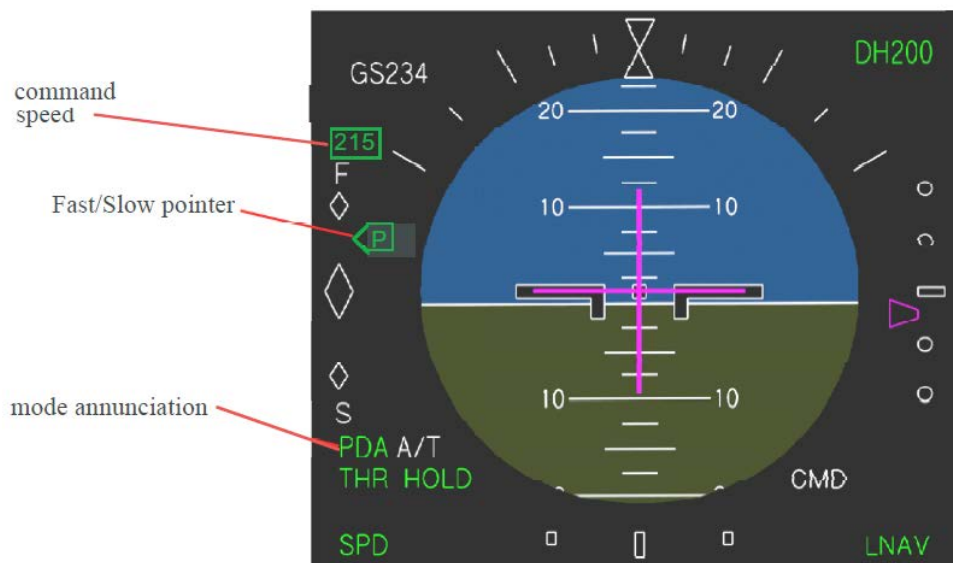


Figure 103: Flight Deck Based Interval Management

NextGen – Automatic Dependent Surveillance-Broadcast (ADS-B) Research Conducted

ADS-B is the more precise, satellite-based successor to radar. ADS-B Out uses GPS to determine an aircraft's location, airspeed and other data. It broadcasts information to a network of ground stations (which relays the data to ATC Controllers) and to nearby aircraft equipped to receive the data via ADS-B In. ADS-B In provides operators of properly equipped aircraft with weather and traffic information delivered directly to the cockpit. ADS-B Out equipage has been mandated in most controlled airspace, generally where transponders are required today by January 1, 2020. ADS-B In equipage is not currently mandated.

The FAA completed the baseline deployment of 634 ground stations in 2014. ADS-B has now been integrated into the automation platforms at 22 of 24 enroute ATC facilities (19 of 20 enroute Automation Modernization systems and three of four microprocessor enroute Automated Radar Tracking systems), which control high-altitude traffic. ADS-B traffic in addition, weather broadcasts are now available nationwide. Similar system upgrades in our terminal radar approach control facilities are also on track and will be completed by 2016.

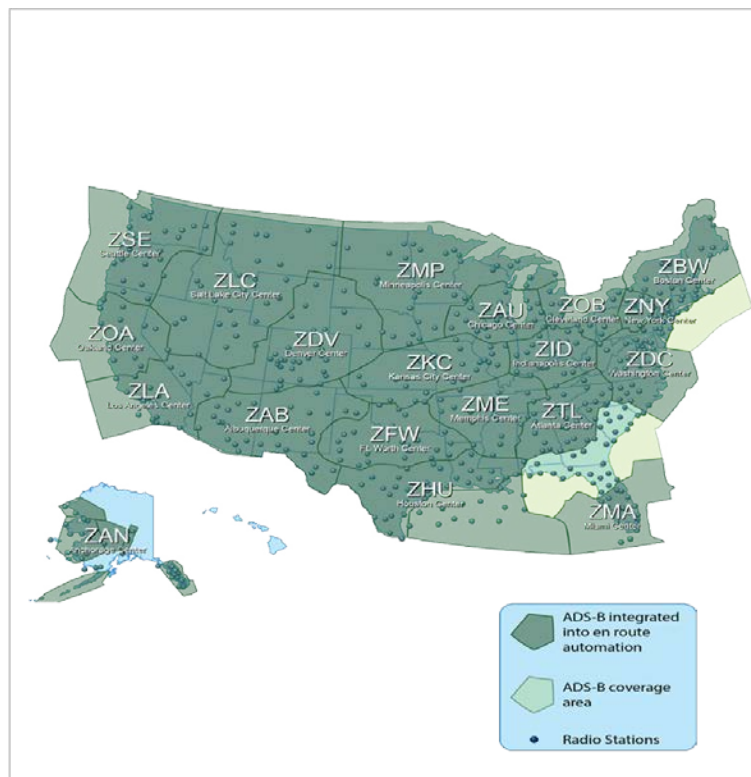


Figure 104: Automatic Dependent Surveillance-Broadcast Coverage and EnRoute Integration as of February 2015

Research conducted by NextGen –System Wide Information Management (SWIM)

SWIM is the digital data-sharing backbone of NextGen. SWIM infrastructure enables ATM related information sharing among diverse, qualified systems. SWIM also provides information governance. SWIM has been distributing weather and flight planning information to NAS users; mainly airline operations centers, since 2010 and will continue to develop and add services.

SWIM Segment II consists of two parts. Segment 2a (2015) includes:

- Capabilities added to the NAS Enterprise Messaging Services (NEMS); an information-sharing infrastructure that enables the publication and sharing of NAS data;
- NEMS nodes at all air route traffic control centers (e.g., currently at Atlanta, Boston, Chicago, Fort Worth, Los Angeles, Minneapolis, Miami, Salt Lake City, Seattle and Washington);
- Increased security capabilities;
- The ability for consumers to self-manage data subscriptions;
- An enriched set of traffic flow data for external consumers to maintain common situational, and
- Awareness of the NAS.

Segment 2b builds upon the infrastructure foundation laid by Segment 2a, and:

- Increases and improves products from SWIM Flight Data Publication Service
- Increases the security of NAS data flows with identify verification and access management that provides a certificate management service to enable more secure data exchanges with outside partners;
- Builds upon the monitoring capability of the existing infrastructure by adding status information about producers and consumers (this aims to build end-to-end situational awareness of all elements of, or participants in, an information exchange);
- Adds additional terminal data to the list of STDDS published information and enriches the functionality of existing services;
- Adds new data query functionality to the NAS. The NAS Common Reference supports complex data queries for NAS flight weather and aeronautical information, and

- Enables the efficient transition to global harmonization of information standards, including aeronautical information exchange, weather information exchange and Flight Information eXchange Model

SWIM provides increased ground situational awareness with data shared from STDDS via NEMS to TRACONS and airport authorities (e.g., Southern California TRACON and Los Angeles runway construction, operational April 2014; San Francisco runway construction, operational May 2014). The FAA has already installed the SWIM Visualization Tool (SVT) at the New York, Chicago, Houston, Boston and Louisville TRACONS in 2015, enabling controllers to see aircraft moving on the surface at airports they serve. SVT is installed at nine TRACON Traffic Management Unit (TMU) stations providing situational awareness during peak traffic and during airport construction and runway closures. The initial SVT deployment to these nine sites has supported the Terminal Flight Data Manager (TFDM) early implementation strategy. The FAA Notices to Airmen (NOTAM) Distribution Service (NDS) has made digital NOTAM data available on request using SWIM. NDS will be expanded to a publication-subscription capability in 2015. This modernization of the NOTAM system provides more timely information that can be electronically sorted to suit the needs of pilots flying a particular route. The DoD has recently adopted this service and is progressively expanding their capabilities within the SWIM environment.

NextGen – Wake Turbulence Research Conducted

Probabilistic Tool Developed for Use in Evaluating Wake Encounter Relative Risk:

The FAA identified a need for an analysis tool to evaluate the risk of aircraft encountering the wakes generated by nearby aircraft when flying on NextGen cruise air routes and when conducting NextGen approaches and departures from airports. The analysis tool would need to be able to compare in relative terms the wake encounter risk of the NextGen ATC procedures to the wake encounter risk associated with legacy ATC procedures and supporting infrastructure. In the tool's assessment of relative risk, it also had to consider the probabilities of the track of the wake generating aircraft, its generated wake, and the track of the following aircraft; along with accounting for the statistics of the aircraft types that would be using the NextGen procedure. The task of developing the analysis tool was given to the FAA Consortium in Aviation Operations Research (NEXTOR II), Universities of Virginia Polytechnic Institute and State University (Virginia Tech), George Mason University, and Massachusetts Institute of Technology. These universities worked in collaboration on an overall concept for the analysis tool, the design of the tool and the coding and testing of the tool. The core of the developed analysis tool utilizes a fast time model of aircraft wake turbulence generation that was provided to the universities by the NASA Langley Research Center. An example of the tool's output is shown in figure 105 below.

Notional Example

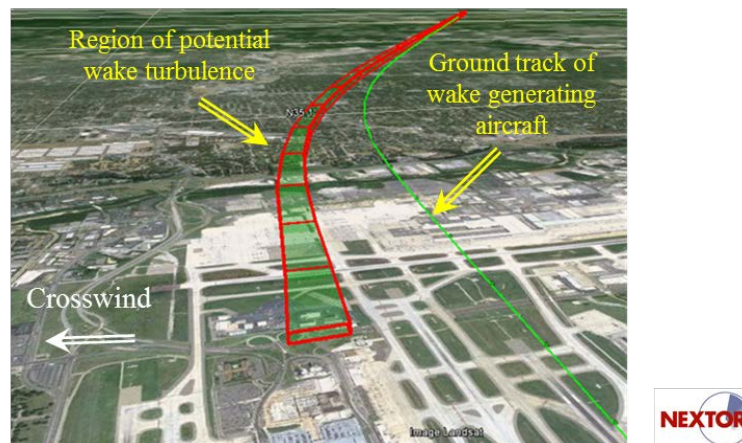


Figure 105: Analysis Tool's Depiction of Potential Regions of Wake Encounter

Subsequent to the delivery of the NEXTOR II analysis tool to the FAA, the FAA provided the tool to CSSI Inc. to perform wake relative risk assessments on the ATC procedures that CSSI was developing for the FAA to increase throughput of the NAS. CSSI, with the assistance of NEXTOR II, successfully applied the analysis tool in evaluating the relative wake encounter risk of the procedures CSSI had developed; including a flight track offset procedure for both manned and unmanned aircraft. Figure 106 below, is an example of the CSSI's application of the NEXTOR II analysis tool.

