

FY 2014

R&D Annual Review

August 2015

**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 2014 R&D Annual Review

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The *R&D Annual Review* is a companion document to the *National Aviation Research Plan* (NARP), a report of the Federal Aviation Administration 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 Federal Aviation Administration (FAA) research and development (R&D) mission is to conduct, coordinate, and support domestic and international R&D of aviation-related products and services that will ensure a safe, efficient, and environmentally sound global air transportation system. It supports a range of research activities from materials and aeromedical research to the development of new products, services, and procedures.

The FAA R&D portfolio supports both the day-to-day operations of the National Airspace System (NAS) and the development of the Next Generation Air Transportation System (NextGen). To achieve balance between the near-, mid-, and far-term, the FAA has defined three R&D principles to focus and integrate its programs. The R&D principles help the FAA align, plan, and evaluate its R&D portfolio. The R&D principles include the following:

- **Improve Aviation Safety** – systematically expand and apply knowledge to produce useful materials, devices, systems, or methods that will improve aviation and space 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 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 to a level that does not constrain growth.

The *R&D Annual Review* highlights the significant R&D accomplishments of the FAA and serves as a companion to the FAA *National Aviation Research Plan* (NARP). The significant accomplishments are organized by the three R&D principles described in Chapters 1 through 3 of the NARP.

R&D Principle 1 – Improve Aviation Safety

Systematically expand and apply knowledge to produce useful materials, devices, systems, or methods that will improve aviation space safety and achieve the lowest possible accident rate.

Assessment of Impact Threats to Composite Aircraft Structure:

This research evaluates modeling capability to simulate damage to composite aircraft structures when subjected to soft or “blunt” impact loads. Two types of structures have been the focus of study: 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 has been performed through the FAA’s Joint Advanced Materials and Structures Center of Excellence at member school, University of California San Diego (UCSD). Severe GSE contact is the major source of significant damage to existing (metal) commercial aircraft and therefore a major damage source for composite aircraft. This year’s effort was to evaluate the capability to predict a large 5-frame panel blunt impact and compare to experiments conducted at UCSD. These full panel simulation results, shown in Figure 1, involve first developing accurate smaller-scale modeling capability to account for shear ties crushing (significant energy absorption), and also assessing whether skin cracking occurs at the skin-

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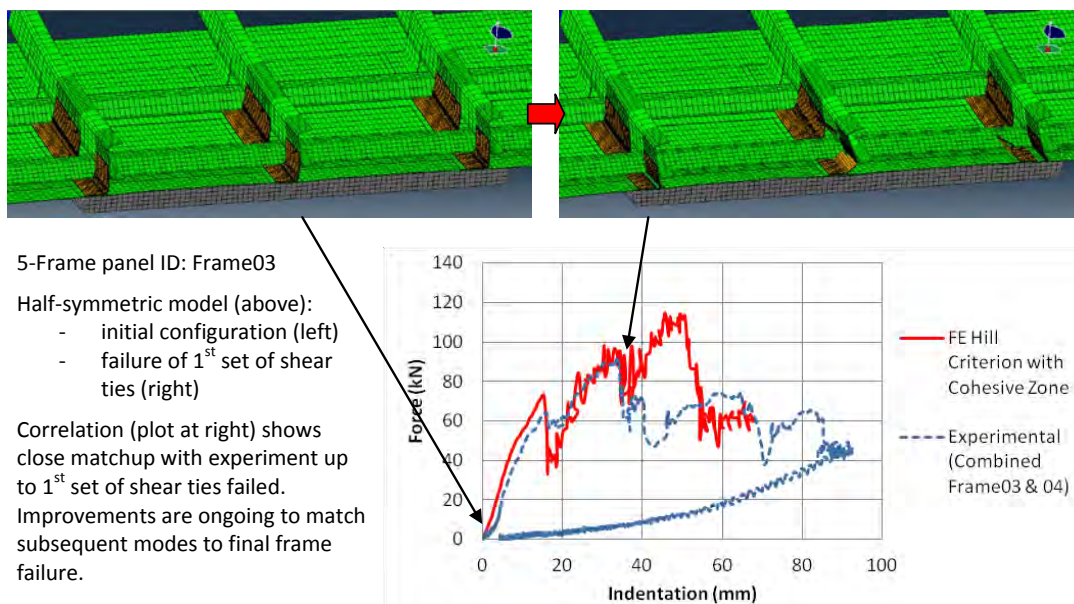


Figure 1: Simulation Validation of GSE Impact Loading on 5-Frame

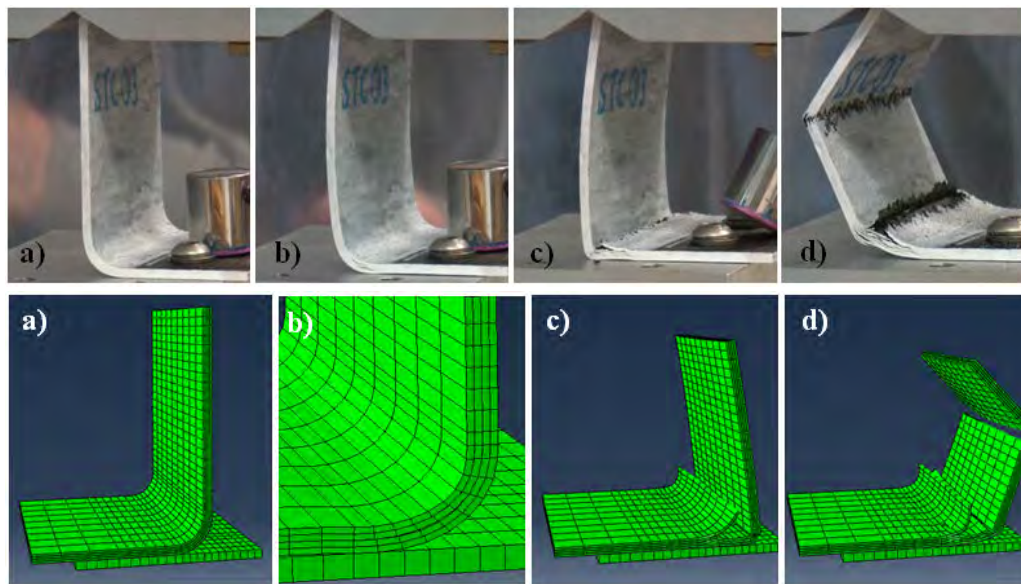


Figure 2: Shear Tie Crushing Model Validation

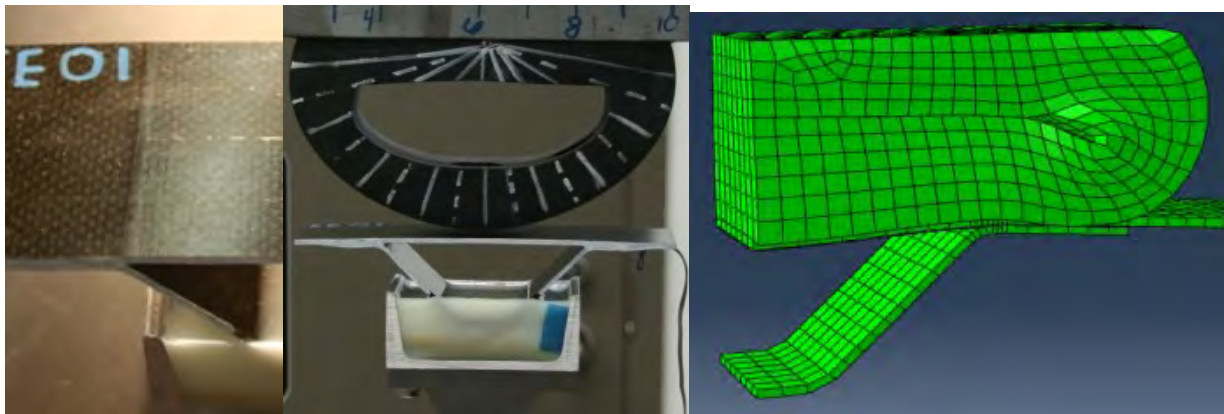


Figure 3: Skin Cracking Model Validation

Each of these small-scale modeling developments is validated with carefully controlled lab-scale tests of simple structural elements, as shown in Figure 4 and Figure 5. Load versus displacement as well as failure modes must match between models and experiment, with models formulated based on accurate material properties, and no “adjusting of model properties and parameters is permitted in order to achieve better correlation. These accurate models then enable accurate prediction of full-scale large panel behavior (see Figure 4), including both initial failure modes and damage progression. The overall scheme of the modeling development is summarized in Figure 4, where modeling capability that accurately captures the key physics of the damage scenario, is applicable to investigating other configurations of interest for which experimental data might not be available.

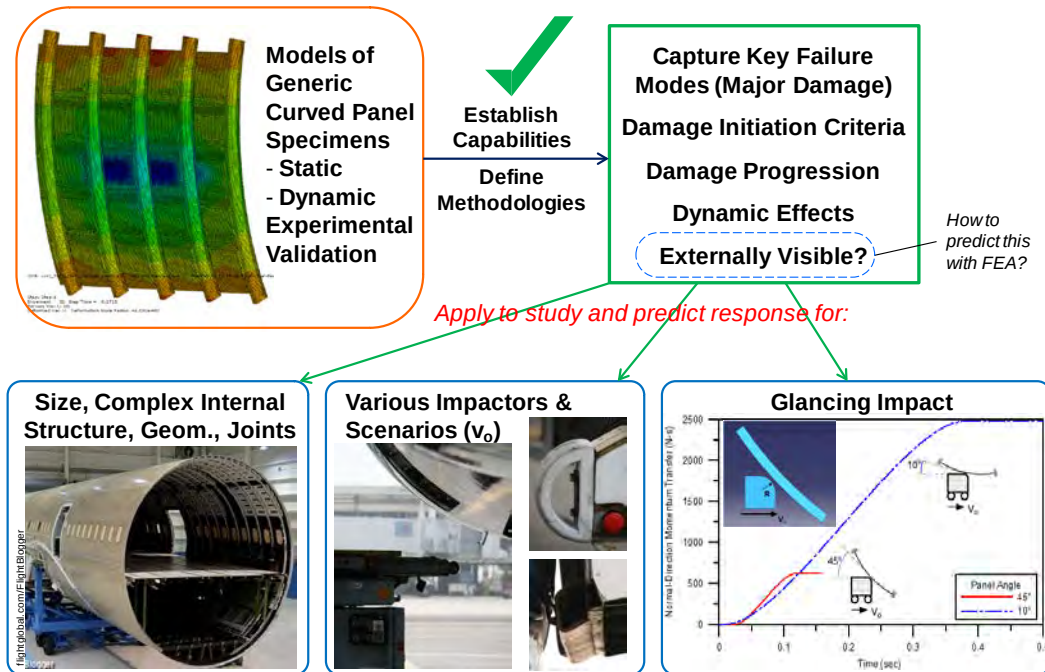


Figure 4: UCSD Model Development Roadmap for Establishing Blunt Impact Simulation Capability

This year, the investigations shifted to frame-centric failure modes (see Figure 5) including frame-floor interactions and accounting for the effect of different fuselage impact locations. Test planning is ongoing for conducting frame element-level bending/torsion tests to generate “lab-scale” frame failure data for model validation.

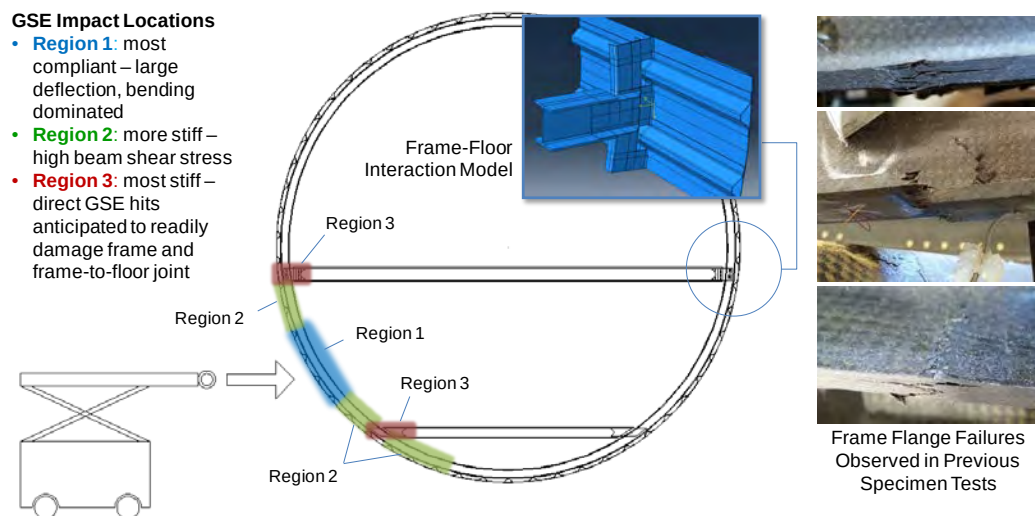


Figure 5: GSE Impact on Various Fuselage Locations, Frame-Floor Interactions, Failure Modes

Impact damage to honeycomb core sandwich panels is a new investigation at UCSD in this year. The damage modes of particular interest are associated with: (i) impacts leaving very low, or even none, visually detectable surface dent or facesheet cracking, and (ii) major reduction of facesheet disbond/separation peeling resistance. Lightweight sandwich specimens extracted from an Airbus A320 aircraft rudder (see Figure 6) were subject to high velocity ice impacts and also low velocity large-radius metal tip impacts to understand the key core damage modes shown in the figure. More highly dynamic semi-soft impacts, e.g., from hail ice, can excite core fracture (Mode D shown in) without leaving any visibly-detectable surface dent (e.g., < 0.1 mm dent shown in Figure 7). Ongoing research is now focused on methods for predicting core crush and facesheet residual indentation.

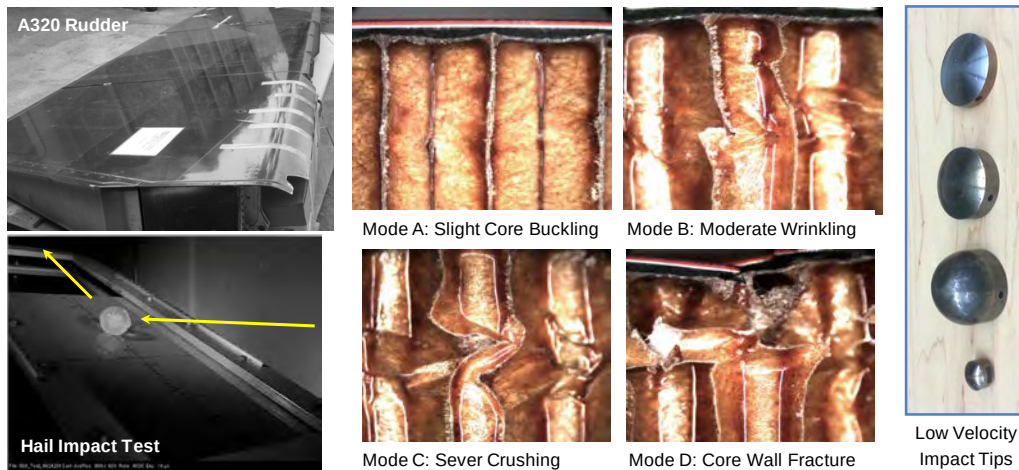


Figure 6: Sandwich Impact Specimen Source, Damage Modes

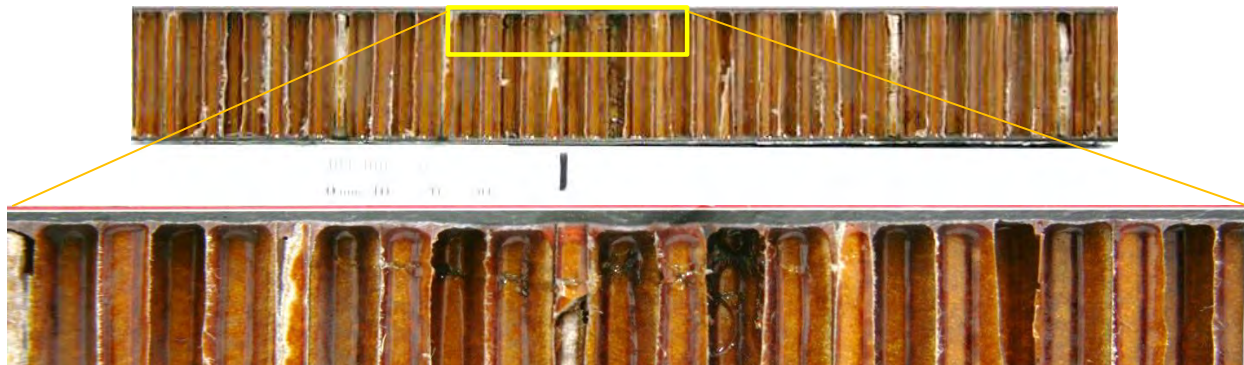


Figure 7: Example High Velocity Ice Impact Damage (0.008 mm Dent Depth with Core Fracture - Mode D)

Analytical models employing focused core crush measurements are being developed, as summarized in Figure 8, with future validation experiments and high-fidelity FEA models planned.