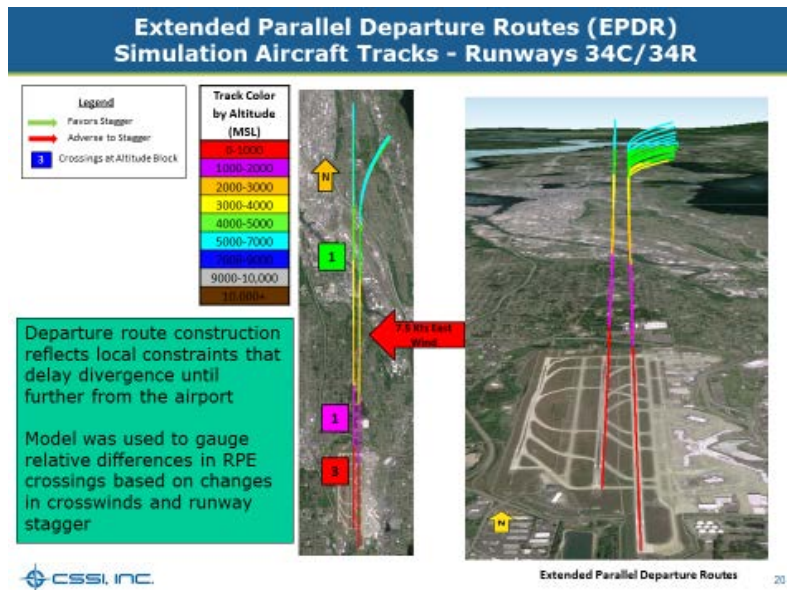


Figure 106: Example of CSSI's Application of the NEXTOR II Analysis Tool

Weather Program Research Conducted

Transition turbulence forecast capability for all flight levels for implementation (as detailed in the NAS infrastructure portfolio section of the *NextGen Implementation Plan* (NGIP)):

Completed a technical review, safety risk management, and operational evaluation of the Graphical Turbulence Guidance version 3.0 (GTG3) to meet NextGen requirements of high resolution forecasts of atmospheric turbulence for clear air turbulence, mountain wave turbulence, and low-level turbulence (surface to flight level 45000). This upgraded capability also extends the forecast from 12 out to 18 hours. GTG3.0 is anticipated to be operational on the NWS Aviation Digital Data Service, fourth quarter FY 2015.

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) Research Conducted

Assess the Current Body of Knowledge Regarding the Impact of Airport Operations on Air Quality and Public Health:

The communities surrounding airports have become increasingly aware of potential impacts to air quality and public health from airport operations. A number of airport air quality and health studies have been completed or are underway in North America (e.g., Los Angeles International, Boston Logan, T.F. Green, and Santa Monica) and Europe. Most of these studies are required by regulatory agencies or legislated, in response to airport improvement projects, or to public health concerns from local government or citizen groups. These studies vary greatly in method, scope and duration; include air sampling, modeling, and health assessment. There is a need to compile and assess relevant information on airport air quality and public health studies to provide an understanding of how these studies can be useful for airport operators.

The objective of this research was to assess the current body of knowledge regarding the impact of airport operations (e.g., aircraft, ground service equipment, ground transportation, and stationary sources) on air quality and public health to aid airport operators in responding to concerns about air quality in the vicinity of airports. Research has been completed and results are published in Report 135.

Develop an Inventory Methodology to Help Airports Quantify Aircraft Lead Emissions at Airports:

The current National Ambient Air Quality Standard (NAAQS) for lead is significantly more stringent than the previous standard. Current regulations are considered to affect five airports, which have numerous operations from piston engine aircraft that use leaded aviation gas (avgas). On December 23, 2009, the U.S. Environmental Protection Agency (EPA) proposed to revise the ambient monitoring requirements for measuring airborne lead. The proposed regulation changes lead monitoring threshold and may affect up to 73 airports. This revised threshold will be the basis for State Air Quality Agencies requiring source-oriented monitors is installed near any applicable source, and it may require airports to be treated as any other source of lead when determining whether source-oriented lead monitoring is needed. The inputs used to determine applicability were based on a number of assumptions and can be improved by obtaining airport-specific information.

The EPA has limited quantitative data to evaluate on-airport or off-airport ambient lead concentrations associated with airports. If this proposed regulation is enacted, airports would need to document applicability or work with state agencies to monitor ambient lead

concentration of the surrounding air. Airport owners and operators may face future regulatory and resource impacts to quantify or mitigate emissions. As such, research is needed to assist airports in quantifying lead emissions from leaded avgas that accounts for applicable variables. This has been published as ACRP Report 133, titled Best Practices Guidebook for Preparing Lead Emission Inventories from Piston-Powered Aircraft with the Emission Inventory Analysis Tool. The report has also been published as ACRP web-only Document 21, Quantifying Aircraft Lead Emissions at Airport.

Produce Guidance on the Application of Whole Effluent Toxicity (WET) Testing to Airport Deicing Runoff:

Whole Effluent Toxicity (WET) refers to the aggregate effect to aquatic organisms from all pollutants contained in a facility's wastewater. WET tests measure wastewater's effect on specific test organisms' ability to survive, grow, and reproduce. The WET test methodology consists of exposing living organisms, such as water fleas (*ceriodaphnia dubia*) and fathead minnows (*pimephales promelas*) to various concentrations of a sample facility's wastewater effluent stream. WET test results are used by National Pollutant Discharge Elimination System (NPDES), permitting authorities to determine whether a facility's permit will need to include specific WET-related requirements. The U.S. EPA and various state permitting authorities have required some airports to conduct WET testing of storm water runoff from portions of the airport where pavement and aircraft deicing occurs to determine if additional sampling or corrective actions will be required. However, factors include:

- Episodic nature of airport storm water deicing discharges;
- The potential for multiple discharge locations;
- Variations in size and flow of receiving water bodies;
- Exposure of organisms to varying deicing concentrations, and
- The effect of seasonality, and other issues, WET testing at airports faces unique challenges.

Research was necessary to produce guidance on how to appropriately conduct and apply WET testing for evaluating the effects of airport storm water deicing discharges. The objectives of the research were to:

- Describe how WET testing is used at airports for monitoring storm water deicing discharges, including WET testing strengths and weaknesses;
- Evaluate whether current WET sampling protocols accurately reflect the toxicity of episodic airport storm water discharges containing deicing fluids;
- Develop approaches for accurately applying the results of laboratory WET testing of episodic airport storm water discharges containing deicing fluids to determine if in situ water quality impacts are occurring or will occur, and

- Provide guidance on the use of WET testing at airports for storm water deicing discharges.

The research has been completed and results are published in Report 134.

Review, Evaluate, and Document Current Helicopter Noise Models and Identify Potential Improvements to the Integrated Noise Model and the Aviation Environmental Design Tool to Better Capture the Unique Complexity of Helicopter Operations:

Sound land use planning requires accurate predictions of the acoustic signatures at noise-sensitive receiver points and methods for interpreting the effect of acoustic signatures on public health, safety, and welfare. Historically, the study of noise impacts from aviation has been focused on fixed-wing aircraft, while the complexity of helicopter and new-technology rotary-wing aircraft has not been given adequate attention. The FAA Integrated Noise Model (INM) is currently the agency's required tool for NEPA-related studies and FAR Part 150 studies. The Heliport Noise Model Version 2.2 was recently incorporated into INM Version 7.0 with a helicopter noise database collected through both FAA and manufacturer certification measurements. Currently, the FAA is incorporating INM, along with emission and fuel burn calculation methodologies into the Aviation Environmental Design Tool (AEDT). The fixed-wing aircraft noise prediction techniques employed in INM/AEDT rely on the widely accepted methodologies described in documents such as SAE International's SAE-AIR-1845 and the European Civil Aviation Conference's Document 29. However, in contrast to guidance related to fixed-wing aircraft, there is no peer-reviewed guidance document describing an integrated modeling technique for the prediction of helicopter noise. Research is necessary to document current practice, improve modeling methods, and provide guidance for using INM/AEDT to predict helicopter noise.

The objective of the research is to review, evaluate, and document current helicopter noise models and identify potential improvements to INM/AEDT to better capture the unique complexity of helicopter operations. The contractor submitted the draft final report in June 2015 and panel comments were due July 29, 2015. The revised final report is anticipated in the fall of 2015.

Environment and Energy (E&E) Research Conducted

Advance the Understanding of Noise Impacts on Social Welfare and Health:

In order to minimize environmental consequences of aviation, the FAA is conducting research to advance the understanding of noise impacts on social welfare and health. This year a comprehensive survey of residents living around 20 airports in the US was initiated to study how many people are annoyed by airplane noise and by how much. The purpose of this research is to conduct a nation-wide survey to update the scientific evidence of the relationship between aircraft noise exposure and its effects on communities around airports. The selected airports represent all US airports. Data collection will be conducted using both a paper mail survey and a computer-assisted telephone interview of residence of airports surrounding communities exposed

to different civil aircraft noise levels. The questionnaires and data collection procedures used in this study are based on a pilot study conducted through the National Academy of Sciences. The studies on annoyance are expanded beyond just fixed wing aircraft: the FAA initiated studies to explore impacts from rotorcraft noise and studies to improve rotorcraft environmental modeling.

During the last year the FAA continued research investigating the long-term cardiovascular health impacts of noise exposure by linking noise exposure data with existing US longitudinal health cohorts. The earlier study was completed using the Medicare database and the results indicate there could be a statistically significant association between aircraft noise from 89 US airports and cardiovascular hospital admissions among Medicare beneficiaries. The study had several limitations, including reliance on ZIP code resolution address information and limited data on individual and social risk factors. A follow-up study has been initiated to evaluate the effects of aircraft noise exposure on cardiovascular disease using the longitudinal Women's Health Initiative (WHI) study cohorts, in which over 160,000 women were recruited from 1993 to 1998 from 40 clinics in 24 states. The WHI has collected individual-level socio-demographics, anthropometrics, blood pressures, electrocardiograms and biomarkers, as well as medical records and death certificate data, with geocoded participant residential addresses. Phase one of this project involves completing procedural steps for accessing WHI data, obtaining new noise modeling data to assign noise exposures to specific residential addresses over time and linking to individual, air pollution and roadway proximity/density data. Results from this study, the first to incorporate longitudinal aircraft noise exposure into a US cohort study, will provide data to inform future decision making regarding aircraft noise.

For the first time, there was a pilot field study conducted in the US to assess sleep-disturbance due to aircraft noise using a new low-cost technique for acquiring physiological data. Awakenings will be either determined by an automatic algorithm based on actigraphy and ECG. For each aircraft noise event, the physiological data will be screened for an EEG awakening for the duration of the noise event. This exposure-response relationship will be compared to the one derived from a study at Frankfurt airport using the same methodology. The primary outcome of this study will be an exposure-response relationship between acoustical properties of single aircraft noise events and physiological reactions during the sleep period. Secondary analyses will include models that incorporate individual (age, gender), situational (elapsed sleep time), and acoustical moderators. Sleep fragmentation will be calculated for and compared between the exposure and the control group. The medical data was collected for 3 nights for 40 aircraft noise exposed subjects and 40 control subjects not exposed to aircraft noise. Noise measurements were conducted inside of the bedroom and outside of the house. The subjects were selected by door-to-door recruitment in areas near the airport exposed to various night-time noise levels and in areas of not exposed to aircraft noise. Models will be developed which relate acoustical properties of single aircraft noise events and awakenings during the sleep period. Awakenings will also be calculated for the control group using ECG and actigraphy. Sleep fragmentation will be calculated for and compared between the exposure and the control group.

A completed assessment of aircraft noise conditions affecting students learning for 917 exposed elementary schools showed a small but statistically significant correlation between noise and performance of children in grades 3 through 5.

Recently new studies of commercial space flights on environment were initiated to evaluate existing launch noise models, and their potential integration with noise models currently used for commercial aviation assessment. The work continues on exploring the human response to flyover of supersonic vehicles producing different shaped sonic booms on a ground to determine if there is a potential for acceptability of certain “low booms.”

Develop Approved Method for Measuring Particulate Matter from Gas Turbine Engines:

Subsequent to the publication of the Society of Automotive Engineers Aircraft Exhaust Emissions Measurements Committee (SAE E31) Aerospace Information Report (AIR 6241) that standardized the measurement of non-volatile particulate matter (nvPM) from gas turbine engines, FAA has sponsored the development and use of the North American reference nvPM measurement system. This North American reference nvPM measurement system has been used in many measurement campaigns. A schematic of the standardized system is shown in Figure 107 below.

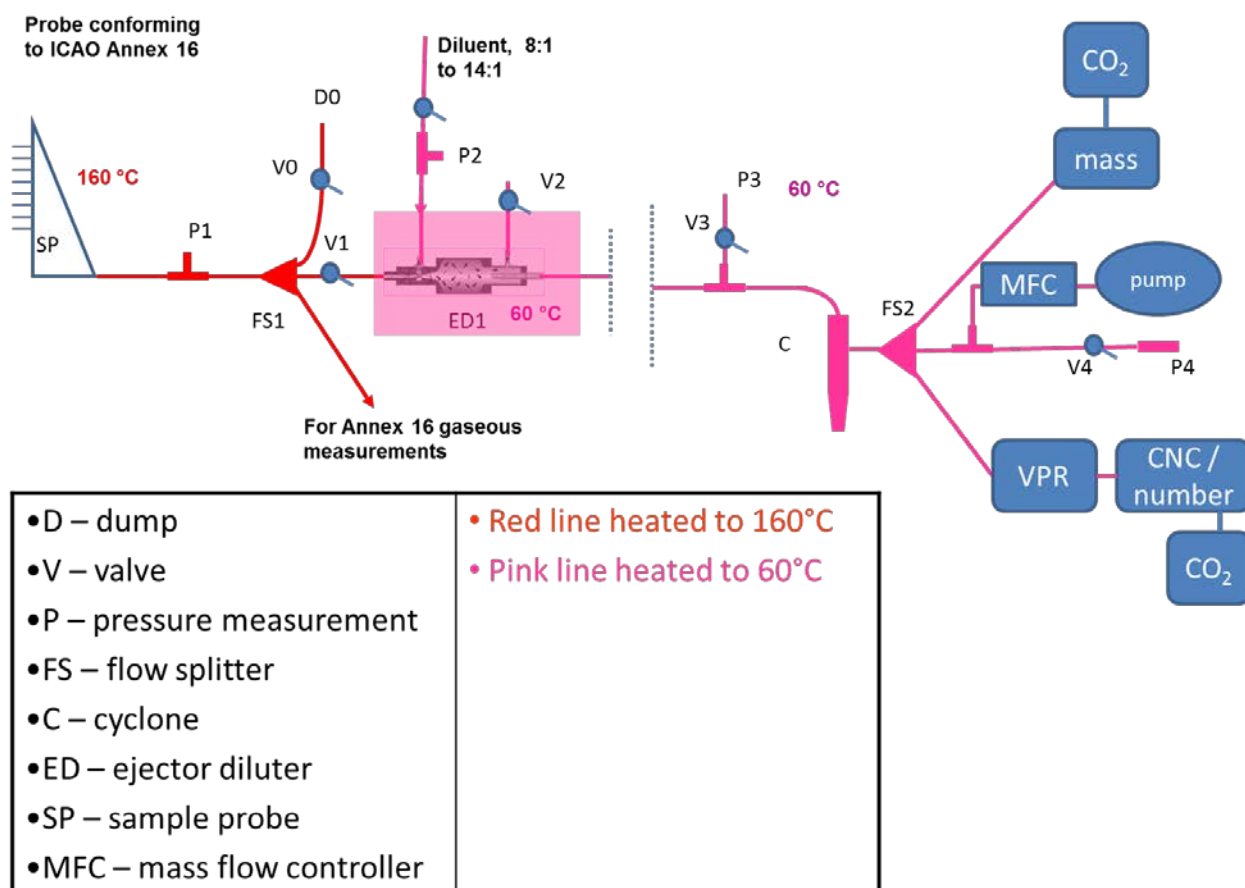


Figure 107: A Schematic of the Standardized nvPM Measurement System

The North American reference nvPM measurement system has been deployed at various aircraft engine manufacturers across North America. In the past 12 months, direct measurements of

nvPM were performed at a Honeywell facility in Phoenix, AZ and a Rolls Royce USA facility in Indiana. These demonstration/ inter-comparison studies provide datasets to the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) Particulate Matter Task Group (PMTG) to facilitate development of aircraft engine nvPM regulations. Engine measurement campaigns are scheduled for General Electric Aviation, OH; Pratt and Whitney, CT and Honeywell, AZ in the next 12 months. In addition, the standardized approach will be used in a combustor rig measurement of nvPM to quantify the impact of ambient conditions on the nvPM emissions.

The standardized measurement method is currently being implemented in ICAO Annex 16 Vol. II to facilitate the promulgation of an international engine nvPM emissions standard by ICAO by February 2016. This first of its kind standard combines the health-based nvPM emissions with the visibility-based Smoke Number standard. Data from 25 representative engines, some of which will be acquired using the North American reference nvPM measurement system, will inform the development of a more stringent Landing and Take-Off (LTO) cycle based nvPM mass and number standard that is proposed to be promulgated by February 2019.

Develop Methods to Account for Regional Climate Impact of Aviation Emissions:

Metrics are commonly used for quantifying the impact of human activity on climate. Metrics, such as the Global Warming Potential (GWP), are tools for aggregating information and for placing emissions of different components on a common scale. They are particularly useful when comparing and evaluating the climate effects of several species; sources or sectors and they are frequently applied to assess the global consequences of possible mitigation measures. Traditionally, metrics use globally-averaged input to produce globally-averaged measures and give no information about the spatial variability of the impact. Many perturbations of atmospheric species, especially short-lived ones, produce a distinctly heterogeneous radiative forcing and response, and the latter can be strongly dependent on the location of the forcing. Therefore, metrics to provide estimates of impacts on a regional scale need to be developed.

One of the metrics to provide estimates of impacts on a sub-global scale is the Regional Temperature Change Potential (RTP). RTP is an emission metric that provides time-varying surface temperature response to emissions in four latitude bands, accounting for the regional RF caused by the emissions. The RTP is analogous to the Global Temperature change Potential (GTP), which provides an estimate of the global mean temperature response to a given emission based on that emission's global mean RF as a function of time. The RTP provides additional insight into the spatial pattern of temperature response to inhomogeneous forcing beyond that available from traditional global metrics.

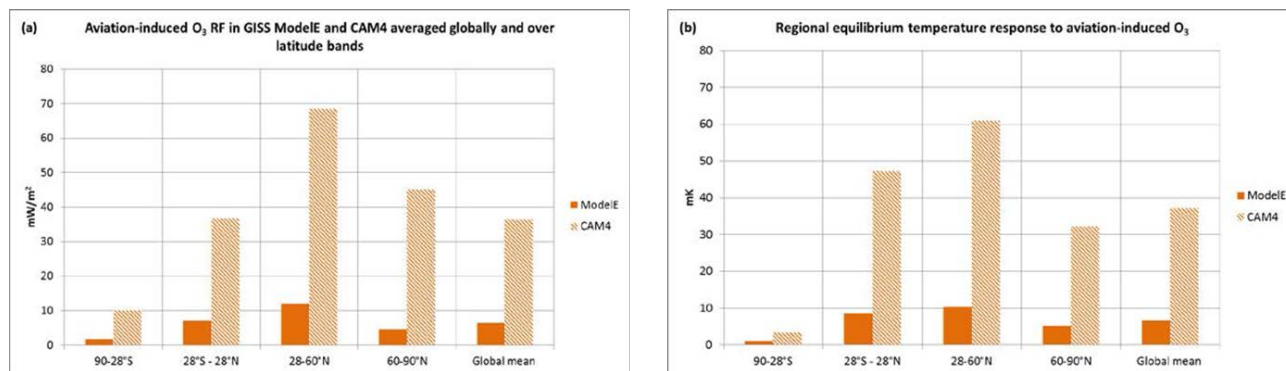


Figure 108: (a) Radiative forcing of aviation-induced O₃ changes from NASA ModelE2 and CAM4 averaged globally and over separate latitude bands (left) and (b) corresponding equilibrium surface temperature responses (right) estimated using the RTP concept

The RTP coefficients were applied to the RF of aviation-induced ozone (O₃) changes to estimate the corresponding regional equilibrium surface temperature response from two computer models. The results are shown in Figure 108 for NASA ModelE2 (darker bars) and CAM4 (lighter bars), with the averaged RF in the left panel and corresponding estimated temperature response in the right panel. In terms of magnitude there is significant difference in O₃ RF between the two models; while NASA ModelE2 gives a global mean RF of 6.4 mW/m², the RF of O₃ is 36.5 mW/m² in CAM4. The regional O₃ RF and temperature response deviates significantly from the global mean. The latitudinal distribution of forcing is similar for both models, except for in the Arctic where ModelE2 gives a lower RF than the global average, while the opposite is seen from the CAM4 results. A similar trend is also seen for aerosol forcing.

Research and Development 2015 Highlights for Understanding of the Impacts of Aircraft Emissions in Urban Airshed Area:

One of the FAA Environment and Energy goals is to achieve an absolute reduction of significant air quality related health and welfare impacts attributable to aviation, despite growth in civil operations. While the air quality related health impact of Landing and Take Off (LTO) cycle emissions can extend much farther away from individual airports located in various airsheds, a suitable tool did not exist to quantify such impacts in an airshed region. Therefore, the goal of this project is to develop a tool to estimate the contributions of airports in various airsheds to air pollution and health risk in the continental United States. Specifically, this tool should be able to quantify the distribution of primary and secondary particulate matter and ozone concentrations around airports with a view to develop a metric for significant health impacts that can be used to quantify surface air quality impacts of aviation emissions.

An initial version of such a tool has been developed based on the Community Multiscale Air Quality - Direct Decoupled Method tool (CMAQ DDM). CMAQ DDM calculates tangential sensitivities to parameters at each model time step; therefore the model runtime is decreased. CMAQ-DDM is more extensible and flexible than other rapid methods, and better at identifying the impacts due to small changes in aviation emissions.