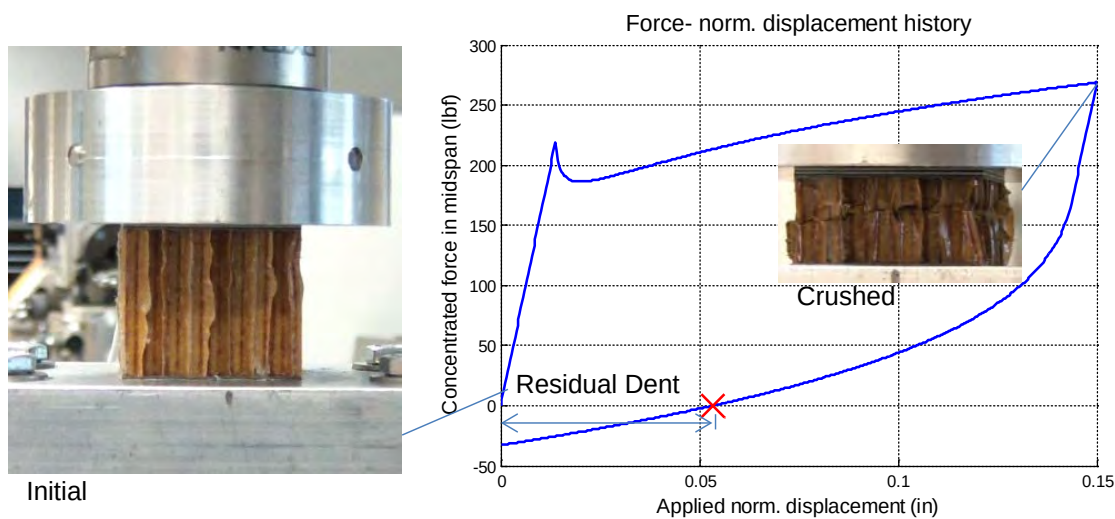


Figure 8: Core Crush Experimental Data Used in Dent Depth Prediction Analytical Modeling

This program will provide technical support for civil certification by analysis efforts of the next generation of fuel efficient aircraft. (Advanced Materials – Structural Safety)

CACRC Round Robin Repair Station Capabilities Evaluation:

The FAA CACRC depot bonded repair round robin research evaluates existing Commercial Aircraft Composite Repair Committee (CACRC) standards and approved materials used for repair of composite airframe structures. The interest is in assessing the process variability between performing organizations such as repair depots but also variability due to technician training, experience and currency. The research methodology manufactures composite repair sandwich elements representative of composite aircraft production parts using OEM (Original Equipment Manufacturer) materials and processes then repairing these elements using OEM-factory and CACRC- field methods and materials. This work has been performed through the FAA Joint Advanced Materials and Structures Center of Excellence at member school, Wichita State University (WSU).

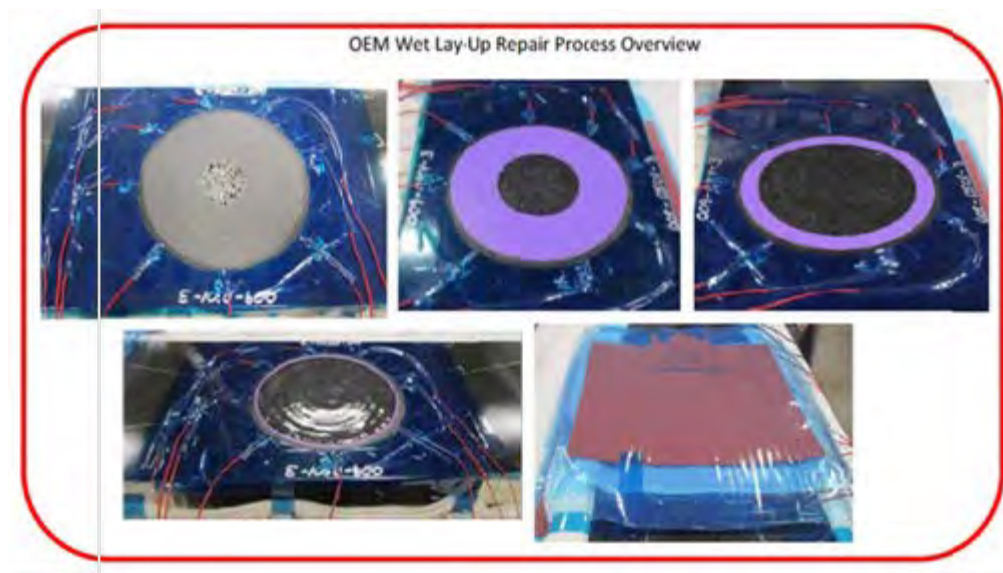


Figure 9: OEM Wet Lay-Up Repair Process Overview

CACRC repairs have been performed at WSU/NIAR and also by depot personnel from five participating airlines/MROs (Maintenance and Repair Organization). The same repair procedure has been provided to all depots along with kits with the required repair materials. Repairs have been conducted at the participating depots using a Structural Repair Manual-like procedure referencing the CACRC repair techniques. Repaired elements were inspected, instrumented, conditioned and tested. Preliminary CACRC repair residual strength results (G904/M20 PW with EA9695 adhesive) show variability in the repair element strength values obtained for the various depots.

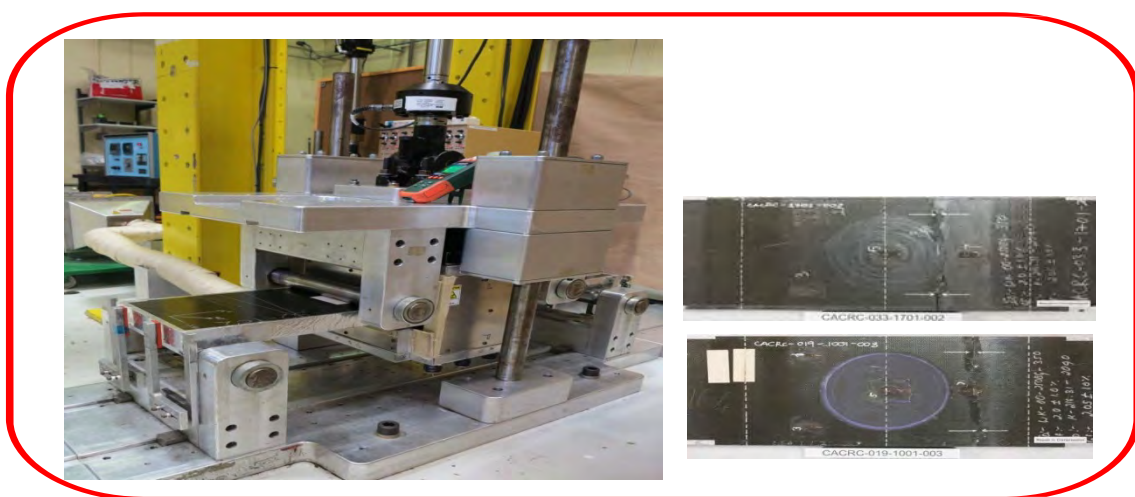


Figure 10: Repair Element Testing/ Failure Modes

Round robin bonded repair tests were performed at OEM and five repair depots with a total of 117 panels. Repair materials and procedures were provided to each repair depot. The result showed that workmanship, mechanic skill, knowledge and experience levels of the depot personnel does affect the residual strength of a repair. It was also found that experience alone does not guarantee a fully capable repair (e.g., a repair with safety margins as predicted by the design). Four fifths of mechanical tests were done by the end of FY 2014 and were expected to be completed by the end of the calendar year.

This work will support the development of policies and guidance on the requirements for repairs to the increasing number of composite fuselage and wings in the civil aviation fleet. (Advanced Materials – Structural Safety)

Development of Crash Dynamics Model for Narrow Body Aircraft Fuselage:

Current crashworthiness aircraft response and occupant safety standards are predicated on the use of metallic structures of traditional semi-monocoque design. The growing use of composite materials in the aircraft primary load structure has necessitated the establishment of crashworthiness requirements for composite and other non-traditional design concept for aircraft to maintain a comparable level of occupant safety.

This year, the FAA developed a full-scale metallic aircraft model to evaluate fuselage response and occupant response to various fuselage/impact parameters. This model will be used to help establish baseline values for composite crashworthiness certification requirements by developing an understanding of traditional structures crash response. The development, verification and validation of the model will be compared to data available from the Turkish Airlines flight that crashed during landing at Amsterdam Schiphol Airport, Netherlands on February 25, 2009 (see Figure 11). The model will allow for parametric studies on parameters that influence fuselage response during aircraft impact and provide a means to study aircraft impact scenarios and determine structural and occupant response. Injury data, terrain impact conditions, structural deformation and aircraft configuration including aircraft flight data records will be used to develop the model and simulation. The overall geometry and significant details have been incorporated into the model and work continues to add the necessary boundary and impact conditions.



Figure 11: Turkish Airlines flight crash in 2009

The details in the development of the model will also be incorporated into future best practice guidance material to support the use of Certification by Analysis to demonstrate aircraft crashworthiness. In addition to the full-scale model, a method to develop dynamic tension properties of composite materials was developed. A task was also undertaken to study the load transfer between components and how to properly model joints and subassemblies connections. Previous studies have shown that considerable energy is transferred to the rivet joints and other connections there are a considerable number of these in an aircraft and appropriate considerations must be given as not to oversimplify the analysis nor exceed available computational resources. This work, when completed, will provide a more efficient approach to determine crashworthiness of civil aircraft. (Advanced Materials – Structural Safety)

Structural Bonding of Composite Structures:

In 2014, research on bonded structures performed through the FAA Joint Advanced Materials and Structures Center of Excellence at the University of Utah was used to update a previously-developed benchmark first created in 2004 for current and future needs of bonded composite structures. This updating was made possible through a workshop held by and for known practitioners of composite bonding design and manufacturing from industry, academia and regulatory bodies. Recent difficulties with bonded structure have heightened the need for additional guidance on the proper control and repair of these structures. For example, there have been instances of helicopter main rotor blade metal bonding failures (Figure 12), metal bond processing with rudder deboning, and improperly reworked control structures (Figure 13).

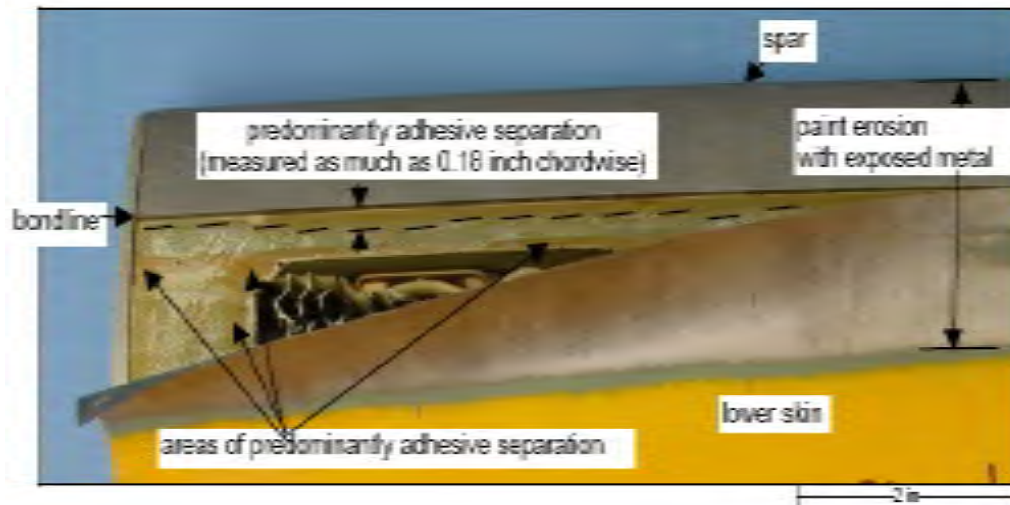


Figure 12: Delamination of a bonded metallic structure



Figure 13: Repaired metallic structure not conforming to geometry

The workshop: 1) gathered international experts on bonded structures to assess changes since 2004 in standard practices in bonding control and durability assessments, 2) identified known issues and development needs to provide adequate safety in aircraft structures of bonded joints, and 3) resulted in actions for utilization of bonded structures categorized into transport aircraft, GA and rotorcraft and long term application needs.

The output of the workshop has been reviewed and will be used to formulate future policy, guidance and research in this important area. Changes to the FAA's Aviation Safety National

Plan are being generated to align with the information gathered in the exchange. (Advanced Materials – Structural Safety)

Out-of-Plane Loading on Composite Structures:

Research was conducted to evaluate the analysis techniques that are useful for the substantiation of design of composite aircraft structure subjected to general out-of-plane loading. The FY 2014 effort was focused on improving mode III shear modeling and simulation using commercial finite element analysis software Abaqus. This included an evaluation of solid and shell elements. Improvements to the Abaqus/Explicit model such as changing mesh density and implementing mass scaling parameters were explored, and the effects of damage softening parameters in Simulation Composite Analysis (SCA) were also studied. A sensitivity study was used to determine which parameters for Hashin damage criteria have a significant effect on the max load predicted by finite element analysis (FEA) simulations. Regression modeling of the sensitivity study was used to determine if errors in provided material parameters could explain errors in simulations.

The use of solid elements is severely limited in composites analysis as Abaqus Hashin damage can currently only be implemented with shell elements. This limits the evaluation of solid elements to SCA. Solids elements which were shown to be computationally prohibitive because a very fine mesh through the thickness is required to simulate mode III shearing of a composite plate. This severely limits the accuracy and practicality of using solid elements for this analysis.

The result strongly recommended using shell elements for simulation of composites in mode III shear as solid elements were limited and computationally intensive. Abaqus/Explicit showed the best agreement with experiments and mass scaling is strongly recommended to limit computation time (see Figure 14 and Figure 15 for example results).

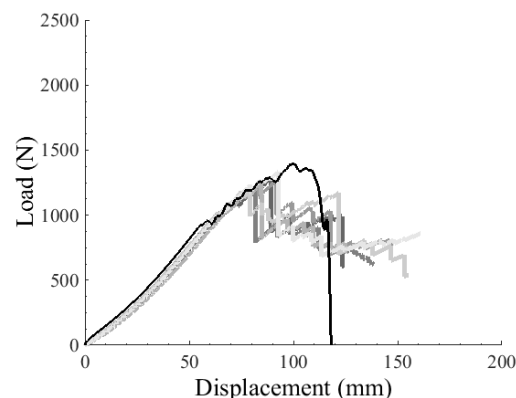


Figure 14: Load versus displacement behavior of Explicit analysis for 20 ply thick laminate with 10% 0° plies compared to

experiment. The dark black line represents FEA results. All others experimental results

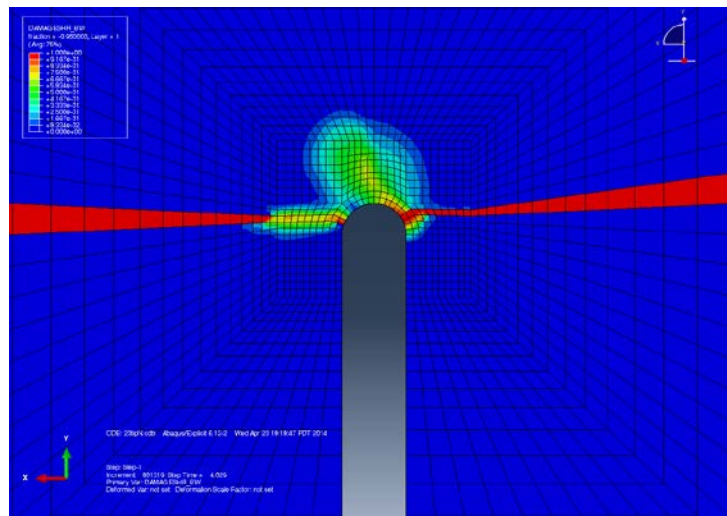


Figure 15: Damage path prediction for 20 ply thick laminate with 10% 0° plies using Abaqus/Explicit with mass scaling.