Figure 109 below shows contributions to $PM_{2.5}$ due to various precursors from various airports in different airsheds around the US. Each bar represents the total $PM_{2.5}$ formed at the airports' home grid-cell due to each airport's emissions, broken down by the precursor species. The bars are sorted by the magnitude of $PM_{2.5}$ contribution. For example, aviation activities at three airports contribute at least 0.01 ug/m^3 of $PM_{2.5}$, with the dominant precursor species that is contributing the $PM_{2.5}$ being NOx. Figure 110 shows the relative contribution of aviation activities at these airports to the $PM_{2.5}$ concentrations at these air sheds. In other words, it places these emissions in the context of the background emissions concentrations from all other sources. The x-axis provides the contribution to $PM_{2.5}$ from all sources while the y-axis provides the contribution due to aviation. The dotted lines show the percent contributions from aviation at each airport with lines showing 0.01%, 0.1% and 1%. Eleven of the U.S. airports contribute between 0.1% and 1% of the total $PM_{2.5}$ in the airport grid-cell and none contribute more than 1%. It is important to note that other sources contribute over 99% of the ambient concentrations of pollutants in these modeled grid cells. Work continues on these tools to perform additional analyses to compute the relative contribution of aviation emissions to background air quality at airports at varied airsheds around the US.

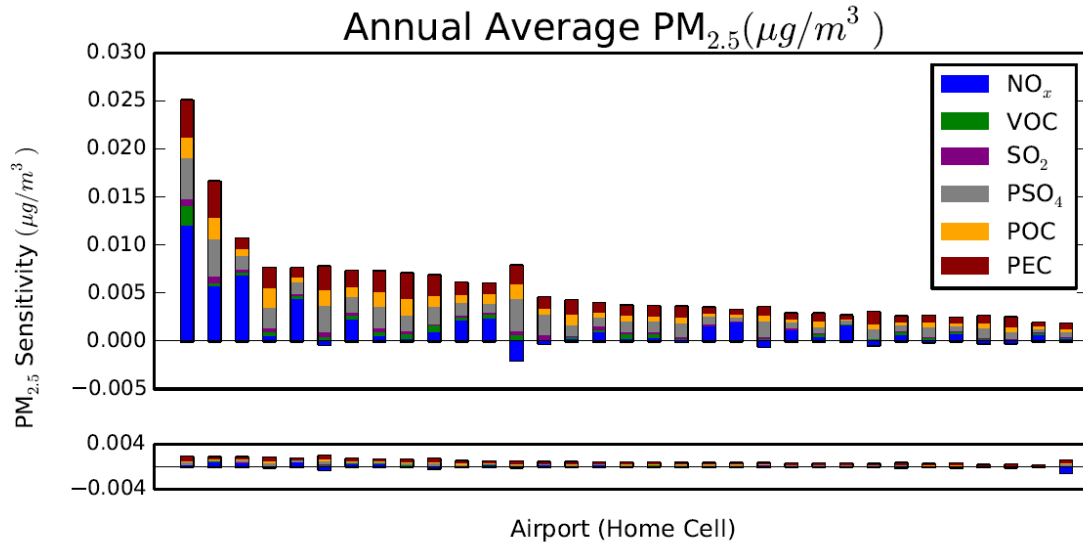


Figure 109: Sensitivities of all $PM_{2.5}$ Species to Each Precursor Species at grid cell containing the respective airport located in an airshed

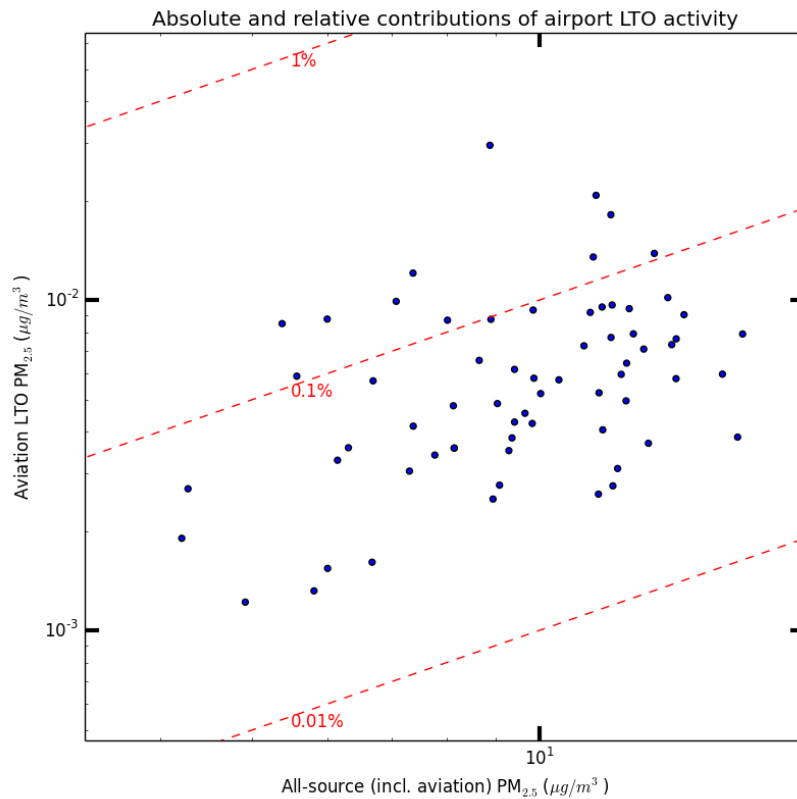


Figure 110: Logarithmic comparison of airport sensitivities to base case (background plus flight) concentrations. Red dashed lines represent proportion of total $PM_{2.5}$ concentration from aviation activity in the grid cell

NextGen – Alternative Fuels for General Aviation Research Conducted

Alternative Fuels for General Aviation:

In 2010, the FAA established a milestone to identify a replacement fuel(s) for leaded aviation gasoline that is usable by most GA aircraft by the end of calendar year 2018. As a result, the FAA established the Unleaded Aviation Gasoline (Avgas) Transition Aviation Rulemaking Committee (UAT ARC) to provide the FAA with recommendations to transition from 100 octane Low Lead avgas (100LL) to an unleaded Avgas. In accordance with the requirements of the FAA Modernization and Reform Act of 2012, Section 910, Aviation Fuel Research and Development Program (R&D), the Avgas and UAT ARC final report provides the FAA with success in their efforts to qualify an unleaded aviation fuel and to safely transition the fleet of piston engine aircraft to that fuel. It includes information on research and development activities, information obtained in collaboration with industry stakeholders, and policies and guidelines developed by the FAA to implement the transition.

Historically, the commercial aviation industry has relied on a very limited number of well proven, conventional fuels for certification and operation of aircraft and engines. The vast majority of today's engines and aircraft were designed and certified to operate on one of two basic fuels, such as kerosene-based fuel for turbine powered aircraft and leaded Avgas for spark ignition reciprocating engine powered aircraft. These fuels are produced and handled as bulk commodities, with multiple producers sending fuel through the distribution system to airports and aircraft. They are defined and controlled by industry consensus-based fuel specifications, ASTM International D1655 for jet fuel and ASTM D910 for aviation gasoline. These specifications, along with the oversight of the ASTM International aviation fuel industry committee, accommodate the need to move the fuel as a commodity.

The evaluation and qualification process for a new fuel specification intended for existing aircraft and engines designed to operate on 100LL is complex. The process to evaluate new aviation gasoline is progressive and iterative in nature, with the extent of continued testing determined by the fuel properties, characteristics, and test results revealed at each successive stage. The extent of testing necessary grows with increasing degree of divergence from the composition, properties, performance, and experience with existing 100LL. The FAA regulations pertaining to aircraft, engines, and aviation fuel were structured to complement the industry development and oversight concept. They require that type certificate applicants identify the fuel specifications used in their products during certification. Once compliance with the airworthiness certification regulations has been demonstrated, the fuel grade designation or specification becomes part of the airplane, rotorcraft, and engine operating limitations. These operating limitations are specified in the Type Certificate Data Sheet (TCDS) and in the Airplane Flight Manual (AFM), Rotorcraft Flight Manual (RFM), and Engine Operating Instruction (EOI). Aircraft operators are required by 14 CFR § 91.9 to only use fuels and oils listed in the Airplane Flight Manual or RFM. These fuels must be identified with sufficient specificity to ensure that the engine and aircraft continue to meet their airworthiness certification basis during service.

The UAT ARC was chartered by the FAA Administrator in January 31, 2011. The UAT ARC was tasked to investigate, prioritize, and summarize current issues relating to the transition to an unleaded avgas and to recommend the tasks necessary to investigate and resolve these issues. It was also tasked to provide recommendations for collaborative industry-government initiatives to facilitate the development and deployment of an unleaded avgas with the least impact on the existing piston-engine aircraft fleet. The UAT ARC was comprised of key stakeholders from the GA community, including aviation trade/membership associations, aircraft and engine manufacturers, petroleum and other fuel producers, the EPA, and FAA. The UAT ARC completed its final report on February 17, 2012. The report contains the following five key recommendations (and 14 additional recommendations) to facilitate the transition to a fleet-wide replacement Avgas:

1. Implementation of the Fuel Development Roadmap – Avgas Readiness Levels (ARL) developed by the UAT ARC that identifies the key milestones in the aviation gasoline development process and the information needed to support assessment of the viability of candidate fuels in terms of impact upon the existing fleet, production and distribution infrastructure, environment and toxicology, and economic considerations.
2. Centralized testing of candidate unleaded fuels at the FAA WJHTC funded by government and industry in-kind contributions. Centralized assessment and testing would generate standardized qualification and certification data that can be used by the fuel developer/sponsor to support both ASTM specification development and FAA fleet-wide certification eliminating the need for redundant testing.
3. Establishment of a solicitation and selection process for candidate unleaded avgas for the centralized fuel-testing program. This process should include a FAA review board with the technical expertise necessary to evaluate the feasibility of candidate fuels.
4. Establishment of a centralized certification office with sufficient resources to support unleaded aviation gasoline projects.
5. Establishment of a collaborative industry-government initiative referred to as the Piston Aviation Fuels Initiative (PAFI) to implement the UAT ARC recommendations in this report to facilitate the development and deployment of an unleaded avgas with the least impact on the existing piston-engine aircraft fleet. The overall objective of this initiative is to identify candidate unleaded aviation gasolines, to provide for the generation of qualification and certification data on those fuels, and to support fleet-wide certification of the most promising fuels.

The research effort at the FAA WJHTC Propulsion and Airpower Engineering Research (POWER) facility directly supports recommendation number two above. The candidate fuels to be evaluated will be decided by recommendations one and three above, and research efforts will be coordinated in agreement with recommendations four and five above.

The FAA WJHTC is to develop standardized test procedures for laboratory, rig, engine and aircraft testing and perform standardized testing on candidate unleaded fuels. The data from that

standardized testing will be used by the fuel offer, or to obtain an ASTM fuel specification and FAA transparent fleet engine and aircraft certification. This standardized testing will be facilitated, promoted, and guided by the PAFI PSG. A PAFI Technical Advisory Committee (TAC) comprised on specific industry representatives to provide technical input and in-kind contributions has been formed.

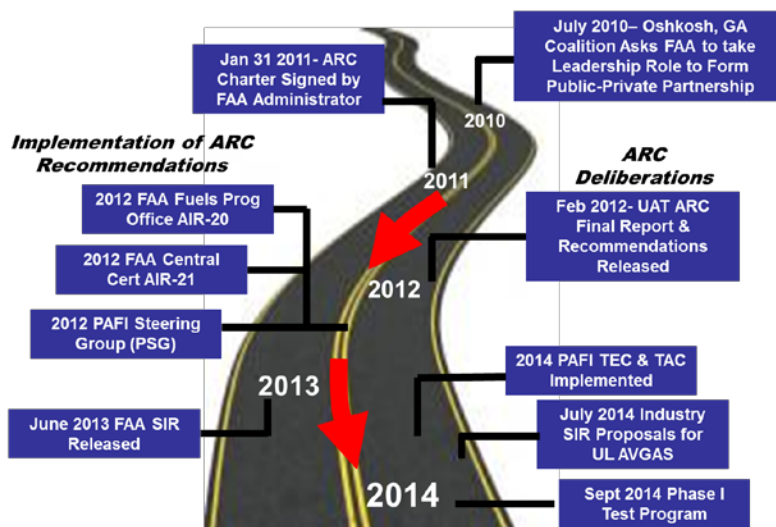


Figure 111: The Path to an Unleaded Aviation Gasoline

This research program is divided into two phases with each phase containing a preparatory stage and a project stage. The first phase of testing involves investigating the laboratory and FFP properties of novel fuels that are selected for entry into the process by an FAA review board. At the end of the first phase of testing, the FAA Technical Evaluation Committee (TEC) will down select the best fuels for entrance into Phase 2 testing for full-scale engine and aircraft testing. In the preparatory stage of Phase 1, the laboratory and FFP property standardized test procedures were developed for the specific novel fuels. In the project stage for Phase 1 the use of those standardized laboratory and FFP property procedures are being used to produce standardized data that will be provided to the fuel applicant. In the preparatory stage of Phase 2 the engine and aircraft standardized test procedures will be developed for the specific novel fuels. In the project stage for Phase 2 the use of those standardized engine and aircraft test procedures will be used to produce standardized data. The data from both Phase 1 and Phase 2 testing will be used by an applicant to obtain an ASTM production fuel specification and obtain FAA fleet certification.

This program provides research products that directly support the PAFI (UAT ARC recommendation number five) by developing the following products:

- Standardized laboratory testing methodologies for novel fuels;
- Laboratory data on novel fuels to be used for ASTM fuel specification development and FAA certification approval;
- Standardized rig testing methodologies for novel fuels;

- Rig data on novel fuels to be used for ASTM fuel specification development and FAA certification approval;
- Standardized engine testing methodologies for novel fuels;
- Engine data on novel fuels to be used for ASTM fuel specification development and FAA certification approval;
- Standardized flight testing methodologies for novel fuels, and
- Flight data on novel fuels to be used for ASTM fuel specification development and FAA certification approval.

Removal of the additive Tetra-Ethyl-Lead (TEL) from 100LL aviation gasoline results in a fuel with significantly reduced octane. The high level of anti-knock performance provided by 100LL is required by high performance aircraft and engines to suppress damaging detonation in the engine, and was the basis for the certification of the majority of the fleet. Attempts to replace the significant octane provided by TEL, requires use of significant quantities, often the majority of the volume of a gallon of fuel, of novel chemicals. While octane is of primary importance for safety, aviation fuel specifications also cover many other important fuel properties such as:

- Combustion
- Fluidity
- Volatility
- Corrosion
- Contaminants
- Additives
- Stability

Use of large quantities of novel chemicals to obtain the same anti-knock capability as 100LL, results in an unleaded fuel that will not meet many of these other critical fuel specification properties for which the legacy fleet was certificated. The current aviation gasoline fuel specification for 100LL specifies laboratory and Fit-For-Purpose (FFP) test methods to address the above fuel specification categories and FAA regulations contain testing requirements to certificate aircraft and engines on fuels similar to 100LL. FFP properties are those properties that are not necessarily captured by a standardized laboratory test limitation but which are critical to the fuel being fit for the intended purpose. By way of example, a novel fuel that satisfies the freeze point specification limitation for traditional fuels but that exhibits cold fuel flow ability issues. Cold fuel flow ability could be a FFP property for that novel fuel.

This research will address re-certification of legacy hardware with use of novel fuels, for which many current ASTM laboratory and FFP tests are not applicable or do not exist, and for which FAA regulations are not adequate.

Lead removal in Avgas is prompted by increased environmental regulations and litigation. The UAT ARC deemed that investigation into potential emissions issues from use of novel chemicals is needed to ensure that use of large volumes of novel chemicals do not present greater environmental impact. Research will establish the capability to measure bulk exhaust gas

emissions from aircraft engines. Investigation of the impact of use of aviation gasoline without lead on engines and aircraft will also be conducted. A high quality aviation alkylate, which is the base of 100LL fuel currently in production, is considered a fallback option to meet the Administrator's goal for 2018, in the event that a satisfactory high-octane unleaded fuel does not prove out. Use of a mid-octane, unleaded aviation alkylate reduces fuel complexity issues to that of octane alone, as the fuel specification, FFP, production and distribution issues would not change appreciably from those of the currently used 100LL.

Research involves the FAA WJHTC engine and aircraft testing. Engine tests are performed by in-house contractors at the FAA POWER lab. In-flight testing will be performed by FAA WJHTC contractors and will use the FAA WJHTC flight test group aircraft currently in use. The standardized FFP test methods and procedures to be developed will consist of current fuel specification laboratory test methods, and newly developed specific fuel-related laboratory tests, material compatibility, toxicology, and rig tests. Identification of material compatibility test methods, ecological risk test methods, and legacy aircraft fleet makeup and materials, requires the services of respective SMEs. The SMEs will be part of a follow-on labor support contract that will match the expanded scope of this work.

Laboratory Fit-for-Purpose Test Methods for Anticipated Replacement Fuels (Phase 1 – Stage 1):

ASTM test methods for use with leaded fuels meeting fuel specification ASTM D910 are not necessarily applicable to potential replacement fuels. Many proposed replacement fuels are considerably different in composition than the current experience of the fleet and the lab methods do not address or are not applicable to fuels of significantly different chemistry. This research involved a cooperative effort between the PAFI TAC and the FAA to identify applicable lab test methods for the candidate alternative fuels.

Identify Rig Test Procedures for Anticipated Replacement Fuels (Phase 1 – Stage 1):

Many anticipated replacement fuels will generate additional fit-for-purpose issues for which standardized rig test methods do not currently exist and may need to be developed. The legacy fleet contract SME, with expert knowledge in the makeup of the piston engine fleet fuel systems, will identify additional fuel fit-for-purpose issues and the necessary rig tests to address these issues.

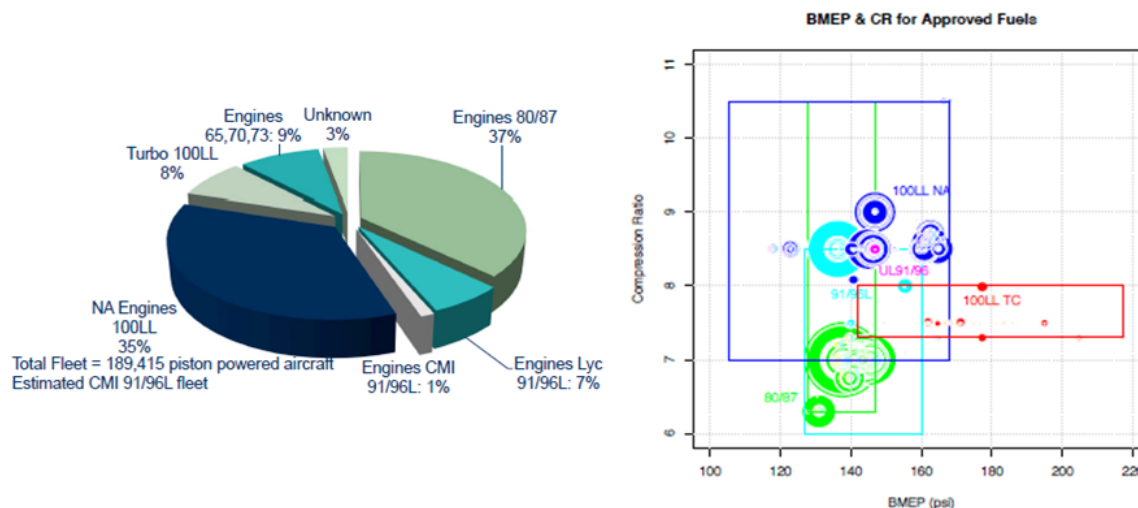


Figure 112: FAA GA Piston Fleet Assessment

Evaluate Material Compatibility Test Procedures (Phase 1 – Stage 1):

Anticipated fuel chemistries, which differ considerably from the experience of the existing GA fleet, will pose new and additional material compatibility issues, particularly with the legacy aircraft. This milestone requires a fuel chemistry subject matter expert to identify a legacy engine and aircraft fleet materials lists and identify standardized material compatibility lab test methods to address the materials compatibility with the candidate fuels. The SME will technically document these lab methods and develop engine and aircraft materials lists, assist in the drafting of a solicitation of an independent material testing lab to evaluate the fuel impact on legacy aircraft materials.

Evaluate Fuel Toxicological Test Procedures (Phase 1 – Stage 1):

Potential new fuel chemistries may pose additional toxicological risks that could result in future environmental regulatory action. Because of the significant scope of this problem it is desired to prevent approvals of fuel that are significantly worse than the currently available leaded fuels. This requires a fuel environmental toxicology risk subject matter expert to perform extensive literature searches on the PAFI fuel compositions, and identify risks, as compared to the current constituents in 100LL aviation gasoline. The SME will also identify standardized lab test methods to potentially address the ecological risk of candidate fuels, if so needed. The SME will document the ecological risk methods used and draft a solicitation of an independent fuel toxicological testing lab to potentially be used to evaluate the candidate fuel risk on the environment.

In response to the UAT ARC final recommendation to number three, above, the FAA Technical Center released a fuel solicitation to fuel producers to encourage the submittal of unleaded fuel candidates for testing at the FAA WJHTC in the PAFI process. This solicitation closed on July 1, 2014 and a TEC was formed to review the proposed submitted fuels. In response to the FAA WJHTC solicitation DTFAC-13-R-00015, six offerors submitted 17 different fuel formulations for consideration. Of the 17 fuels submitted, four fuels were selected by an FAA TEC into the

PAFI testing program. Each successful fuel offer submitted 390 gallons for testing in Phase 1 fit-for-purpose testing (see figure 113 below). Worse case formulations for specifically identified tests were requested and delivered to the FAA WJHTC for testing.