However, mass scaling limited the predictability of the simulation since it was a parameter of the solver that had no physical meaning. SCA showed good results, but often had severe convergence problems. Sensitivity studies showed tensile and compressive strengths have the greatest effect on the maximum load of the parameters considered. Regression modeling showed that errors in the reported values Hashin damage parameters alone were not able to predict the errors in experiments. This was due to nonlinearity in the finite element model response and other possible errors not captured by regression modeling of the material parameters considered in the study. This research will be used to understand the capabilities of composite civil aircraft structures to withstand out-of-plane loading, which is identified as a risk for composite structure. The certification groups at the FAA will use the research to assure type certificate applicants have addressed the risk. (Advanced Materials – Structural Safety)

Alcohol Limits and Public Safety:

On May 14, 2013, the National Transportation Safety Board (NTSB) recommended lowering the alcohol driving limit to 0.05 grams per deciliter (g/dL) in blood for the United States (U.S.) in an effort to reduce the risk of injuries and deaths caused by alcohol impairment (NTSB/SR-13/01). This recommendation has prompted several different organizations and agencies to evaluate and consider supporting this action. The Aerospace Medical Research Division of Civil Aerospace Medical Institute (CAMI) conducted a study that examined 554 alcohol related publications to determine the feasibility and advisability of lowering the U.S. driving limit to 0.05 g/dL blood alcohol content (BAC). Alcohol pharmacokinetics, instrument reliability, risk factors, law

enforcement, and adjudication were considered in this overview of the literature for lowering alcohol limits. The results are available in: Alcohol Limits and Public Safety. D. V. Canfield, Civil Aerospace Medical Institute, U.S. Federal Aviation Administration, Oklahoma City, Oklahoma, K. M. Dubowski, University of Oklahoma Health Sciences Center (Retired), Oklahoma City, Oklahoma, M. Cowan, Texas Department of Public Safety, Austin, Texas, P. M., Harding Toxicology Section (Retired), Wisconsin State Laboratory of Hygiene Madison, Wisconsin¹. (Aeromedical Research)

Colloquium on Postmortem Forensic Toxicology in Aviation:

A Colloquium on Postmortem Forensic Toxicology in Aviation was conducted to address important issues and topics of postmortem aviation toxicology. The meeting was a scientific platform for medical examiners, coroners, forensic toxicologists, regional flight surgeons, NTSB personnel, and other accident investigation authorities, including FAA's' Flight Standards District Offices and FAA's Office of Accident Investigation and Prevention employees. The overall outcome of the colloquium was the identification of new avenues for future research activities in the field of aerospace medicine and toxicology, specifically regarding:

- Quality Control and Quality Assurance
- Immunoassay Drug Screening of Postmortem Biological Samples
- Glucose and Hemoglobin A1C Analyses in Postmortem Specimens
- Analyses of Specimens for Ethanol and Other Volatiles
- Drug Screening of Biological Samples by Gas Chromatography/Mass Spectrometry and Liquid Chromatography/Mass Spectrometry
- Coordination of Aviation Accident Postmortem Sample Collection and Shipment
- Aeromedical Aspects of Toxicological Findings in Aviation Accidents
- Postmortem Aviation Forensic Toxicology
- Processing of Postmortem Aviation Chain of Custody of Specimens
- Analyses of Blood for Asphyxiant Toxicants
- Review of Analytical Data and Analytical Reports
- Litigation and Expert Court Testimony

¹ Forensic Science Review (www.forensicsciencereview.com), Volume Twenty-Six, Number One, January 2014

(Aeromedical Research)

Evacuation Equipment/Aids:

A project was undertaken to identify, assess, and develop improved evacuation equipment and evacuation aids for visual, aural and tactile aides (such as lighting, aural way-finding systems, and symbolic information media) to enhance rapid evacuation. Based on the results of the studies and equipment technology identified, additional guidance material and new regulatory requirements may be developed. Initial implementation in the form of operational advice (e.g., Safety Alert for Operators) can be used to encourage early adoption of enhanced evacuation systems. (Aeromedical Research)

Hypoxia – Rapid Decompression:

Aeromedical researchers conducted and developed a research protocol to investigate the feasibility of novel hypoxia biomarkers (e.g., HPH1, S100B) in rapid decompression studies. Research was conducted to validate a recently developed computational model that predicts physiological responses of passengers to rapid decompressions. Physiologic monitoring included electroencephalography, transcranial doppler blood flow, cardiovascular, and respiratory responses. *Partial Validation of Physiological Modeling Analysis of Rapid Decompressions to 40,000 and 45,000 Feet*. D. Self, J. Mandella, L. Paskoff ASEM 2014;85(3):364[509]. (Aeromedical Research)

Biomarkers for Disqualifying Pathologies:

Researchers evaluated biomarkers for the prediction and/or identification of an array of disqualifying pathologies that may cause incapacitation or impairment in-flight and result in aviation accidents (heart attacks, strokes, and others). Molecular biomarkers that signal disease are continuously being discovered. The identification of these biomarkers could aid in the development of methods to facilitate disease diagnosis and development of decision support tools for medical certification and accident investigation process. A review of the literature for single nucleotide polymorphisms (SNPs) associated with cardiovascular disease (CVD) revealed about 30 high confidence SNPs. Individually, none are predictive for CVD. Several authors combined some number of these SNPs into a genetic risk score (GRS) modelled on the Framingham Risk Score that is based on traditional risk factors (TRFs) including lipid profile, hypertension, age, family history, diabetes, and smoking status. All GRSs were associated with CVD and had a similar predictive value as TRFs; however, when GRSs were combined with

predictive scores based on TRFs, there was minimal increase in predictive value. Therefore, genetic profile discovery across a population is not recommended because TRF-based scores have similar predictive power, are less expensive, and easily interpreted by the medical community. (Aeromedical Research)

Cabin Altitude and Pulmonary Disease:

In collaboration with the University of Oklahoma Health Sciences Center (sponsored by the Flight Attendants Medical Research Institute), FAA researchers assessed the clinical effects of cabin altitude during air travel on patients with pulmonary disease. Researchers also evaluated potential increased risks to compromised individuals, such as patients with Chronic Obstructive Pulmonary Disease (or COPD), to determine if an inflammatory response to hypoxia exists. Data sampling and collection phases have been completed. (Aeromedical Research)

Diabetes in Civil Aviation:

A Scientific Information System developed at the Civil Aerospace Medical Institute (CAMI) has assisted in several studies of the U.S. civil pilot population. The Numerical Sciences Research Team at CAMI used this unique data construct to examine the aeromedical and aviation safety aspects of diabetes. The team studied the prevalence of diabetes from 1983 through 2005 and its associated risk factor - obesity - along with issues associated with medical certification for aviators with diabetes and their effects on the U.S. civil pilot population. The number of airmen with diabetes in the U.S. active population of airmen has risen from 2,768 in 1983 to 10,806 in 2005. The increasing proportion of reported diabetes within the U.S. civil pilot population escalated to 1.6 percent and 0.5 percent for men and women, respectively, by 2005. The contribution of diabetes conditions in aviation accidents is not causal but rather serves as a marker for airmen with multiple comorbid chronic conditions. While these multiple comorbid chronic conditions were not shown to be medically disqualifying individually, they were found to lead to an elevated safety risk in combination with diabetes. (Aeromedical Research)

Prevalence of Wheel Well Passengers:

A study was conducted to assess the prevalence of wheel well passengers and the characteristics of those who survive. Result showed that only about 25 percent survive. Stowaways in aircraft wheel wells face numerous health risks, many of which are fatal, such as bodily harm from undercarriage retraction, tinnitus, deafness, hypothermia, hypoxia, frostbite, acidosis, and falling when the doors of the compartment reopen. The landing gear compartment is not equipped with

heating, pressure or oxygen, which are vital for survival at a high altitude. (Aeromedical Research)

CARI - NAIRAS Cosmic Radiation Assessment Tool:

Researchers developed a version of CARI (CARI-NAIRAS) that uses NASA's near real time Nowcast of Atmospheric Ionizing Radiation System (NAIRAS). The NAIRAS model predicts atmospheric radiation exposure from galactic cosmic rays and solar energetic particle events. The development of this CARI model required the performance of Monte Carlo simulation/calculations and thus relied on high performance computing capability. (Aeromedical Research)

Symbolic Exit Signs in Small Transport Airplanes:

The team conducted a study of the identification and comprehension of symbolic emergency exit signs for small transport airplanes, which use variations of approved symbols and are smaller than the signs approved for placement on single, large transport category airplanes. This study evaluated the smaller symbolic exit sign, comparing it with the approved sign in combination with variations of individual sign elements.

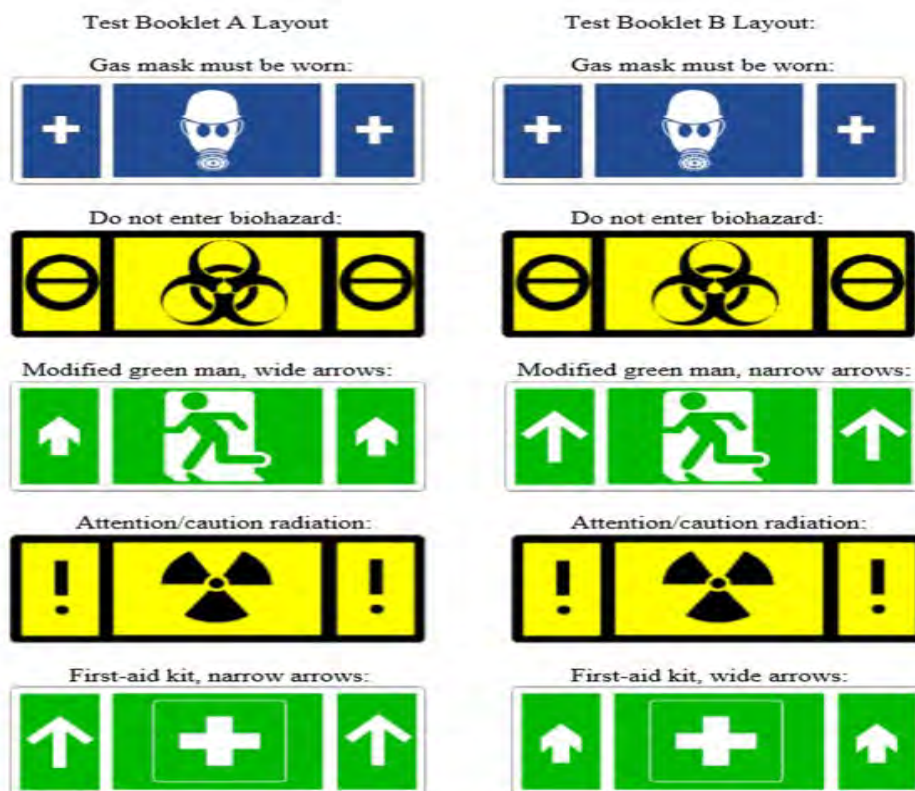


Figure 16: Assessment of symbolic exit signs in small transport airplanes

Overall, there was little difference in the identification of either the approved or proposed running man element, although participants were better able to identify the type of arrow element currently approved for the larger transport airplanes. The main recommendations from this study are that future symbolic exit signs on transport-category airplanes be standardized and spaced within the cabin to provide the visual size needed for proper identification and comprehension. (Aeromedical Research)

Passenger Safety Information Media:

Researchers developed effective media for enhanced aircraft passenger safety. Phase I consisted of assessing the degree of comprehension of placards, pictorials, pictograms, and other safety briefing materials on board. In Phase II, findings from studies of emergency information resources were applied to define enhanced safety information formats and media, including persuasive technology. Results were published as follows:

- Weed DB. Effective Presentation Media for Passenger Safety: Comprehension of Briefing Card Content, Perspective, and Presentation. Proceedings of the Seventh Triennial International Fire & Cabin Safety Research Conference (7TH IAFCSRC), December 2013, Philadelphia, PA.
- Weed DB, Paskoff LN, Ruppel DJ, Corbett CL. Effective Presentation Media for Passenger Safety II: Comprehension of Briefing Card Pictorials and Pictograms.
- Weed DB. Effective Presentation Media for Passenger Safety: Comprehension of Briefing Cards Gestalt and Elements. (7TH IAFCSRC).
- Chittaro L. Computer-based Evacuation Aids for Aircraft Passengers. (7TH IAFCSRC).
- Chittaro L. Learning Cabin Safety through Play: Using Video Game Technology in Passengers' Education. (7TH IAFCSRC).
- Chittaro, L. "Changing User's Safety Locus of Control through Persuasive Play: An Application to Aviation Safety", In: Persuasive Technology, LNCS vol. 8462, Springer International Publishing, Switzerland (2014), pp. 31-42 ISBN: 978-3-319-07126-8.
- Brace for Impact app for Facebook, android, and iPhone now available online.

(Aeromedical Research)

Mathematical Prediction of Emergency Evacuation Performance:

An airplane evacuation simulation computer program was developed by Rutgers, the State University of New Jersey, with the FAA's Civil Aerospace Medical Institute. An advantage of computer simulation is that it can replicate different scenarios with specific hazardous conditions and analyze an entire detailed evacuation process. One specific hazardous condition, the effect of injured passengers for airplane evacuation, was studied using the computer evacuation program. The injured passengers represent the passengers who can only move very slowly, including: disabled passengers, those passengers who need special assistance, or passengers injured due to the emergency evacuation situation. Similar to other crew redirection algorithms, two principles of the crew redirection were simulated with different locations of injured passengers. To simulate the crew redirection with the injured passenger, two typical dual aisle airplanes were modeled with 100 percent passenger occupancy rate, and Monte Carlo simulations were performed. It was found that the overall evacuation time was increased with the presence of injured passengers. *Aircraft Emergency Evacuation Study on Injured Passengers and Crew Redirection*. Gea HC, McLean GA. (7TH IAFCSRC). (Aeromedical Research)

Fatal Stalls, Spins, and Aeromedical Data:

A study was conducted in response to the FAAST National Operations office, which asked for assistance with the collection, analysis, and reporting on fatal accident data where a stall, a stall/spin, or a spin, was determined to be a causal factor in the accident. This study provided operational data that will be collated with underlying human factors, medical, medical certification, and training issues. *Potential Causation of Fatal General Aviation Stall and Spin Aircraft Accidents*. K.G. Larcher and D.B. Weed. (Aeromedical Research)

Comprehensive Forensic Drug Screening Methodology:

A comprehensive drug screening method was developed that utilizes solid-phase extraction and ultra-performance liquid chromatography time-of-flight mass spectrometry (UPLC–MS TOF) to screen for 514 drugs in biological matrixes. This method can also identify drugs outside of the 514 drug library. TOF MS provides accurate mass data and, therefore, the collected data can be searched for unknowns using accurate mass databases, which are publicly available, or can be searched retrospectively when new drugs are identified. By incorporating UPLC, this method was able to provide very narrow peaks, further providing specific and accurate determination of drugs.



Figure 17: A Comprehensive Forensic Drug Screening Methodology was developed in the ultra-performance liquid chromatography time-of-flight mass spectrometry (UPLC-MS TOF)

This method is the next generation of postmortem drug screening. It is a rapid, sensitive and accurate method for determining drugs in postmortem samples in support of aircraft accident investigation. New medications are more potent and efficient and therapeutic levels of 1 or 2 nanogram/200 picograms in blood are hard to detect, yet may cause significant performance decrements. This project developed more comprehensive and sensitive screening methodology for the identification of drugs at these levels. (Aeromedical Research)

System Integrity Risk Analysis Process (SI-RAP):

As part of the Air Traffic Organization's (ATO) effort to improve NAS availability, reliability, and safety culture a new risk analysis process was created to analyze the severity and repeatability of NAS outages. The repeatability portion of the process makes use of a simplified taxonomy that results in the identification of causal and contributing factors for each major system outage. These causal and contributing factors are then fed forward to corrective actions to avoid a repetition of outages traceable to maintenance errors, procedural inadequacies, system design flaws, and environmental aggravations. The product is being used to enhance NAS safety by anticipating and correcting potential sources of risk before they can jeopardize safety. In addition, the product is used to move safety to the next level by collecting and analyzing data to identify potential hazards, improving ATOs SMS by enhancing safety risk analytics, and

providing operations with the data & tools necessary to facilitate continuous improvement. This provides the ATO with the ability to increase awareness of previously unknown occurrences, better understand how unplanned, unexpected service interruptions impact the safe delivery of ATC services, thereby providing a greater ability to prioritize resources based on risk. The neutralized taxonomy will allow ATO to view individual occurrences and better understand both what went wrong and what went right. (Air Traffic Control/Technical Operations Human Factors)

Technical Operations Abbreviation Standard:

This standard covers the format and content requirements for developing and using FAA Technical Operations abbreviations. Abbreviations are commonly used in labeling NAS equipment and in technical manuals. There is currently a lack of standardization in the use of abbreviations in the NAS leading to confusion and errors when abbreviations are neither obvious nor intuitive. This standard specifies requirements that shall be adhered to in the development of new abbreviations or use of authorized abbreviations. The standard also contains a list of approved abbreviations to be used in future NAS procurements and for general system design. (Air Traffic Control/Technical Operations Human Factors)

Analysis of Air Traffic Control Facility Training Outcomes by Recruitment Source:

The purpose of this study was to compare on-the-job training outcomes at the first facility by recruitment source with formal statistical testing. 5,195 persons hired by the FAA from 2005 through 2010 were categorized by recruitment source on the basis of official registers maintained by the Aviation Careers Division for each source. Analyses were conducted for the overall group and then by facility type. Overall, larger proportions of Veteran's Recruitment Appointment (VRA) and FAA Air Traffic Collegiate Training Initiative (CTI) hires achieved Certified Professional Controller (CPC) status than did general public hires. Based on those differences, a simple model suggested that preferring VRA and CTI hires over general public hires could produce more net CPCs than a policy of equal (or no) preference for recruitment sources. Several technical and general recommendations are presented in closing. (Air Traffic Control/Technical Operations Human Factors)

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 2014, a new material model was developed, and a titanium material was characterized. (Aircraft Catastrophic Failure Prevention Research)

Development of an Enhanced Material Model for Certification by Analysis:

In 2014, 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 a 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 to accommodate yield stress differences in tension, compression, and shear. The new model, MAT Tabulated Johnson Cook-Generalized Yield Surface (LS-DYNA MAT 224-GYS) passed quality assurance at Livermore Software Technology Corporation and is currently available in the code.

A team consisting of The Ohio State University (OSU), The George Washington University (GWU), and the National Aeronautics and Space Administration Glenn Research Center (NASA-GRC), worked with the FAA Aircraft Catastrophic Failure Prevention Research Program at the William J. Hughes Technical Center to develop a generic yield enhancement to the material model in LS-DYNA for 2024 aluminum. This new material model more accurately identifies yield and plastic deformation in different stress states.

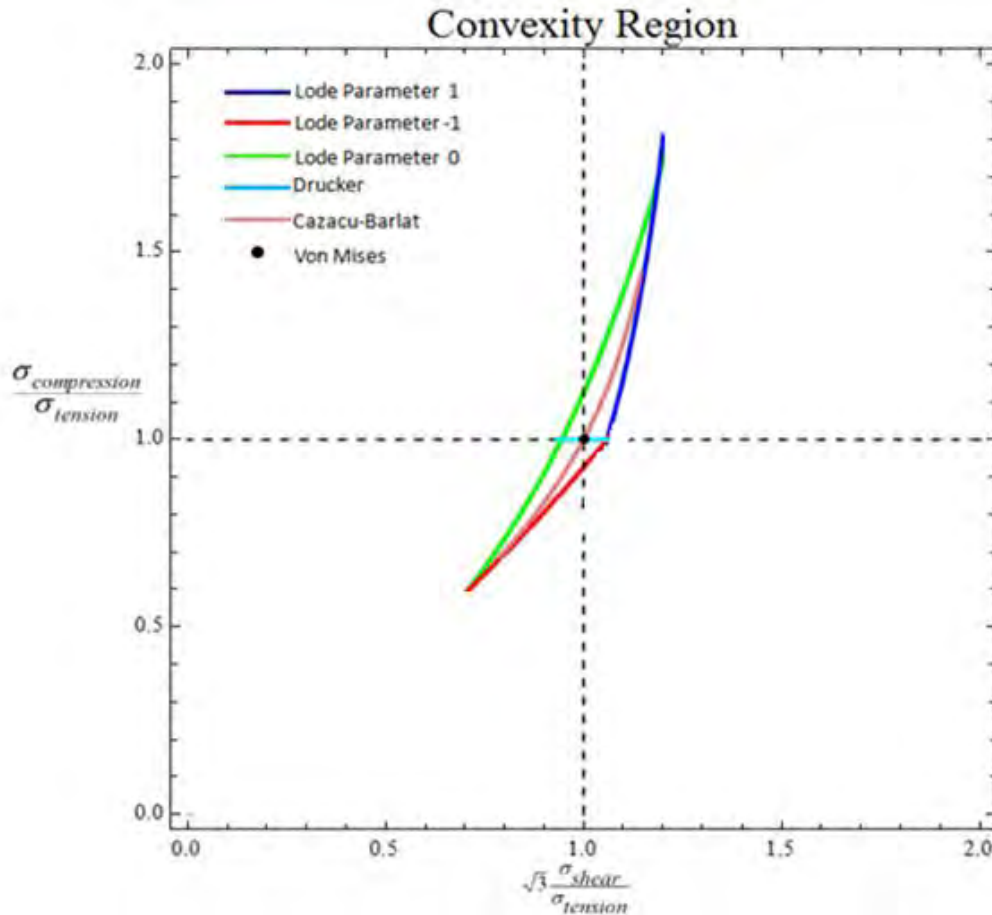


Figure 18: Stress Ratio solved for the Convexity Region

The enhancement to the model is depicted in the stress ratio plot shown in Figure 18. Convexity is the mathematical necessity that the curve being solved does not have peaks and valleys which could produce multiple solutions leading to numerical instability. The Lode parameter is the boundary for the convexity region. It covers the linear relationship developed by Drucker to vary the relationship between tensile and shear yield, and the linear relationship developed by Cazacu and Barlat to vary the relationship between tension, compression and shear and creates a surface and expands the solvable combinations to the area bounded by the Lode parameter. Lode varies from 1 to -1 for all states of stress where 1 is tension and -1 is compression. This expanded area is a significant enhancement over the standard material model based upon von Mises which is a point in the center of Figure 18.

This improvement makes it easier for engine manufacturers to demonstrate close correlation between test and analysis, as it takes into account the different stress states and yield points allowing the simulation to be more accurate in varying stress states. This improvement is another step towards predictive analysis and improves the accuracy of results. (Aircraft Catastrophic Failure Prevention Research)

Tabulated Material Model for Titanium - 6 Aluminum – 4 Vanadium (Ti-6-4) MAT-224:

A team consisting of OSU, GWU, George Mason University, and NASA-GRC, worked with the FAA's Aircraft Catastrophic Failure Prevention Research Program to develop a new material model in LS-DYNA for Ti-6-4. This completes the second new constitutive material model developed under this joint effort for MAT Tabulated Johnson Cook (LS-DYNA MAT 224).

The experimental material characterization work investigated plastic deformation and ductile fracture behavior of 12.7 mm, Ti-6-4 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 finite element program as the simulation progresses. Shapes and general layout are depicted in Figure 19.

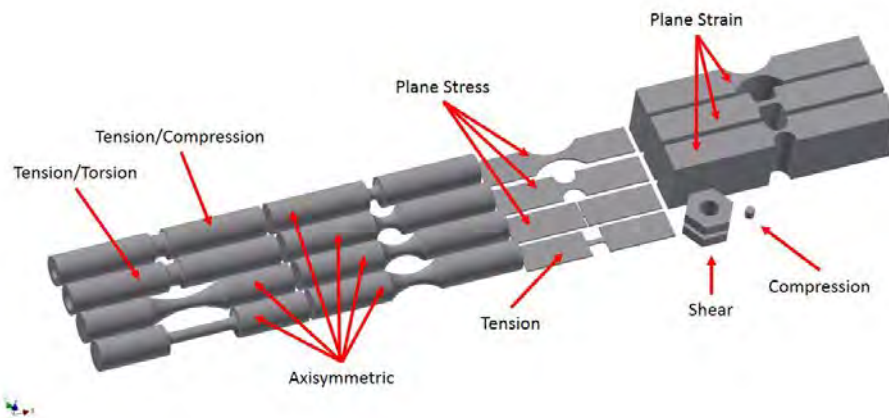


Figure 19: Orientation of Specimens from Plate Material of Ti-6-4

Each of the test specimens has a location in the three dimensional failure surface. 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 developed failure surface is shown in Figure 20.

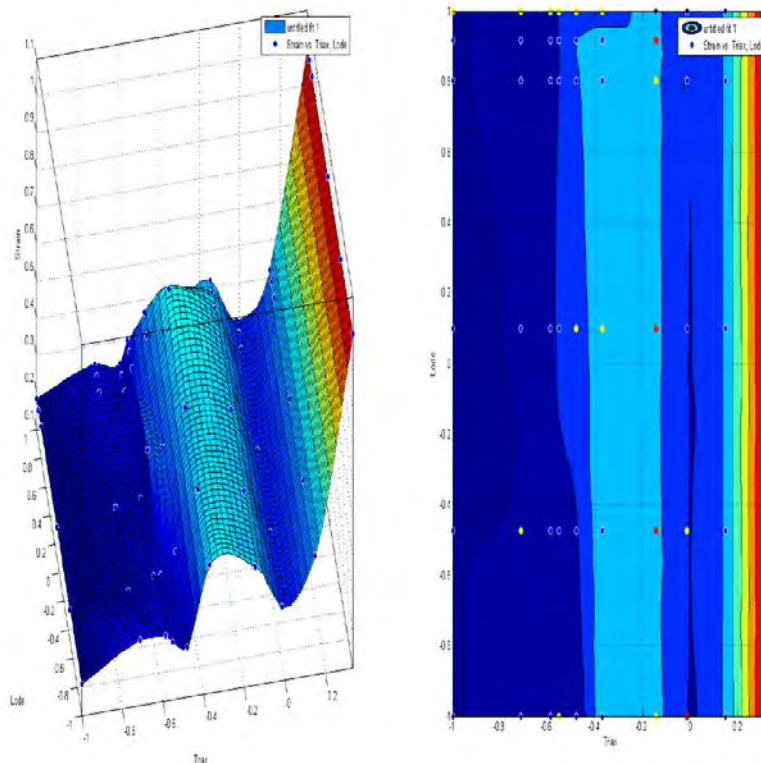


Figure 20: MAT 224 Failure Surface Generated from Test Data

The research team ran a series of penetration test simulations compare this surface against actual test data. The dots in the figure represent the points used to generate the surface. In real-life tests, there is a probability of penetration where some projectiles penetrate and other does not.

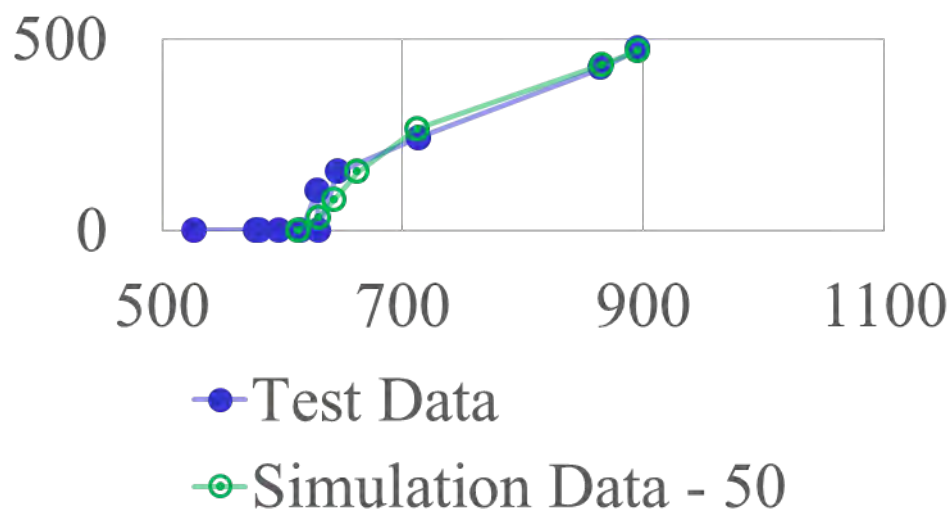


Figure 21: Ballistic Test vs Simulation Data Comparison

In Figure 21 the abscissa has a zoom of the initial velocity from 500 to 1,100 feet per second. The ordinate shows the residual velocity after penetration from 0 up to 500 feet per second. The ballistic limit of this test is roughly 625 feet per second. In the low residual velocity region, the structure tends to absorb more energy. At the higher residual velocities the failure mode occurs more rapidly and absorbs less energy. The ability to match both of these regions is a significant improvement of the new material model. (Aircraft Catastrophic Failure Prevention Research)

Demonstration of Fuselage Shielding for Aircraft with Open Rotor Engines:

The FAA is working with the European Aviation Safety Agency (EASA) to define a certification basis for engines on future large commercial aircraft that would not have a containment structure. Current regulations for aircraft with ducted fans stipulate that the loss of a single fan blade will not cause hazard to the aircraft. The challenge with an open-rotor design is to achieve an equivalent level of safety to ducted fan engines which contain single fan blade failures. One means of mitigation for passengers and critical aircraft systems from a released blade is fuselage shielding. Previous work on uncontained engine fragment shielding paved the way for FAA and NASA to design an open rotor engine shield in 2013. In 2014, the shield design was tested.

The full scale test was a simulation of an open rotor fan blade off event. It was performed on February 20, 2014, at the Naval Air Warfare Weapons Division Weapons Survivability Lab (NAWCWD WSL). The objective of the test was to evaluate the effectiveness of composite panels to stop the penetration of an open rotor aircraft engine blade into the fuselage of the aircraft. NASA Glenn Research Center provided the design of the composite shield and provided digital photography equipment and analysis to document the event. NAWCWD WSL conducted the test and provided the test hardware.



Figure 22: 1980's Un-Ducted Fan demonstrator Engine

Two blades, similar in size and construction to that expected for open rotor engines on a mid-size commercial aircraft, were mounted on a spin fixture and run at a representative velocity. Using a linear shape charge, the two blade sections were released simultaneously such that they impacted the composite shields. Based on the NASA analysis, two shield thicknesses were tested, 20 ply and 24 ply. The test was designed to duplicate the worst case scenario. The blades were released at a high power climb rotor speed, with both blade sections impacting tip first, with the blade aligned with the trajectory of the center of gravity of each blade. Pre-test analysis predicted a penetration of the 20 ply, but not the 24 ply composite material.