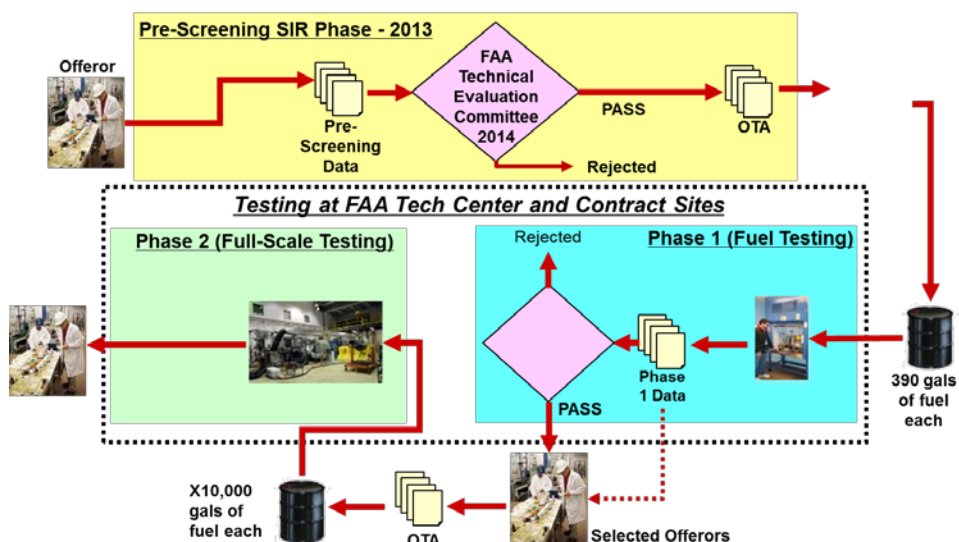


Figure 113: The Successful PAFI Fuel Offerors and the PAFI Testing Process

Dixie Services was contracted by the FAA WHJTC to support Phase 1 Testing for laboratory services and baseline fuel blending. An example is provided in figure 114 below.

EXAMPLE ONLY	Formulation #	Overall Fuel Quantity (gals.)	GCxGC MS Fuel Quantity (ml)	FAA TC Lab Testing Fuel Quantity (gals)	SWRI Emissions Testing (gals)	Dixie Services Lab Testing Fuel Quantity (gals)	Purdue Rig Testing Fuel Quantity (gals)	Purdue Material Comp Lab Fuel Quantity (gals)
Detonation/ Emissions	X ₁	50	10 ml	35	10	5		
Materials Compatibility	X ₂	130						130
Rig No. 1 Low Temp Fuel Flow Ability	X ₃	35	10 ml	5		5	25	
Rig No. 2 Carburetor Icing	X ₄	30		10			20	
Rig No. 3 Dynamic Fuel System	X ₅	100					100	
Rig No. 4 Storage Stability	X ₆	30					30	
Rig No. 5 Cold Storage	X ₇	5					5	
Rig No. 6 Hot Surface Ignition	X ₈	10	10 ml			5	5	
Overall Fuel Quantity		390						

Figure 114: Sample Fuel Submittal for Each Offeror Selected for Phase 1 Testing

Phase I laboratory, rig, and preliminary engine testing currently underway, encompasses the following testing:

- Chemical makeup: Gas Chromatography Mass Spectroscopy (GC MS), GCxGC MS (2 dimensional GC MS)

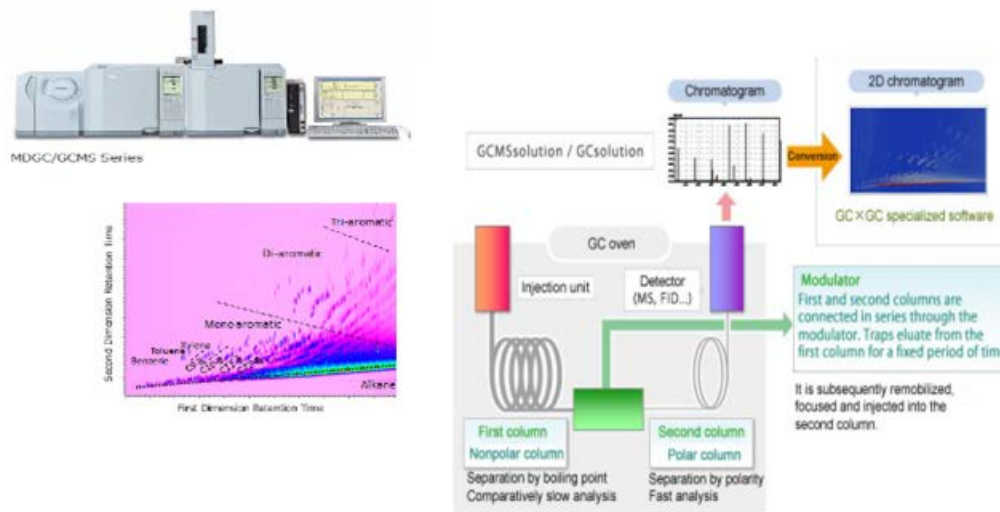


Figure 115: Gas Chromatography Mass Spectroscopy (GC MS), GCxGC MS (2 dimensional GC MS)

- Fuel system rigs: low temperature flow ability, carburetor icing, dynamic fuel system, storage stability (ambient and hot), cold storage, hot surface ignition, as shown in figure 116, below.



Figure 116: Low Temperature Flow Ability Rig

- Engine out emissions: particulate and bulk gas, as shown in figure 117 below.



Figure 117: Engine Emissions Console

- Fuel anti-knock performance in a full-scale engine: determine ability of fuel to resist detonation, as shown in figure 118 below.

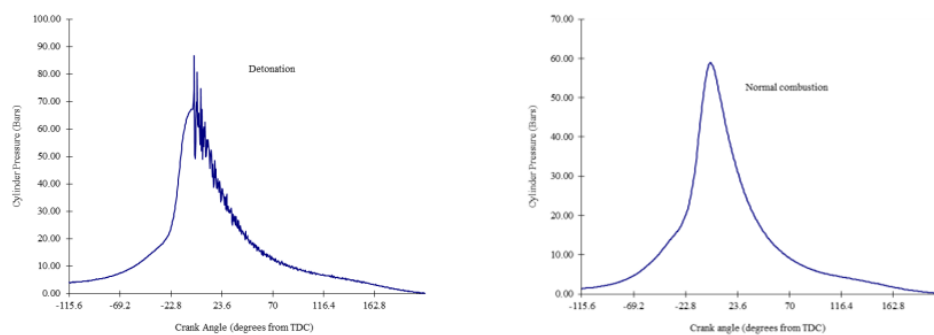


Figure 118: Combustion Cycles Showing Detonation and Normal Combustion

- Fuel performance in a full-scale engine: determine performance of fuel due to higher mass density and reduced energy content;
- Engine start ability: evaluate ability to start engine after soaking in cool engine;
- Materials compatibility: evaluate typical wetted fuel system components with proposed fuels (non-metals, metals, fabrics, composites, bladders, distribution system materials), shown in figure 119 below.

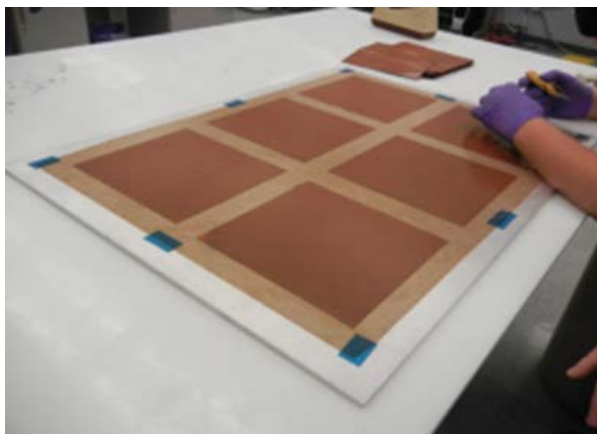


Figure 119: Example of a Materials Testing Frame

- Toxicological risk assessment: identification of the issues in the available literature and references for each of the major fuel components that differ from the community experience with 100LL, along with the experience regarding the use of components in additional modal transportation fuels.
- Laboratory fuel properties testing – measure performance properties of proposed fuels (e.g. freeze point, vapor pressure, octane, heat content, water reaction, distillation, etc.), shown in figure 120 below.

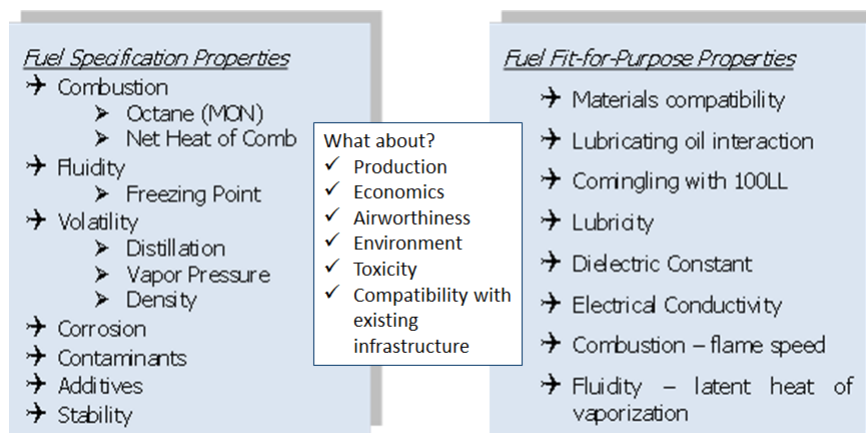


Figure 120: Laboratory Fuel Properties Testing

Six different baseline 100LL blends were specially made to meet certain specification criteria, to be used for comparative testing in each of the areas listed below in figure 121.