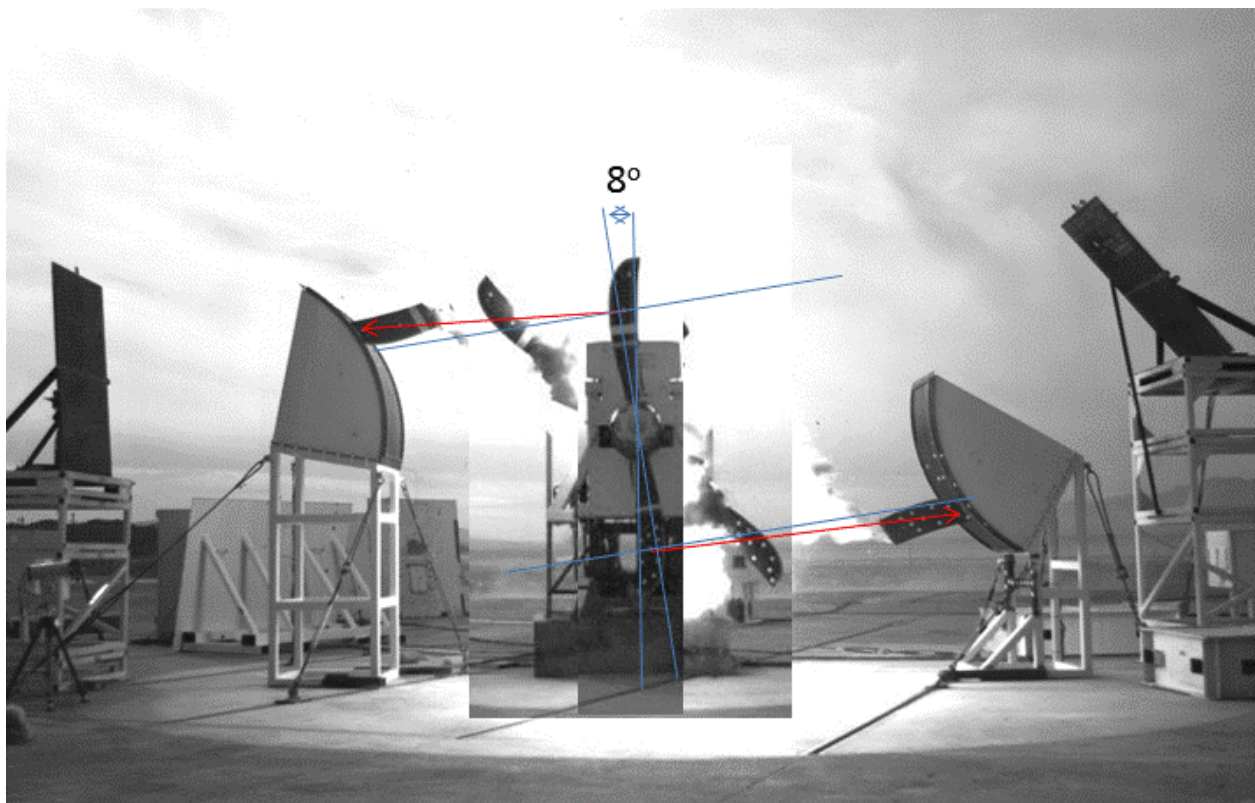


Figure 23: Composite Photograph: pre-release and release (center image), and impact with shields (images to left and right)

Test results supported the predictions of the NASA analysis. The blade penetrated the 20 ply design shown on the right in Figure 23. The shield on the left is the 24 ply design and the blade rotates through perpendicular as it crushes at the tip and then slides off the shield. Test results correlated very well with the NASA pre-test analysis. This test demonstrated that a lightweight composite shield could stop a composite blade similar in size and construction to anticipated open rotor configurations. This research will help the FAA's Aircraft Certification Service and the industry achieve an equivalent safety for fan-blade-off with open rotor engines that exists for ducted fan engines. (Aircraft Catastrophic Failure Prevention Program)

Testing Simulated Ice Shapes With and Without Roughness on Swept Wing Model at Low to Moderate Reynolds Number:

An FAA-led research team conducted a two-week aerodynamic test campaign in August 2014 at the Walter H. Beech Icing Research Tunnel at the National Institute for Aviation Research located at Wichita State University. The model was tested both “clean” and with simulated ice roughness. Several combinations of splitter plates and shrouds were evaluated in terms of their effect on the aerodynamic performance and stalling characteristics of the model. The splitter plate and shroud combination is important for mitigating the interaction of the wind-tunnel floor boundary-layer with the flow over the model. Testing will be conducted in other tunnels, including the ONERA F1 facility in France. Information from the testing is essential to the design of the splitter plate and shroud combination for the ONERA F1. The campaign also explored the ability to manufacture simulated leading-edge ice roughness in high-fidelity artificial ice shapes. The roughness, which was very small at the scales used, was simulated using a pattern developed in a CAD model and built using rapid-prototype manufacturing. The process produces a high-fidelity simulation of ice roughness with aerodynamic results comparable to those obtained using traditional, much more labor- and time-intensive methods of simulating ice roughness with silicon-carbide grit applied to the model leading edge. (Aircraft Icing/Digital System Safety)

Software Assurance Approaches, Considerations, and Limitations:

The cost of developing software in compliance with RTCA/DO-178B and/or RTCA/DO-278 is generally considered to be high. Nevertheless, software systems assured to these standards have excellent operational histories. A research study entitled “Alternative Approaches to Software Assurance” was undertaken to evaluate the current state of software assurance process and propose alternative approaches with the potential to streamline the process and reduce the assurance costs without compromising safety.

During the initial phase of the work, alternative assurance approaches and a comparison of the aerospace industry standards to other safety critical industry’s standards were examined. To obtain general impression and issues with the current standards, a poll to query aviation industry personnel on their experience with RTCA standards on software assurance DO-178B/C and DO-278 was conducted. It was concluded that DO-178B or DO-278 have good processes in place and have been serving the industry in assuring the safety. To improve the existing standards and to accommodate technological advancements, it was recommended to look into new tools and safety analysis techniques that could still meet the goal of the study, but were not necessarily alternatives to DO-178B/C and DO-278.

Some of the techniques that were investigated further are the Systems Theoretic Process Analysis (STPA), model-based development, and formal verification techniques. Although the latter two methods have been around for some time, there have been advancements in model-based development and formal verification that deemed it worthwhile to re-visit them. Through the application of STPA process to a flight guidance system, it was demonstrated that STPA can identify more system and software errors in the requirements than some other hazard analysis techniques. The analysis demonstrated how STPA could be applied to a flight guidance system and how hazard causes could be mitigated. The research also looked at cost savings that was attained by industry when they used model-based development and formal verification on their projects, as well as a discussion on shortcomings of using model-based development and formal verification. (Aircraft Icing – Digital System Safety)

Assurance Case Applicability for Digital Systems:

Software Considerations in Airborne Systems and Equipment Certification standard RTCA/DO-178B is the de facto civil aviation standard and guidance document for the development of aviation software. A new edition of the standard, DO-178C, was published by RTCA in late 2011. The stated purpose of DO-178C remains essentially unchanged from its predecessor: providing guidance “for the production of software for airborne systems and equipment that performs its intended function with a level of confidence in safety that complies with airworthiness requirements.” In DO-178B, little or no rationale is given for how a particular objective or collection of objectives contributes to achieving this purpose. Thus, the assurance case for the document is implicit. Although empirical evidence suggests that this implicit assurance case has been adequate so far, its implicitness makes determining the reasons for this adequacy quite difficult. Without knowing the reasons for past success, accurately predicting whether this success will continue into the future is problematic. To get a better understanding of the standards through assurance case, this research carefully studied DO-178C, assessed applicability of confidence argument concept, classified the objectives, and developed an approach for creating arguments. Initially, a prototype assurance case for DO-178C Level D argument was developed using Goal Structuring Notation tools developed by Dependable Computing, Inc.

The work was expanded to include the development of assurance cases for Level C, Level B and Level A. A set of evaluation criteria and evaluation questions were also developed to evaluate the adequacy of arguments in each assurance cases. The output of the research will be used to develop training material for certification engineers while applying the DO-178C standards in assuring airborne software. (Aircraft Icing – Digital System Safety)

Single Event Effects Mitigation Techniques:

The evolution of electronic components toward higher density parts increases these components susceptibility to upset from atmospheric radiations. The radiation effect, which is called single event effects (SEE), could result in the loss of function or malfunction of safety critical aircraft systems highlighting the need to identify which components within aircraft systems are sensitive to SEE and need a mitigation technique and to evaluate the effectiveness of the SEE mitigation technique. The Single Event Effects Mitigation Techniques research supports the development of guidelines for the acceptance of semiconductor microelectronic devices and electronic systems. The research provides a series of recommendations and guidelines for an analysis of SEEs that integrates within the existing system safety assessment process. Specifically, the research findings articulate:

- The identification of components sensitive to SEEs;
- The considerations to be made when assessing mitigation techniques against SEEs;
- The integration of the SEE analysis within the existing aircraft system safety assessment process.

(Aircraft Icing – Digital System Safety)

Field Campaign on High Ice Water Content Ice Crystal Atmospheric Environments:

The FAA, NASA, Australian Bureau of Meteorology, Transport Canada, Environment Canada, National Research Council of Canada, and Boeing collaborated on the High Ice Water Content (HIWC) ice crystal field campaign project. The project objective was to better understand convective ice crystal environments where more than 140 ice crystal engine power loss events have occurred in the last 18 years. The HIWC team joined with the European High Altitude Ice Crystal (HIAC) field campaign project, so that the two projects could share expertise and resources, specifically the Falcon 20 research aircraft. The Falcon 20 is owned by the Centre National de la Recherche Scientifique (CNRS) in France [translated: National Center for Scientific Research] and operated by the Service des Avions Français Instrumentés pour la Recherche en Environnement (SAFIRE) [translated: Service of French Aircraft Instrumented for Environmental Research]. The field campaign, located in Darwin, Australia from January – March of 2014, allowed the project to obtain a large set of high ice water content ice crystal data in convective, high altitude conditions. The data collected will support development of new engineering standards for certification, improved simulation of ice crystal conditions in engine icing test facilities, and development of better now-casting/forecasting capabilities for avoidance of the hazardous conditions. A second HIWC-HAIC campaign is tentatively scheduled for April 2015. (Aircraft Icing/Digital System Safety)

Experimental and Analytical Examination of the Formation, Adherence, and Shedding of Ice in a Test Environment Simulating the Environment in an Engine Low Pressure Compressor:

FAA researchers and the National Research Council (NRC) of Canada conducted experimental studies at the NRC Research Altitude Test Facility (RATFAC) over a period of several years under the FAA-NRC Memorandum of Cooperation NAT-I-8417. The research supported improvements in modeling of ice accretion processes in a low-pressure compressor and investigation of procedures for conducting sea level engine tests with ice crystals, which include altitude effects and the effect of dynamic pressure. The research used various test articles to explore the effect of pressure and other parameters on the formation, adherence, and shedding of ice in a test environment simulating the environment in an engine low-pressure compressor. As a result, an important focus of the experimental work in 2014 was the production of data for the development and evaluation of analytical scaling methods for sea level engine icing facilities without altitude-pressure capability (which encompasses most such facilities). Valuable data was obtained and analyzed, but it is not yet clear how well such tests can adequately reproduce ice crystal events experienced at higher altitudes. Further testing will be done, exploring whether matching liquid water content/total water content and varying the inlet concentration ratio can match accretion onset at low and high pressures and dynamic pressures. In particular, the testing will focus on the effect of dynamic pressure, which is a particular concern of engine manufacturers for sea level testing attempting to adequately simulate conditions at higher altitudes. Progress was made toward the development of a parameter-scaling framework for testing of engines in static sea level facilities to evaluate their operation in ice crystal clouds at high altitude. (Aircraft Icing/Digital System Safety)

Complete Feasibility Evaluation to Determine Implementation of Bird Radar Displays in Air Traffic Control Towers:

Commercial avian detection radar system displays and existing display requirements were assessed to determine the potential fit into air traffic control (ATC) environments including towers and TRACONS. The assessment resulted in a determination that it is feasible to introduce a bird radar display into ATC environments. Implementation of a display concept requires extensive development and validation work. The subsequent effort, referred to as the Wildlife Surveillance Concept (WiSC), is being conducted in collaboration with the FAA's Concept Development and Validation Branch and includes a series of research activities aimed at maturing the WiSC. New milestones will be assigned to track that effort as distinct from the initial feasibility study. (Airport Technology Research Program)

Taxiway Centerline Deviation Data Collection for Airplane Design Group – III:

Researchers completed collecting taxiway centerline deviation data at Airplane Design Group-III airports. The data was collected from West Palm Beach International Airport, FL; Salisbury-Ocean City Wicomico Regional Airport, MD; Key West International Airport, FL; and Westchester County Airport, NY. The data has been forwarded to Boeing for statistical analysis. (Airport Technology Research Program)

Evaluation of Approach Hold/Runway Safety Area Signage and Markings:

Evaluations of approach hold/runway safety area signage and markings were conducted at the William J. Hughes Technical Center and through simulation. Through these evaluations, researchers were able to eliminate signage featuring multiple lines of stacked text. The remaining signs will be evaluated during a full-scale test at two airports in FY 2015. (Airport Technology Research Program)

Review of Problematic Taxiway Locations Leading to Runway Incursions:

An inventory of problematic taxiway locations was conducted at all towered, NPIAS airports. This included 603 locations currently designated as hot spots and 6,102 additional problematic taxiway locations. These locations were entered into a geodatabase using aerial and satellite imagery and FAA airport diagrams. All surface incidents and runway incursions for the period October 1, 2007 through September 30, 2013 were georeferenced and placed on the corresponding problematic taxiway location. The locations were categorized based on the number of incidents, and will serve as the basis for an improvement plan by the FAA's Office of Airports to minimize the number of runway incursions attributed to problematic geometry. (Airport Technology Research Program)

Small Scale Fire Testing of Aviation Biofuels:

Three alternative aviation fuels which are currently approved by the ASTM testing process have been tested to determine the impacts that these new fuel chemistries pose to the effectiveness of current firefighting foams. (Airport Technology Research Program)

Low Cost Surface Awareness:

The presence of airport surface surveillance has been found to improve air traffic controllers' situation awareness of the airport surface, dramatically decreasing the frequency of runway incursions by up to 70 percent. The FAA is currently completing the installation of integrated surface surveillance capabilities (e.g., Airport Surface Detection Equipment – Model X; ASDE-X) at about 45 of the nation's largest airports. These systems use X-band radar and multilateration to determine the precise location of aircraft on the taxiways and runways of an airport, displaying that information and relevant flight data to controllers in the tower. However, these systems cost the FAA between \$20 and \$25 million per airport, thus making them cost prohibitive for nearly 450 towered airports in the United States. As a result, these small and medium airports are not able to reap the potential safety benefits associated with such systems.

To address this need, the FAA's Center for Advanced Aviation System Development (CAASD) has developed Low Cost Surface Awareness, a block occupancy-based surface surveillance concept and prototype display using off-the-shelf infrared cameras and magnetic sensors for coarse surveillance input. Under this concept, runways and taxiways on the airport surface are divided into operationally relevant blocks, and sensors monitor aircraft and ground vehicles entering and exiting these blocks. As targets move on the taxiways and runways, sensors detect an entry into or an exit from a block, the surveillance system identifies the occupancy status of each block, the status of the block is transmitted to the air traffic control tower, and a user interface presents this status information to controllers.

In the first two years of research, CAASD developed a preliminary concept of operations for Low Cost Surface Awareness and validated the concept by testing a prototype display with experienced controllers in a human-in-the-loop simulation. This prototype display is shown in Figure 24. The team also developed a small sensor network, which was tested with ground vehicles in a parking lot. Collected data was ingested into newly developed algorithms, which were designed to take in raw sensor signals, filter noise, derive block occupancy, and display the occupied block on the prototype display. In FY 2014, CAASD expanded sensor testing to a set of three airports, including Warrenton-Fauquier Airport, Manassas Regional Airport, and Washington Dulles International Airport.

The testing was successful in enabling evaluation of candidate sensor technologies, refining signal processing and block occupancy algorithms, and maturing the concept of operations.



Figure 24: Low Cost Surface Awareness Prototype Display

In order to inform technology transfer activities, the team conducted an examination of the 450 airports in the United States without surface awareness systems to identify the subset of airports which are likely to serve as potential implementation locations. Of those 450 airports, 43 airports were identified as experiencing runway incursion rates similar to those associated with existing ASDE-X airports, indicating a need for improved surface awareness. CAASD estimated that outfitting these 43 airports with Low Cost Surface Awareness would cost \$3.5 million per airport, which is five times less expensive than the ASDE-X system. Due to these promising indications CAASD is continuing its investment in testing and improving LCSA with a goal of transferring the technology to governments and industry worldwide.

Low Cost Surface Awareness is expected to improve controller situation awareness of aircraft and vehicles on the surface, particularly in low visibility conditions. Low Cost Surface Awareness is expected to reduce the number of runway incursions at small and medium airports, as has been observed as a result of the installation of ASDE-X at large airports. (CAASD)

Aviation Safety Information Analysis and Sharing (ASIAS) Capabilities for General Aviation:

The FAA's CAASD recently deployed the General Aviation Airborne Recording Device (GAARD), a prototype low-cost flight data monitoring capability for General Aviation (GA) operators. The capability, a mobile application for a smart phone or a tablet, provides the GA community with a means to record and voluntarily submit basic flight data to a national archive. This capability provides functionality similar to the flight data collection for the commercial

airline community via the FAA Aviation Safety Information Analysis and Sharing (ASIAS) program. Unlike the commercial aircraft fleet, the vast majority of GA fleet has no current capability to record the flight data required for safety analyses. This flight data monitoring capability is a key enabler for the FAA's GA Demonstration Project, a program designed to identify, track, and mitigate safety issues experienced by GA operators.

CAASD researchers designed, tested, and released the prototype software application in response to needs from the General Aviation Joint Steering Committee (GAJSC), a committee formed to improve GA safety through data-driven risk reduction efforts. Voluntary data stored on operators' phones or tablets are collected in the national archive for aggregation and future analysis. Similar to the commercial aircraft ASIAS program, the data will be used to detect and address GA safety trends and provide a means by which a GA pilot can assess his/her performance against an aggregated collection of flight metrics, but will not be used for enforcement actions against the operator.

In developing this prototype capability, CAASD performed a market survey of available technologies, such as installed avionics, mobile devices, and portable attitude and heading reference systems (AHRS). Using this set of options, CAASD designed and developed a proof of concept mobile application, the GAARD, which collects all available data from mobile device sensors, as well as all data provided by an AHRS unit. For proof-of-concept testing, GAARD was placed in a glass panel equipped, four seat Cessna 172 GA airplane. The data collected during the flights was compared to determine the potential quality of GAARD using phone sensors alone, GAARD in combination with the AHRS, and the certified glass panel by itself. Results of the testing showed that each data option had merit and would be a valuable data collection addition to the ASIAS program. User interface screens from the GAARD application are shown in

Figure 25.

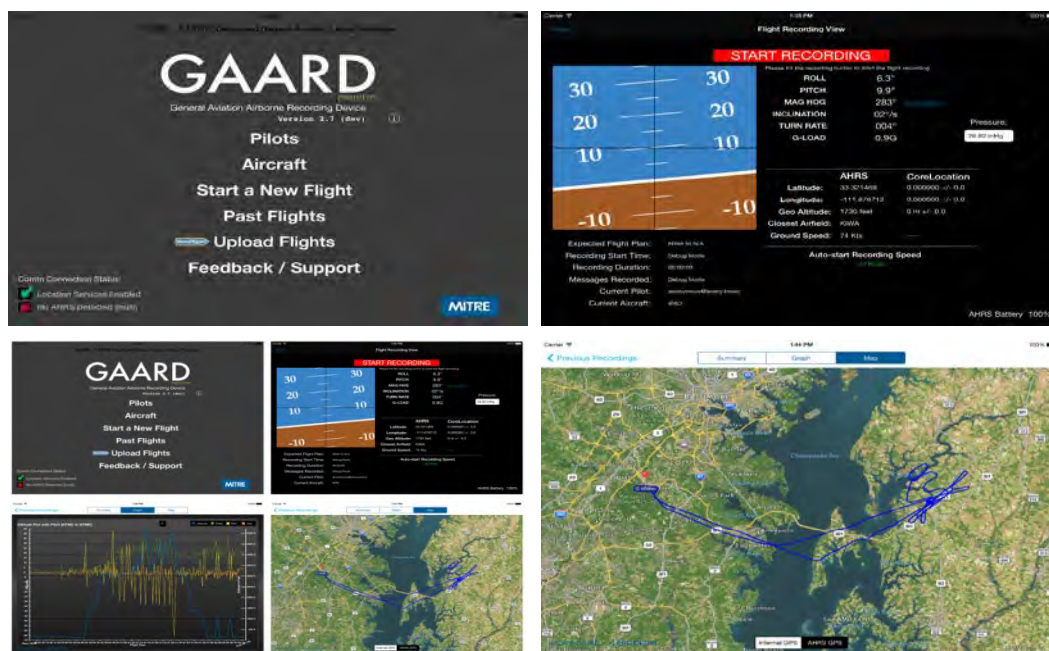


Figure 25: Sample GAARD User Interface Screens

In order to promote pilot use of the GAARD application, and thereby satisfy GAJSC needs, two factors are important. First, the user needs to feel that they are helping the community while not being individually targeted for enforcement. Second, they need to receive something in return for their efforts. Working with user groups in the Phoenix area, as well as with the FAA, National Transportation Safety Board (NTSB), and various industry partners, CAASD developed the user interface for GAARD allowing the operator to securely and privately collect and provide the data to ASIAs, as well as receive valuable feedback on their flights. Multiple iterations of testing and refinement took place, and the iOS application and the Android application were released to the Apple App Store and Google Play, respectively.

The GAARD applications are a critical component of the ASIAs GA Demonstration Project, currently focused on the GA community in the greater Phoenix, Arizona area. Ongoing outreach efforts will bring awareness to the project and to the GAARD apps to determine the viability and effectiveness of the concept. Recent feedback indicates a potential expansion of the GAARD user base to include the Corporate/Business and Rotorcraft communities, both of which also have limited data collection capabilities today. As more operators know about and understand the effort, additional data will be collected and added to the ASIAs program, allowing for earlier identification of safety trends and enabling more community dialog to address the safety risks. As with similar CAASD developed applications, CAASD plans to tech transfer this application to industry, with the goal that this capability becomes a standard feature in the commonly used mobile aviation applications for GA. (CAASD)

Report Centrifuge Test Results Evaluating Biomedical Monitoring Equipment:

Research was completed and the results were presented at the 2014 Aerospace Medical Association Conference in San Diego, CA in May 2014. A journal article was published in July, 2014: Blue, Rebecca S., et al. “Tolerance of centrifuge-simulated suborbital spaceflight by medical condition.” [*Aviation, space, and environmental medicine*](#) 5.7 (2014): 721-729. (Commercial Space)

Rotorcraft Flight Testing:

The HUMS program was developed to validate the Advisory Circular AC29-2C MG15 “Airworthiness Approval of Rotorcraft Health and Usage Monitoring Systems (HUMS)”. A flight test program was performed by the US Army on the UH-60M helicopter to support this research. The purpose of the flight test program was to validate the algorithms for predicting the gross weight and center of gravity of a helicopter while in flight. This work was accomplished with fiber optic sensors developed and provide by Epsilon Optics which were installed in the UH-60M’s 3 landing gear. The algorithms were developed by Sikorsky Aircraft Company and are used with the HUMS system to monitor flight regimes flown. The Army flew flights scripted by Sikorsky, to collect data from the Epsilon sensors to validate the existing algorithms. Data is currently being analyzed by Sikorsky.

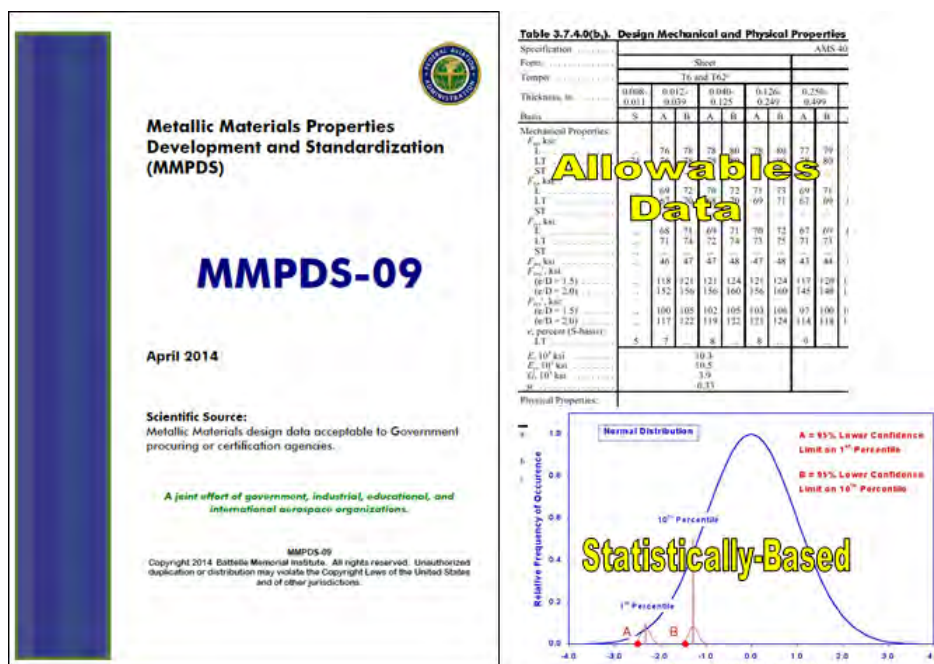


Figure 26: UH-60M Test Aircraft, US Army CERDEC Lakehurst
NJ

Metallic Materials Properties Development and Standardization (MMPDS):

The Metallic Materials Properties Development and Standardization (MMPDS) is an effort led by the FAA to continue the Handbook process entitled “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-09 was released April 2014. Significant changes to the Handbook include a new aluminum-lithium alloy, aluminum sand cast alloy, and a magnesium alloy. There are also additional thickness ranges and upgrades from S-basis to A- and B-basis design allowable properties for a steel alloy, several aluminum alloys, and a copper-nickel alloy. Many other material sections were revised, including updates for stabilized AMS specifications.



NASGRO® Fracture Mechanics and Fatigue Crack Growth Analysis Software:

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.

NASGRO is a NASA-developed software package capable of performing state-of-the-art fracture and fatigue crack growth analysis. Under continuous 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;
- Capabilities to model elastic-plastic loading, failure of glass or glass-like materials under constant loading, and critical crack size.

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 whom 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 FY 2014 have been the release of major version 7.1 in July 2014, as well as release of version 7.01, a maintenance update to the previous version (v7.0), in December 2013. Version 7.1 contains important new technology and improvements, including:

- Solutions for Corner Cracks at offset holes in plates under remote tension, bending, and pin loading;

- Solutions for semi-elliptical offset Surface Cracks in plates under local univariant and bivariant stress gradients;
- A solution for a Through Crack in a plate under remote displacement control;
- Additional capabilities to model the evolution of cracks from one class to another (for example, growing from a corner crack to a through crack);
- Improved capabilities for multi-temperature crack growth analysis;
- Recasting the material properties database from an archaic sequence-based format to a modern XML-based format;
- Addition of fracture and fatigue crack growth material properties for five aluminum and four steel alloys.

(Continued Airworthiness)

Active Flutter Suppression – The Development of a Research Plan:

Flutter is an aeroelastic 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.

This project aims at assessing the state of the art of active flutter suppression (AFS) technology; identifying contributors and collaborators from among the leading industry, government labs, and research organizations active in this area; and creating a recommended research plan for the FAA to pursue that would address all important issues to prepare the FAA for future AFS challenges.

Project accomplishments for this fiscal year include:

- the creation of a thorough data base of AFS technology publications covering a wide spectrum of contributions;
- numerous meetings with experts and stakeholders, including Boeing Commercial and Boeing Research & Technology;

- outreach to potential contributors via presentations at conferences, including the American Flutter and Dynamics Council (AFDC) and a visit to NASA Armstrong Research Center at Edwards Air Force Base (Center of NASA's and the USAF flutter flight testing) and Lockheed-Martin's Skunkworks, designers and developers of the USAF-funded X56 flight test system for aeroelastic/aeroservoelastic flight testing of advanced aircraft configurations.

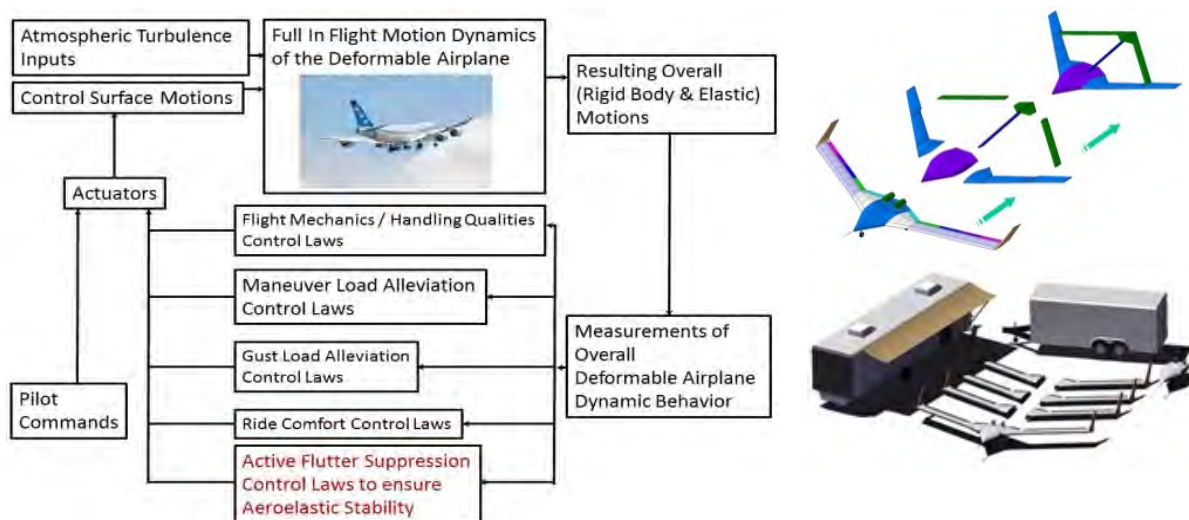


Figure 28: Active Flutter Suppression

A team of experts that would assist the AFS research plan development is currently being finalized. (Continued Airworthiness)

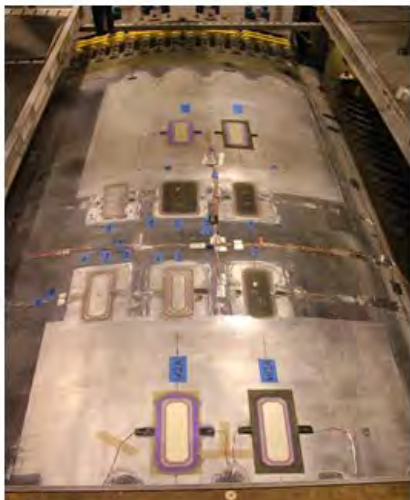
Bonded Repair Technology:

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 FAA Full-Scale Aircraft Structural Test Evaluation and Research (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.

A phased approach is being taken involving the testing and analysis of several panels containing boron/epoxy (B/Ep) composite and aluminum bonded patches, Figure 29. A variety of loading and environmental conditions, damage scenarios, and repair conditions are being considered. The first panel tested (Panel 1) provided baseline data and was completed in FY 2010. The results revealed that properly designed and installed bonded repairs are durable under fatigue and

can effectively contain significant damage under severe static loads in excess of ultimate load requirements.

(a) Fuselage Bonded Repairs



(b) Environmental Chamber



Figure 29: Test step-up used in FASTER Lab: (a) B/Ep and aluminum bonded repair patches; and (b) Environmental chamber to control temperature and humidity

Repair patches on the second panel tested (Panel 2), completed in FY 2012, were intentionally made deficient and to contain defects to permit damage growth. In general, the capability to detect growing flaws under bonded patches and monitor the effectiveness of the repairs was demonstrated using several nondestructive inspection (NDI) methods and a prototype piezoelectric-based structural health monitoring (SHM) system. Model predictions were in good agreement with crack growth test results for the majority of repair patch configurations. However, the test and analysis correlations revealed further research is needed to better account for thermal residual stresses and thick patch configurations.

The two panels previously discussed were tested at laboratory temperature ambient conditions. The next phase of this program was initiated in FY 2013 and focuses on assessing the effects of environment on the durability and fatigue performance of bonded repairs and continued efforts to investigate tools for evaluating and monitoring the repair bond integrity. Further modifications were made to apply synchronous mechanical, temperature and humidity loading profile to test a third panel (Panel 3), Figure 30. With this new enhancement, fuselage panels can now be tested under a variety of operating environments ranging from hot-wet (165 degrees Fahrenheit and 85-95 percent humidity) to extremely cold (-50 degrees Fahrenheit) conditions.

The fatigue test under environmental conditions (165 degrees Fahrenheit and 85 percent humidity) up to 60,000 cycles was completed in FY 2014 for Panel 3. Repair configurations

from the first two panel tests were generally retained for comparison purposes to assess the effects of hot-wet environmental conditions on repair performance. The effectiveness of several NDI methods, including visual inspections, eddy current, flash thermography, and resonance ultrasonic, were studied throughout the test to monitor the growth of the cracks and disbonds.