Method	Specification	100LL Baseline Fuels						D910 Table 1 spec limits min 99.6 MON, min 100 Aviation Lean Rating
		Formula 1 - Detonation	Formula 2 - Emissions	Formula 3 - Materials Compatibility, Rig 1 Low Temp Flow, Rig 3 Dynamic Rig, Rig 5 Cold Storage Rig	Formula 4 - Rig 2 Carburetor Icing	Formula 5 - Rig 4 Storage Stability	Formula 6 -Rig 6 Hot Surface Ignition	
ASTM D2700	Motor O.N. (BRE/30.3in/300°F)	100.6	100.4	102.0	102.7	101.6	103.4	
ASTM D909	ASTM Supercharge rating, mL TEL/gal	1.33	1.29	1.49	1.59	1.33	1.40	
	Performance number	130.7	130.1	132.7	133.9	130.7	131.6	> 130.0
ASTM D2699	Research O.N. (BRE/30.3in/130°F)	101.8	104.2	108.2	108.4	109.1	109.3	
ASTM D5059(A)	Lead, g Pb/L	0.47	0.23	0.46	0.51	0.46	0.56	max 0.53 mL TEL/L and max 0.56 g Pb/L fuel
ASTM D4052	Density at 15°C, kg/m ³	707.9	716.5	714.0	712.8	715.6	714.0	
ASTM D86	Distillation							
	Initial boiling point, °C	37.5	39.8	36.6	37.1	39.2	35.2	Report
	Fuel evaporated							
	10 volume % at °C	70.5	72.6	65.9	63.9	68.9	65.6	Max 75°C
	40 volume % at °C	96.6	97.7	95.9	94.9	96.9	96.0	Min 75°C
	50 volume % at °C	99.2	100.3	99.8	99.5	100.0	99.8	Max 105°C
	90 volume % at °C	109.8	112.1	111.7	111.6	111.6	111.7	Max 135°C
	Final boiling point, °C	145.0	146.0	145.0	144.1	144.4	145.7	Max 170°C
	Sum of 10% + 50% evaporated							
	Temperature, °C	169.7	172.9	165.7	163.4	168.9	165.4	Min 135°C
	Recovery, volume %	98.1	98.3	98.3	98.2	98.5	98.2	Min 97%
	Residue, volume %	1.0	0.8	0.9	0.7	0.8	0.8	Max 1.5%
	Loss, volume %	0.9	0.9	0.8	1.1	0.7	1.0	Max 1.5%
ASTM D5191	Vapor pressure, 38°C, kPa	41.6	40.4	46.2	48.2	43.3	45.9	Min 38.0 D323 or D6190; Max 49.0 D5191
ASTM D2386	Freezing point, °C	< - 70.0	< - 70.0	< - 70.0	< - 70.0	< - 70.0	< - 70.0	Max -58°C
ASTM D4089	Net heat of combustion, MJ/kg	44.124	43.804	43.852	43.896	43.71	43.41	Min 43.5 D4529 or D3338

Figure 121: Specially Manufactured Baseline 100LL Blends for Comparative Testing

As previously described, the testing completed in Phase 1 will be used by the FAA Technical TEC to down select into the Phase 2 full-scale aircraft and engine testing program.



Figure 122: Carburetor Icing Rig Figure

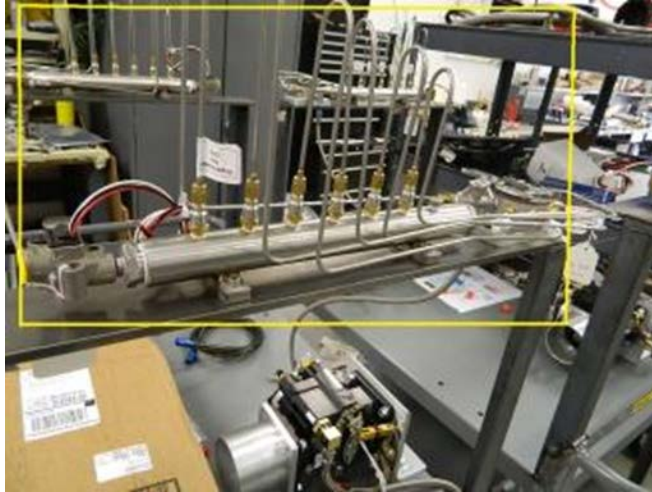


Figure 123: Dynamic Fuel System Rig



Figure 124: Hot Surface Ignition Rig



Figure 125: Piston Aircraft Showing Diversity of Fleet

NextGen Environmental Research – Aircraft Technology, Fuels and Metrics Research Conducted

Aircraft Technology Development under the Continuous Lower Energy, Emissions, and Noise (CLEEN) Program:

In partnership with industry, the Continuous Lower Energy, Emissions, and Noise (CLEEN) Program completed four major demonstrations in FY 2015, significantly accelerating environmentally beneficial airframe and engine technology development and advancing toward commercialization by the end of this decade.

Under CLEEN, Honeywell has designed, built, and demonstrated engine weight reduction and high temperature impeller technologies. These technologies are applied to the high pressure compressor and turbine and use advanced materials and cooling designs to reduce aircraft fuel burn through improved thermal efficiency and reduced weight. Honeywell's testing of these technologies has culminated in ground core and engine tests in FY15, bringing all technologies to technology readiness level (TRL) 6, indicating a high level of maturity and readiness to enter product development outside of the CLEEN Program. The Honeywell CLEEN technologies provide 5% fuel burn reduction as part of a planned 15.7% fuel burn reduction engine package.



Figure 126: Honeywell's High Temperature Compressor Impeller

Pratt & Whitney's development of advanced fan system technologies under CLEEN for an ultra-high bypass geared turbofan (UHB GTF) made great strides in FY 2015 with the completion of scaled model wind tunnel testing of the CLEEN demonstrator engine. This testing was conducted in conjunction with the NASA Environmentally Responsible Aviation (ERA) project and provided aerodynamic and acoustic data on the performance of the fan system. This testing brings the UHB GTF technology to TRL 5. A final full scale CLEEN demonstrator engine is planned to run in 2016 that will bring it to TRL 6 and readying it for entry into service. The Pratt & Whitney CLEEN technologies expand the design space for future engines, enabling 20% fuel burn reduction and 25 EPNdB cumulative noise margin to the Stage 4 standard.



Figure 127: Pratt & Whitney's Fan Rig Model Installed in the NASA Glenn 9' x 15' Wind Tunnel

In FY15 GE Aviation has completed flight testing of flight management system / engine control technologies on the LEAP engine. These technologies work in the areas of adaptive engine

control, vehicle health management, and integrated flight-propulsion control. These three areas of work are estimated to yield up to 1%, 0.5%, and 1% fuel burn reductions, respectively, when applied to single and twin aisle aircraft. This 2015 flight testing brings these technologies to TRL 7.

The CLEEN Program has previously worked with industry in a number of other technology areas.

In 2012 Boeing completed maturation of a wing adaptive trailing edge with a successful flight test demonstration on a 737-800 aircraft. This technology will provide up to 2% fuel burn reduction and 1.5 EPNdB cumulative noise reductions on single and twin aisle aircraft applications. Boeing also completed the development of a high temperature ceramic matrix composite acoustically treated engine exhaust nozzle. This nozzle reduces weight and expands temperature capability, providing up to 1% fuel burn reduction, while providing equal or better noise reduction compared to a baseline metallic nozzle.

GE has completed two other successful programs under CLEEN. In January 2012, GE completed core engine tests of the twin-annular pre-swirl (TAPS) II low nitrogen oxide (NOx) combustor. Results show landing and take-off NOx emissions were reduced 60 percent compared to the International Civil Aviation Organization (ICAO) NOx standard adopted in 2004, meeting one of the CLEEN goals. This combustor will be used in CFM International's LEAP turbofan engine and is expected to enter service in 2016. In 2012 GE also completed a program involving development and wind tunnel testing of open rotor engine concepts. This testing showed that open rotor engines with modern blade designs have the potential to reduce fuel burn by 26% relative to a CFM International CFM56-7B engine and up to 15 EPNdB cumulative noise margin relative to Stage 4 noise standards.

In addition to these accomplishments, Rolls-Royce is currently working on the development of two technologies which enable hotter and more efficient engine cores. These are the ceramic matrix composite turbine blade track and dual wall turbine airfoil. This combination of advanced material and cooling technologies will provide 1% fuel burn reduction.

Finally, the FAA completed a project under the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence focused on modeling and assessment of the CLEEN airframe and engine technologies. Under this project, The Georgia Institute of Technology employed their Environmental Design Space (EDS) modeling tool in conjunction with proprietary data from the CLEEN companies' development work to model and assess the benefits of CLEEN airframe and engine technologies. The majority of the CLEEN technologies were modeled at the component level and EDS was used to evaluate their impact on engine and aircraft design and performance. Vehicle level performance assessments involving these proprietary models are not public; however, fleet level benefits of the modeled CLEEN technologies will be documented in the forthcoming PARTNER project final report. In addition to CLEEN technologies, the PARTNER study also examined other near term aircraft and engine technologies that are being developed by industry. The results of this effort have been incorporated within the US Government's Aviation Greenhouse Gas Emissions Reduction Plan. The work to assess aircraft and engine technologies, including those from the CLEEN Program,

is continuing under ASCENT in a new aircraft technology modeling and assessment project. The work undertaken by these projects provides a complementary independent look at CLEEN technologies' benefits. As each company's efforts under CLEEN wrap up, they are completing their own final benefits assessments that will be made available in project and program public final reports.

Following the success of the CLEEN Program, initiated in 2010, the FAA is awarding eight agreements for further development of new aircraft technologies and alternative jet fuels that reduce aviation's environmental impact. The CLEEN II solicitation was released on September 29, 2014 and closed on February 2, 2015. Following an evaluation and selection period, final contract negotiations are underway. The CLEEN II Program, planned to run from 2015 through 2020, will help these companies accelerate their technologies through a crucial phase in their maturation, culminating in full scale ground and flight test demonstrations and showing readiness for product implementation. At the conclusion of the development effort for a CLEEN II technology, each company, having cost shared the development with FAA, is invested in the technology's success and it is confident the product can enter into service. Once entered into service, the CLEEN II technologies will realize their fuel burn, emissions, and noise benefits throughout the fleet for years to come.

The CLEEN II Program goals include reducing fuel burn by 40 percent relative to year 2000 best-in-class-in service aircraft, reducing landing and takeoff nitrogen oxide emissions by 70 percent over the 2011 International Civil Aviation Organization standard without increasing other emissions, reducing noise levels by 32 dB relative to the FAA Stage 4 noise standard; and facilitating commercialization of "drop-in" alternative jet fuels through support for the fuel approval process.

Sustainable Alternative Jet Fuel Development:

Commercial aviation faces a number of challenges, including - fuel cost volatility, environmental impacts, and energy security. Sustainable alternative jet fuels can help address these challenges. Testing campaigns under CLEEN and ASCENT Center of Excellence are providing necessary data for the approval of new fuels by industry standards organization, ASTM International. In addition, analyses under ASCENT and the Volpe Center will help us identify and overcome barriers to the wide spread use of these fuels.

Under the CLEEN Program, Rolls-Royce has completed a series of laboratory, rig, and auxiliary power unit tests on a range of candidate fuels and blends representing a range of novel raw materials, processes, blend stocks, and final products. This testing was conducted in such a way as to first study the fundamental properties of the novel fuels, down select promising candidate fuels, conduct rig testing, and then run the fuels in an auxiliary power unit, a representative use case for gas turbine engines. Testing included combustor operability, focusing on the ability of these fuels to ignite under adverse conditions, emissions testing, and compatibility with fuel system elastomeric components. Many of the fuels examined show significant promise and potential benefits. While some key differences in properties and performance were identified that warrant further investigation, each of the four fuels downselected for rig testing offers the potential to be drop-in fuels and hence achieve approval for use for the aviation industry. The

testing performed by Honeywell under the CLEEN program represents critical operating conditions for aircraft propulsion systems and will provide essential data to evaluate performance of novel fuels. Honeywell will also complete cold altitude APU relight and APU combustor rig testing using multiple alternative jet fuels. In addition, under CLEEN program, FAA is working with engine manufactured to support research report review of the current approval process.