The effect of environment on fatigue performance of bonded repairs is shown in Figure 30 for a B/Ep composite repair and aluminum patch, UDB and UDA, respectfully. Comparisons were made with results generated from Panel 2 tested under ambient conditions and results from the current Panel 3 tested under hot-wet conditions (165 degrees Fahrenheit and 85 percent humidity). Results for the Boron composite repairs shown in Figure 30 reveal slower crack growth under hot-wet conditions compared to that under ambient lab conditions where the average measured rates were 1.46×10^{-5} in/cycle and 1.95×10^{-5} in/cycle, respectively. In addition, stable crack growth did not occur until after 5,000 cycles under hot-wet conditions. Mismatches in the thermal coefficient of expansion of the composite patch and aluminum fuselage resulted in tensile residual stresses ahead of the notch from the initial patch installation curing process. At elevated temperatures, these tensile residual stresses are relaxed as illustrated in Figure 30. As shown, the hoop strains measured from two notch gages located the same distance from the crack-tip were approximately 14 percent lower under hot-wet conditions compared to ambient conditions.

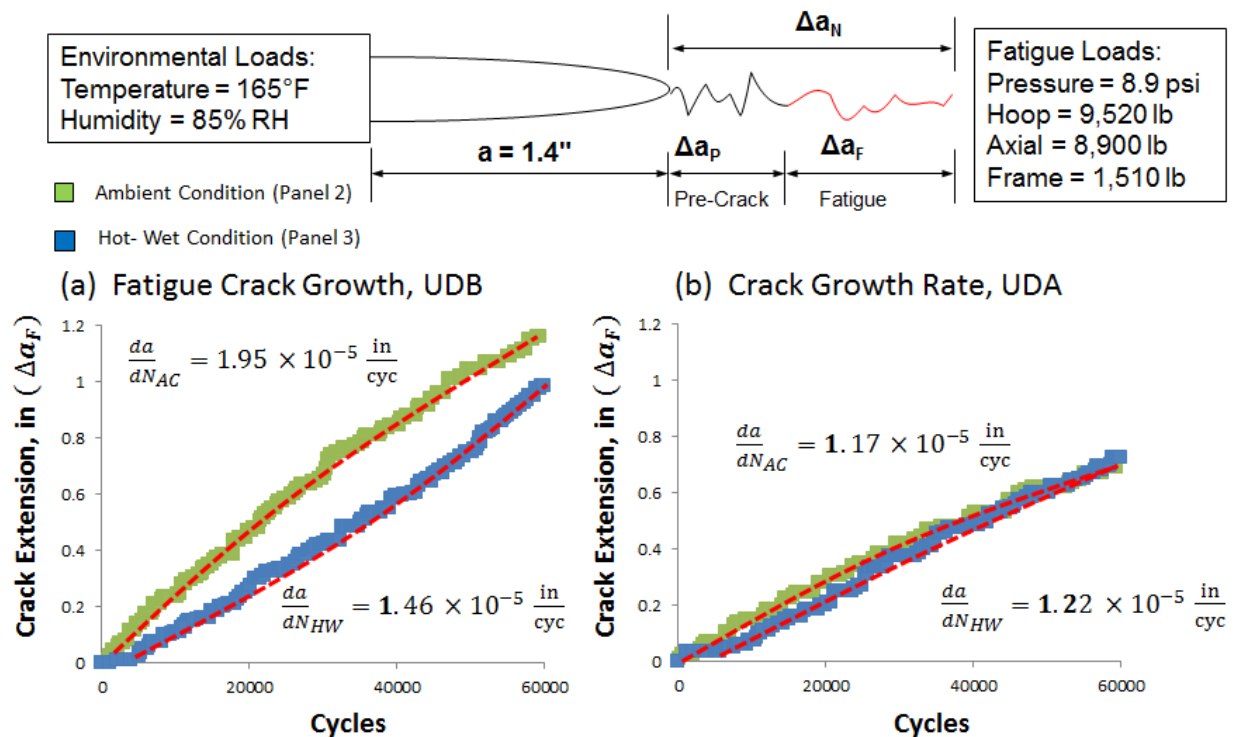


Figure 30: Effect of environment on fatigue crack growth in type-2 repairs: (a) B/Ep, UDB and (b) aluminum, UDA

Results for the aluminum repair indicted limited effect of environment on the fatigue crack growth, Figure 30. As shown the fatigue crack growth behavior was similar for hot-wet and ambient conditions where the measured rates were 1.22×10^{-5} in/cycle and 1.17×10^{-5} in/cycle, respectively. Since both the repair and the fuselage skin are made of aluminum, the coefficients of thermal expansion were similar resulting in limited thermal residual stresses after the initial patch installation curing process. As shown in Figure 31, the hoop strains measured from two notch gages ahead of the crack-tip were similar for both conditions.

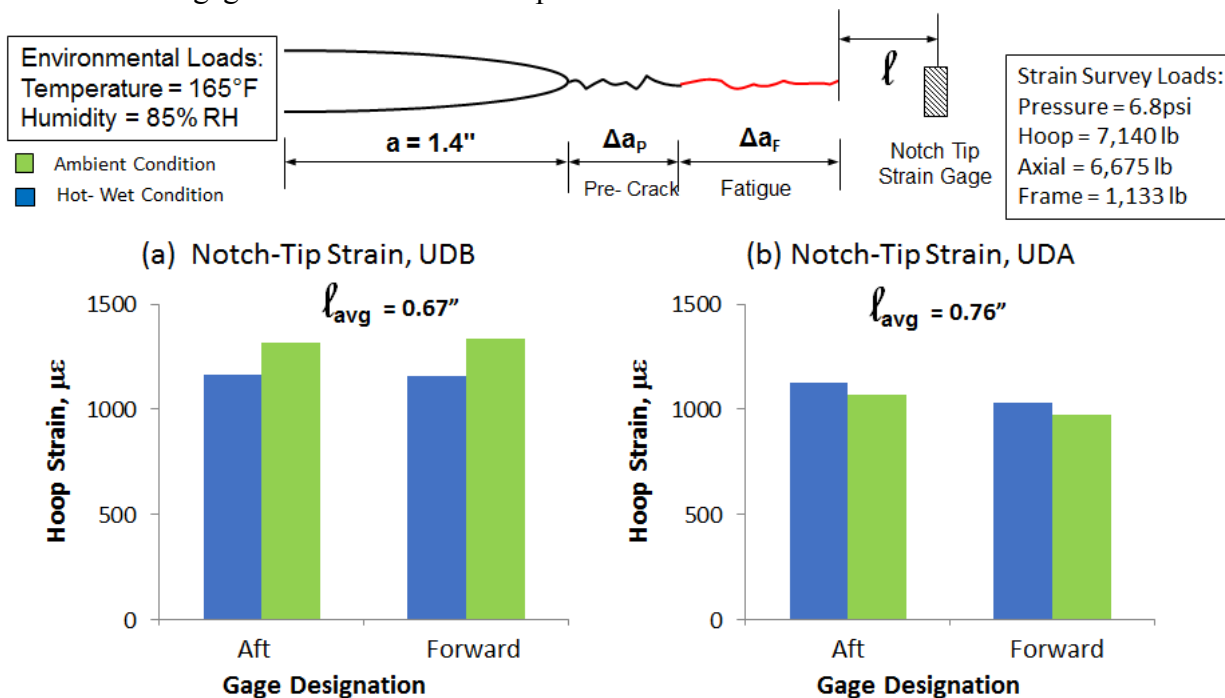


Figure 31: Effect of environment on the residual strains type 2 repairs: (a) B/Ep repair, UDB and (b) aluminum repair, UDA

As part of this phase of testing, improvements in predictive tools to design and analyze bonded repair will be demonstrated and verified through test and analysis correlations. Data from this program will be used to assess methods to quantify bonded repair integrity. (Continued Airworthiness)

Assessment of Advanced Aluminum-Lithium for Primary Structure:

Industry is introducing new metallic alloys seeking to better optimize material properties for specific structural applications. The latest generation of advanced aluminum-lithium alloys (Al-Li) purports to offer potential weight savings compared to conventional aluminum alloys, while maintaining mechanical performance. The latest generation (third generation) of Al-Li alloys

has a lower density, higher modulus, and improved resistance against corrosion compared to the widely used 7xxx and 2xxx series alloys. Previous generations of Al-Li exhibited material behavior (such as low elongation and ductility, low transverse toughness, and inadequate thermal stability and fatigue properties), which restricted their use for many aerospace applications. However, the latest generations of Al-Li alloys are reported to minimize these effects, while also providing significant weight savings.

With these improvements, there has been increased use of Al-Li in recent aircraft and aerospace applications. Bombardier is constructing the entire fuselage of its new C-Series airplane, a Part 25 airplane with 150-seat capacity using Al-Li. Extruded floor beams for the Airbus A380 are now being made of Al-Li. In addition, Al-Li plate applications are being used for the internal structure of the fuselage in the Boeing 787. Although these manufacturers have generated substantial proprietary data to substantiate structural applications, there is a lack of data available in the public domain to thoroughly document the mechanical performance of these latest generation Al-Li alloys.

This study was undertaken 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. As a case study, two Al-Li alloys were considered; namely, 2198-T8 and 2196-T8511 alloys used for skin and extrusion applications, respectively. Several properties were assessed and compared with baseline 2024-T3 and 7075-T6 alloys, including static properties; fatigue life and fatigue crack growth behavior; and supplemental properties. Resources and expertise were leveraged with several organizations including Constellium, Bombardier, NASA-Johnson Space Center (NASA-JSC), Naval Air Systems Command (NAVAIR), University of Dayton Research Institute (UDRI), Drexel University, National Institute for Aviation Research (NIAR), Sandia National Laboratories, Fatigue Technology (FTI) and the FAA Technical Center (FAA-TC). The 2196-T8511 alloy was supplied by Bombardier in the form of I- and Z-shaped extrusions and was tested at thicknesses of 0.06", 0.12", and 0.145". The 2198-T8 alloy was supplied by Constellium in the form of sheet material having thicknesses of 0.071", 0.125", and 0.25". Each material was also tested at three major grain directions (L, LT, and 45°), plus two midpoints (22.5° and 67.5°), to assess the extent of anisotropic behavior in the materials.

The objective of this test program is to obtain data to better define the mechanical properties of typical Al-Li alloys being used in airframe applications. The limited data currently provided in the public domain does not provide a full understanding of the strengths and weaknesses of these materials. Data provided by this program is not intended to establish design values, which would satisfy the regulatory requirements for designing and certifying civil aircraft. Instead, the data from this program will be used to better assess the adequacy of current regulations on this new material type being proposed by applicants in their aircraft designs.

The test program is broken down into three main test types: static properties, fatigue and fatigue crack growth properties, and supplemental properties. Each group then consists of numerous individual test plans, which were carried out by one of the partners listed above. The testing for this program was initiated in FY 2012 and is scheduled to conclude in FY 2015. Through the end of FY 2014 a total of eight individual test plans have been completed, three are currently underway and one is scheduled to begin in early FY 2015.

The results to date have shown that the static properties of the two Al-Li materials have exceeded their applicable MMPDS basis values as expected. The Al-Li alloys did show signs of anisotropy with lower strengths values at the 45° grain direction as illustrated in Figure XX. In axial fatigue testing the 2198-T8 alloy showed similar crack growth resistance for the threshold and stable crack growth regions of the da/dN versus ΔK curve across all grain orientations tested as well as when compared to the baseline 2024-T3. The 2198-T8 did show some signs of anisotropy for the upper region of the curve with the 45° direction recording the highest cracks growth resistance though it also outperformed the 2024-T3 across all grain directions in this region. These results were also seen when the materials were tested under spectrum loading conditions engineered to more closely resemble in-flight load variations shown in Figure XX.

When the materials were fatigue tested in a two-row lap joint configuration the 2198 showed lower cycles to failure across all grain directions compared to the 2024. This initial comparison was done with 2024 bare material however and when repeated with 2024 clad, which is typically used for fuselage skin applications, the 2024 clad showed the lowest cycles to failure. A comparison of the average fatigue lives for the three materials is shown in Figure XX. It is important to note though that the lap joint configuration used was not typical for the aerospace industry and was shown to produce four times the bending. After the lap joints were tested they were examined under a scanning electron microscope (SEM) for a fractographic analysis. A comparison of the fracture surfaces, shown in Figure XX, revealed significant differences between the materials. The 2024 material has a very rugged fatigue surface with very distinct striations. One of the reasons for this is the presence of large constituents in the material that actively affect the progression of the crack front. The constituents appear to arrest local crack growth and form local initiation sites. This is contrasted by the 2198 surface, which is much smoother by comparison. The striations in the 2198 are also much shallower and the constituents are generally clustered along the grain boundaries leading to the formation of a single, dominant crack front. In addition interlaminar cracks were observed in the 2198 exclusively and were found at both the micro and macro levels. A number of lap joint specimens were also run with marker band sequences in the load profile which were designed to alter the fatigue surface roughness which results in a visible (under an SEM) band across the specimen. The pattern of bands can then be used to estimate fatigue crack growth rate and crack front shape throughout the specimen. The work evaluating the marker band specimens is currently underway.

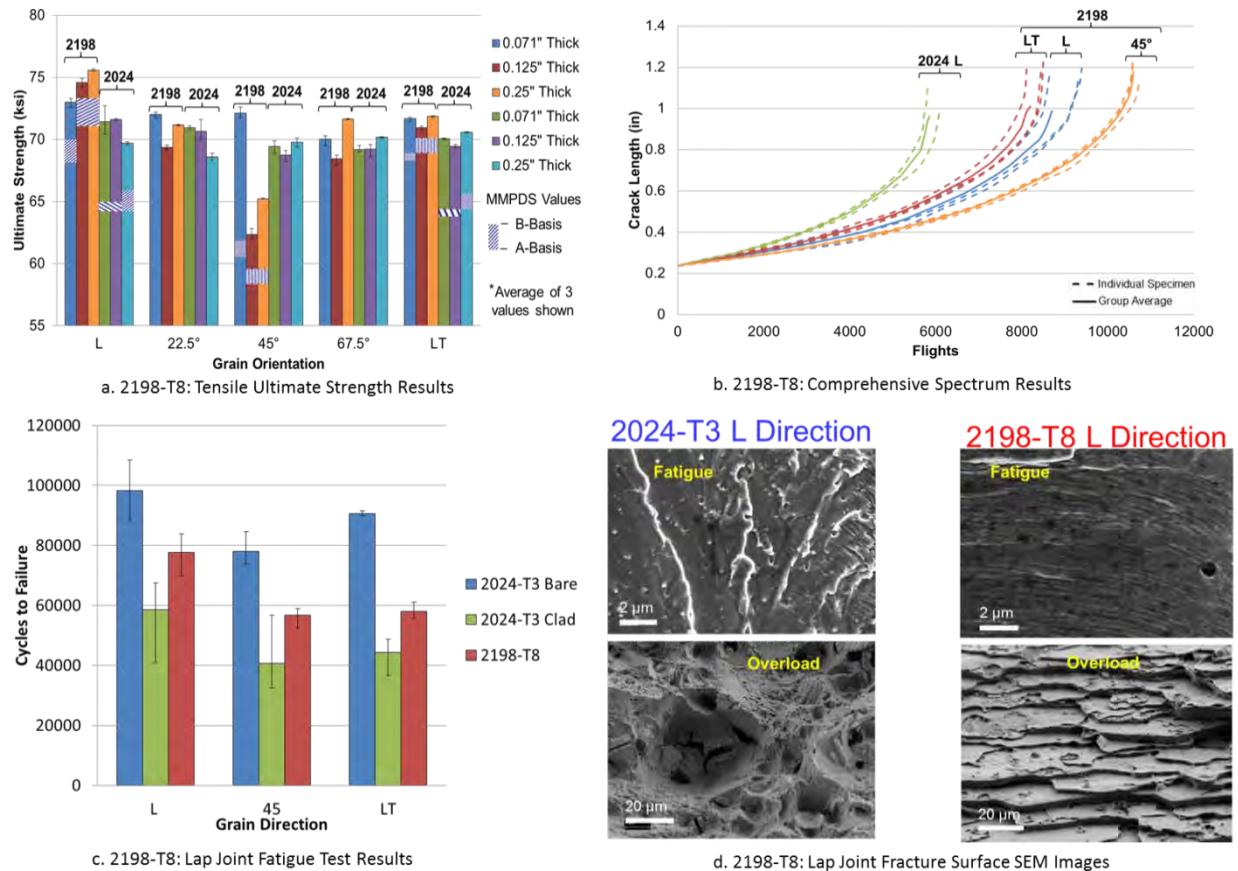


Figure 32: Test results for aluminum lithium

Two of the supplemental property tests are currently underway as well. The environmentally assisted cracking using slow strain rate test is being run by NAVAIR, where specimens are slowly pulled to failure while being exposed to a harsh corrosive environment. The tests are being run at three different speeds with the slowest speed taking up to six weeks per specimen. Also under way is the fastener hole process test. The specimens have been machined with cold worked holes and interference fit fasteners and are now awaiting non-destructive inspection to determine if these common machining practices have any adverse effects on the Al-Li. Finally, a fire burn through test was completed. The 2198 showed a longer burn through time compared to the baseline 2024 and did not show any signs of combustion or reignition. (Continued Airworthiness)

2014 Survey of Emerging Metallic Structures Technology:

New and Emerging Metallic Structural Technology (EMST) is being implemented 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 unique characteristics of these new materials and processes is critical for the FAA's aircraft certification technical specialists to appropriately assess the certification approach for each application.