Figure 128: View Inside a Rolls-Royce Combustor that is used to Conduct Operability Testing on Candidate Fuels

Several projects were also initiated under the ASCENT that will provide test data to aid the existing alternative jet fuel certification and qualification process. In particular, FAA is teaming up with University of Dayton Research Institute to perform laboratory fuel property specification and fit for purpose testing of new alternative fuels. Most recently fuel testing of an Alcohol to Jet fuel from waste industrial gases was conducted. With direct support and participation from several federal agencies and engine manufacturers, the FAA has initiated a new ASCENT program called National Jet Fuels Combustion Program (NJFCP) to streamline the ASTM International fuel approval process using generic fuel combustion testing and modeling approach. Application of NJFCP capabilities, once fully developed and credibly assessed, will help reduce the amount of fuels and time needed to secure the approval of ASTM International for their quicker commercial deployment.

The Aviation Sustainability Center of Excellence (ASCENT) and the Volpe Transportation Center have started a multi-year effort to work together to identify the barriers to alternative jet fuel production that must be overcome to enable a billion gallons of alternative jet fuel production in the near term and an order of magnitude larger production in the longer term. The team is conducting a holistic evaluation of alternative jet fuel production considering the full range of pathways being considered by the aviation industry. The team is considering sustainability from environmental, economic and societal perspectives. The results from the

team's work are supporting domestic efforts in Farm-to-Fly 2.0, the Commercial Aviation Alternative Fuels Initiative (CAAIFI) as well as international efforts within the International Civil Aviation Organization (ICAO Committee on Aviation Environmental Protection (CAEP)).

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Acronym List

Acronym	Definition
0-9	
2D	Two-Dimensional
3D	Three-Dimensional
3D PAM	Three-Dimensional Path Arrival Management
4D	Four-Dimensional
A	
AA-IADS	Aerospace Accident – Injury and Autopsy Data System
AAM	Office of Aerospace Medicine
ABST	Airframe Beam Structure Test
AC	Advisory Circular
ACAC	Airport Construction Advisory Council
ACER	Airliner Cabin Environmental Research
ACERite	Airliner Cabin Environmental Research (ACER) Research in the Intermodal Transport Environment
ACO	Aircraft Certification Office
ADDS	Aviation Digital Data Service
ADS-B	Automatic Dependent Surveillance – Broadcast
ADW	Arrival-Departure Window
AEDT	Aviation Environmental Design Tool
AFDC	American Flutter and Dynamics Council
AFS	Active Flutter Suppression
AJG-R4	FAA Office of Technical Requirements and Forecasting Group
Al-Li	Aluminum Lithium
AM	Additive Manufacturing
AOA	Angle of Attack
AOV	Safety Oversight Service
ARTCC	Air Route Traffic Control Center
APU	Auxiliary Power Unit
AR	Annual Review
ARL	Avgas Readiness Levels
ARAC	Aviation Rulemaking Advisory Committee
ASCENT	Aviation Sustainability Center of Excellence
ASDE-X	Airport Surface Detection Equipment – Model X
ASIAS	Aviation Safety Information Analysis and Sharing
ASTM	American Society for Testing and Materials

ATC	Air Traffic Control
ATCS	Airport Air Traffic Control Specialists
ATCSCC	ATC System Command Center
ATCT	Airport Traffic Control Tower
ATL	Hartsfield-Jackson Atlanta International Airport
ATM	Air Traffic Management
ATO	Air Traffic Organization
ATRP	Airport Technology Research Program
ATSAP	Air Traffic Safety Action Program
Avgas	Aviation Gas
AWC	Aviation Weather Center
C	
CAASD	Center for Advanced Aviation System Development
CACRC	Commercial Aircraft Composite Repair Committee
CAEP	Committee on Aviation Environmental Protection
CAMI	Civil Aerospace Medical Institute
CAT	Clean Air Turbulence
CDTI	Cockpit Display of Traffic Information
CEAT	Center of Excellence for Airport Technology
CFR	Code of Federal Regulations
CIP	Current Icing Product
CHI	Computer Human Interface
CLEEN	Continuous Lower Energy, Emissions, and Noise
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
COE	Center of Excellence
CONUS	Continental United States
COS	Continued Operational Safety
CSET	Composite Structural Engineering Training
CSCC	Control System Command Center
CSPA	Closely-Spaced Parallel Approach
CVM	Comparative Vacuum Monitoring
CWSU	Center Weather Service Unit
D	
DAA	Detect and Avoid
Data Comm	Data Communications
DSS	Decision Support System
DRNP	Dynamic Required Navigation Performance

E	
ECG	Electrocardiogram
ECS	Environmental Control Systems
EDMS	Emissions and Dispersion Modeling System
EDS	Environmental Design Space
EMS	Environmental Management System
EOBT	Earliest Off Block Time
EDR	Eddy Dissipation Rate
EMST	Emerging Metallic Structural Technology
EPA	U.S. Environmental Protection Agency
ERAM	En Route Automation Modernization
F	
FAA	Federal Aviation Administration
FAA-TC	Federal Aviation Administration Technical Center
FAD	Functional Architecture Document
FASTER	Full-Scale Aircraft Structural Test, Evaluation and Research
FCG	Fatigue Crack Growth
FCM	Flow Contingency Management
FDM	Flight Data Monitoring
FDR	Flight Data Recorders
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
FIM	Flight Deck Interval Management System
FIP	Forecast Icing Product
FOD	Foreign Object Debris
FMS	Flight Management System
FMS	Flight Management System
FTIR	Fourier-Transform Infrared Spectroscopy
FY	Fiscal Year
G	
GA	General Aviation
GE	General Electric
GIM	Ground Interval Management
GIM-S	Ground Based Interval Management Spacing
GLARE	Glass Reinforced Aluminum Laminate
GSE	Ground Service Equipment
GSG	Government Steering Group
GTG	Graphical Turbulence Guidance

H	
HEMS	Helicopter Emergency Medical Services
HiRes	High Resolution
HITL	Human In The Loop
HIWC	High Ice Water Content
HPC	High Performance Computing
HPS	Heated Pavement Systems
HVS-A	Heavy Vehicle Simulator – Airfields
I	
ICAO	International Civil Aviation Organization
IDA	Integrated Domain Assessment
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
INM	Integrated Noise Model
IPA	Icing Product Alaska
IPQA	In-Process Quality Assurance
ISG	Industry Steering Group
J	
JAMS	Joint Advanced Materials and Structures
JSC	Johnson Space Center
L	
LCCA	Life Cycle Cost Analysis
LCSA	Low Cost Surface Awareness
LOSA	Line Operations Safety Assessment
LRC	Lighting Research Center
LSTC	Livermore Software Technology Corporation
LTO	Lighting Take-Off
LV/RV	Launch Vehicle/Reentry Vehicle
M	
MCC	Micro Scale Combustion Calorimeter
MMPDS	Metallic Materials Properties Development and Standardization
MRO	Maintenance Repair Organization
MRP	Meter Reference Point

MPSHRe	Minimum Performance Standards for Halon 1301 Replacement
MSAD	Monitor Safety/Analyze Data
MVFR	Marginal Visual Flight Rules
N	
NAPMRC	National Airport Pavement and Material Research Center
NARP	National Aviation Research Plan
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCAMP	National Center for Advanced Materials Performance
NCAR	National Center for Atmospheric Research
ND-TARAM	Not be Detected – Transport Airplane Risk Assessment Methodology
NDI	Nondestructive Inspections
NDIR	Non-Dispersive Infrared
NDS	NOTAM Distribution System
NEMS	NAS Enterprise Messaging Services
NEPA	National Environmental Policy Act
NEST	National Employee Services Team
NextGen	Next Generation Air Transportation System
NFS	Nacelle Fire Simulator
NGAFID	National General Aviation Flight Data Information
NIOSH	National Institute for Occupational Safety and Health
NIAR	National Institute for Aviation Research
NMT	New Mexico Institute of Technology
NOAA	National Oceanic and Atmospheric Administration
NOD	NAS Operations Dashboard
NOM	National Operations Managers

NOTAM	Notices to Airmen
NOx	Nitrogen Oxide
NTSB	National Transportation Safety Board
O	
O&M	Operations and Maintenance
O ₃	Ozone
OEE	Office of Environment and Energy
OEM	Original Equipment Manufacturer
ORA	Operations Research Analyst
P	
PAFI	Piston Aviation Fuels Initiative
PED	Portable Electronic Device
PEGASAS	Partnership to Enhance General Aviation Safety, Accessibility and Sustainability
PFS	Partnership for Safety
POD	Probability of Detection
POWER	Propulsion and Airpower Engineering Research
R	
R&D	Research and Development
RAP	Rapid Update
RATfac	Research Altitude Test Facility
RBDM	Risk-Based Decision Making
RD	Rapid Decompression
RF	Radio Frequency
RFM	Rotorcraft Flight Manual
RTA	Require Time of Arrival
RTP	Regional Temperature Potential

S	
SAA	Sense and Avoid
SAE	Society of Automotive Engineers
SEM	Scanning Electron Microscope
SIF	Stress Intensity Factor
SME	Subject Matter Expert
SMMA	Structured Methyl Methacrylate
SMS	Safety Management System
SPP	Succession Planning Program
SRM	Safety Risk Management
SRMD	Safety Risk Management Document
STH	Static Time Horizon
SVT	SWIM Visualization Tool
SWIM	System Wide Information Management
SwRI	Southwest Research Institute
T	
TAD	Transport Airplane Directorate
TBFM	Time-Based Flow Management
TCAS	Traffic Collision Avoidance System
TCP	Tricresyl Phosphate
TEC	Technical Evaluation Committee
TEL	Tetra-Ethyl-Lead
TORA	Takeoff Run Available
TPFC	Transient Power Fuel Control
TRACON	Terminal Radar Approach Control
TRP	Technical Review Panel

TFMS	Traffic Flow Management System
TQL	Target Queue Length
U	
UAS	Unmanned Aircraft Systems
UCSD	University of California San Diego
U.S.	United States
USAF	United States Air Force
V	
VIPR	Vehicle Integrated Propulsion Research
VFP	Vertical Flame Propagation
W	
WET	Whole Effluence Toxicity
WHI	Women's Health Initiative
WJHTC	William J. Hughes Technical Center
WMA	Warm Mix Asphalt
WTIC	Weather Technology in the Cockpit
WTMD	Wake Turbulence Mitigation for Departures