Regulations, policy, and guidance materials will be applied to these new technologies based on interpretations of the technology, the intended application and any unique characteristics that should be considered. Consistency of application and interpretation of regulation, policy, and advisory materials will be an important aspect of these new certifications.

The following emerging metallic structural technology developments and subsequent issues are highlights from this year's investigations:

Aluminum-Lithium Alloys will be the predominant new EMST for aerospace structure. This is based on the efforts that original equipment manufacturers (OEMs) are placing on qualification of new materials, as well as the large capital investments that material suppliers are investing in new plants to produce and process new Al-Li products like those in Figure 33. Implementation of Al-Li will be seen mostly on new aircraft design of commercial transport aircraft.

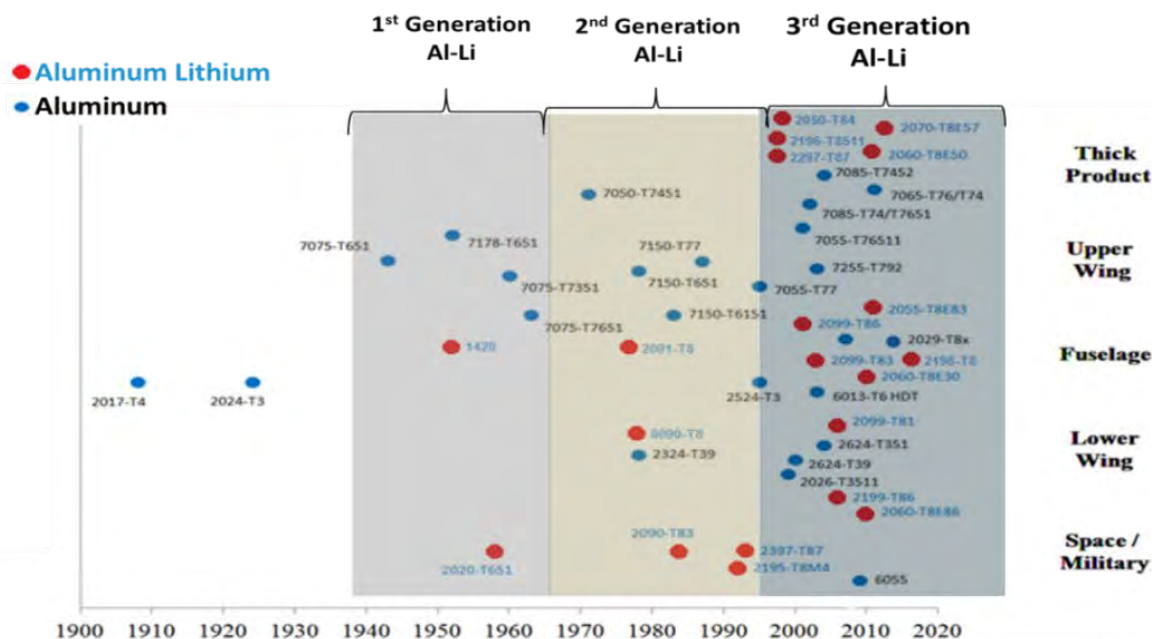


Figure 33: Evolution of aerospace aluminum products

Environmental regulations on the horizon (REACH) will eliminate most of the known materials and processes commonly used for corrosion protection and control. The replacement materials and processes to date are not fully developed and have not yet formed any basis for design or inspection. New Al-Li alloys are inherently suited for galvanic and stress corrosion but with new coatings still being developed the long-term impact is still an unknown.

Automation in manufacturing is given the highest priority in development because it addresses recurring manufacturing costs and reduces variability. The current state-of-the art in aircraft assembly spends considerable time and design to account for manufacturing variability. Figure 34 illustrates that automation already is used to install most fasteners on modern aircraft. Automated inspection and real time inspection techniques for physical features are employed with a great deal of accuracy.



Figure 34: Automated aircraft assembly

Hybrid structures are on the rise as designers seek traditional and non-traditional solutions to improve performance and decrease weight. A hybrid structure may be as simple as laminating multiple sheets of aluminum of differing alloys to optimize the collective laminate performance they desire. 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. Concepts with discrete and differing materials such as the use of a composite strip under an aluminum stiffener show promise of improved durability and crack-arresting characteristics. Inspection and analytical predictive capability is being developed and will need careful validation. Certification standards will need to be developed for these composite/metallic structures that account for thermal and processing stresses as well as the differing requirements for durability and damage tolerance.

Large-scale electron beam and friction welded assemblies are already being delivered in transport aircraft and will continue to rise because this technology is easy to scale up in factory settings. Integral stiffeners in unitized structures eliminate rivets but the definition of a two bay crack and arresting means need to be reviewed. Qualification data on friction welding will continue to be elusive as many certifications will use a point design approach because of the numerous variables and lack of consensus on generic specifications and test requirements.

Additive manufacturing processes are being pursued with earnest with the help of government technology initiatives because it eliminates many steps currently used in traditional subtractive manufacturing processes. Several national initiatives have begun to standardize testing and characterize process to performance. Additive materials and processing pose several issues with aircraft certification as the need to quantify the variability in part performance is complicated by the many numerous variants in material and processes.

Unlike traditional metals where purchased materials come with material certifications guaranteeing performance, additive manufacturing, a process intensive material is totally dependent upon the material and process controls at each manufacturing operation (see Figure # below). Similar challenges were overcome with composites and now have standard processes such as the National Center for Advanced Material Performance (NCAMP) where industry, with FAA oversight developed consensus specifications for build, control and test and the generation of material allowables.

This year an effort was initiated to determine if the existing structure of a process like NCAMP could provide the needed backbone for a similar approach to material properties from an additive process. This study continues in the current fiscal year.



Figure 35: Aircraft parts made from additive direct energy deposition

Computational simulation capabilities have improved tremendously due to improved tools, computer speed and efficiency. Validation techniques are evolving and are in need oversight and standardization. Industry is already looking to the future where simulation may replace conventional processes for inspection, test and predicting material performance. Regulators will

need a broader understanding of the computational simulations being used, their limitations and create consistent policy on validation and acceptance.

Incorporation of EMST into transport aircraft will accelerate because the technology is developing rapidly and customers are demanding better products sooner with improved performance and reduced cost. This will lessen the time given to regulators to evaluate the impact of EMST on the certification approach, regulations, policy and advisory materials. Industry applauded recent FAA efforts to understand EMST and the effect on requirements because understanding the requirements early in the development is easier to address with robust solutions.

An EMST technology roadmap has been developed to address gaps in technology and identify where targeted research should be applied to provide greater insight to the characteristics and limits of these new technologies. The roadmap incorporates the current status of EMST, new EMST, and results of ongoing research and testing in the areas where research should be applied to meet project objectives.

The study use surveys, literature searches, material conferences and symposiums, interviews, and site visits of material manufacturers, aircraft manufacturers, and structural component suppliers. The technologies focused on include several major technologies that offer substantial performance improvements with the potential to meet the new cost targets for the next generation of aircraft. This study has concluded that the identified EMST will see widespread acceptance and usage within the decade and certainly in the next generation of single-aisle transports, regional jets, and general aviation aircraft.

The EMST surveys will continue by contact existing OEMs, follow up on evolving technology and monitor industry research as it may pertain to the assessment of EMST. 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 needed and has been widely praised by industry as a proactive action to improve the FAA's technical position in this evolving technology.
(Continued Airworthiness)

The FAA-Drexel University Fellowship Program:

The FAA-Drexel University Fellowship Program, which was established in 1997, 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 of engineers to address aviation and aerospace safety. The actual R&D is conducted and executed at the FAA's Structures and Materials section facilities at the William J. Hughes Technical Center in Atlantic City. The work is conducted by Drexel's graduate and undergraduate students under the combined supervision of FAA scientists and engineers, led by Dr. John B. Bakuckas, and Drexel faculty Drs. Jonathan Awerbuch and Tein-Min Tan. The course work and academic supervising takes place at Drexel University's campus.

In FY 2014, the FAA-Drexel Fellowship Program supported: 27 undergraduate students in five senior design projects, approximately 20 undergraduate students (working part time, either for credit or for hourly pay) who were involved in many different research projects, 7 co-op students (each six-month long sessions at the FAA-TC), 11 M.S. students (completed and current), 9 Ph.D. students (completed and current), with some 35 of them were awarded various first place prizes within and outside Drexel, generating over 75 conference and journal publications and FAA Reports and a similar number of conference presentations.

In FY 2014, one of the Program Fellows, Andrew Bergan, Ph. D., developed a progressive damage model to analyze the damage containment capability of a PRSEUS fuselage structure. The model was validated using test data from a full-scale PRSEUS panel tested in the FASTER lab. Dr. Bergan actively participated in a team effort with engineers from the FAA, NASA and Boeing during all stages of testing. He was awarded an internship at the NASA Langley Research Center (LaRC) through the Pathways Program and, since receiving his degree, has accepted a full-time position at NASA LaRC. Results of this work conducted in FY 2014 were published as follows:

- Bergan, A.C., Bakuckas, J.G. Jr., and Korkosz, G.J., "FASTER Fixture Modification: PRSEUS Test," FAA Technical Note (Submitted and under review).
- Bergan, A.C., and Bakuckas, J.G. Jr., "Full-Scale Test of an Advanced Stitched Efficient Unitized Structural Concept Panel," FAA Technical Report (Submitted and under review).
- Gould, K., Lovejoy, A.E., Jegley, D., Neal, A.L., Linton, K.A., Bergan, A.C., and Bakuckas, J.G. Jr., "Nonlinear Analysis and Experimental Behavior of a Curved Unitized Stitched Panel," Journal of Aircraft, 2014.
- Bergan, A. C., Dávila, C. G., Leone, F. A., Awerbuch, J., Tan, T., "An Efficient Model for Assessment of Damage Containment in a Notched PRSEUS Fuselage Panel Subject to Combined Loads," Presented in the 2014 Aircraft, Airworthiness and Sustainment Conference, April 14-17, 2014, Baltimore, MD.
- Bergan, A. C., Dávila, C. G., Leone, F. A., Awerbuch, J., Tan, T., "Mode I Cohesive Law Characterization of Through-Crack Propagation in a Multidirectional Laminate," The

29th American Society for Composites Technical Conference, September 8-10, 2014, San Diego, CA.

- Bergan, A. C. “Test and Analysis of Stitched Composite Structures to Assess Damage Containment Capability,” PhD Dissertation, 2014, Drexel University, Philadelphia, PA.

Another Fellow, Mr. Reewanshu Chadha, Ph. D. Candidate, worked on developing a finite element (FE) model of adhesively bonded repairs of aluminum fuselage structure. The modeling follows a three-step analysis:

- i. Develop a global model for a pristine panel and validate with the experimental results;
- ii. Develop a global model with a crack at a chosen mid-bay location, repaired by a bonded patch;
- iii. Develop a local model that represents the cracked mid-bay location with the bonded repair.

The finite element results of the two global models were found to be in good agreement with the experiments. Presently, fatigue crack growth analysis is underway using the local model. Initial comparison of finite element model with experimental results were presented at the 2014 Aircraft Airworthiness and Sustainment Conference held at Baltimore, MD (April 14th -17th 2014). Results of this work conducted in FY 2014 were published as follows:

- Chadha, R., Bakuckas, J., Duong C. and Hunziker K., “Adhesively Bonded Repairs to Metallic Fuselage Structure: Test 2, Monitoring Damage Growth,” FAA Technical Report (Submitted and under review).
- Chadha, R., Bakuckas, J., Awerbuch, J. and Tan, T., “Effect of Adhesively Bonded Composite Patch Stiffness on Fatigue Crack Growth in an Aluminum Fuselage Panel,” Presented in the 2014 Aircraft, Airworthiness and Sustainment Conference, April 14-17, 2014, Baltimore, MD.

Bin Lei, Ph. D. Candidate, studied the effect of environment on the durability of bonded repairs of a metallic fuselage structure. Phase 2 testing of the third B727 fuselage panel was completed. The panel, having both boron/epoxy and aluminum bonded repair patches, was subjected to mechanical fatigue loads of one design service goal (60,000 cycles), under hot-wet environmental condition (165 degrees Fahrenheit and 85 percent humidity). The effects of the environmental condition (i.e., ambient versus hot/wet) on the fatigue crack extension and fatigue crack growth rate, under repair with bonded boron/epoxy and aluminum repair patches, was investigated. Results of this work conducted in FY 2014 were published as follows:

- Bin Lei, Yongzhe Tian, John G. Bakuckas, Jr., Ian Y. Won, Mark Freisthler, Kelly Greene, Carlyn Brewer, Gregory Korkosz, Jonathan Awerbuch, and Tein Min Tan, “Test of Adhesively Bonded Repairs to Fuselage Structure Subjected to Environmental Conditions,” Presented in the 2014 Aircraft, Airworthiness and Sustainment Conference, April 14~17, 2014, Baltimore, MD.

Other Fellows conducted a detailed fatigue fracture surface morphology of aluminum alloys AA2024-T3 and AA2198-T8 in the L, LT, and 45° directions. Primary focus was on examination of the pattern of fatigue striations using scanning electron microscopy (SEM). A particular pattern of flow lines was identified, defined as “striation ridges”. Based on these striation ridges, the cycle number at which fatigue crack initiated could be approximately estimated. Further attempts to establish fatigue initiation sites, based on the shape and area of the fatigue region, is underway. Due to challenging identification of striations, additional fatigue tests were conducted under a spectrum fatigue loading that generates fatigue marker bands. Using the marker band pattern, the shape of the fatigue crack front and crack extension could be more readily identified. Results of this work conducted in FY 2014 were published as follows:

- Awerbuch, J., Bakuckas, J., Anasori, B., Saillot, F., Stanley, D., Stonaker, K., Tan, T., “Fractographic Examinations and Reconstruction of Fatigue Crack Growth in Aluminum Lithium Riveted Lap Joints,” Presented in the 2014 Aircraft Airworthiness & Sustainment Conference, Baltimore, 2014.
- Babak Anasori, Franklin Saillot, David Stanley, Jonathan Awerbuch, Tein-Min Tan, “Fatigue Crack Growth in Aluminum Lithium Riveted Lap Joints,” *Procedia Engineering*, Vol. 74, 2014, Pages 413-416, ISSN 1877-7058, available at <http://dx.doi.org/10.1016/j.proeng.2014.06.291> and <http://www.sciencedirect.com/science/article/pii/S1877705814008613>.
- Babak Anasori, Franklin Saillot, David Stanley, Jonathan Awerbuch, and Tein-Min Tan, “Fatigue Crack Growth in Aluminum Lithium Riveted Lap Joints,” Presented in the XVII International Colloquium on Mechanical Fatigue Of Metals (ICMFM-XVII), Lake Maggiore, Verbania (Italy), 25-27 June 2014.

(Continued Airworthiness)

Effect of Environment on Fatigue Performance of Bonded Repairs:

Researchers completed a major phase of testing in a joint effort between the FAA and the Boeing Company investigating the effects of environment on the structural robustness and fatigue performance of adhesively bonded repair technology using the FAA Full-Scale Aircraft

Structural Test Evaluation and Research (FASTER) lab. B-727 fuselage panels containing boron/epoxy (B/Ep) composite and aluminum bonded patches were fatigue tested under environmental conditions (165 degrees Fahrenheit and 85 percent humidity) up to a typical design service goal of 60,000 cycles. Results for the B/Ep composite repairs reveal slower crack growth under hot-wet conditions compared to that under ambient lab conditions due to relaxation of thermal residual stresses. Data from this program will be used to improve predictive tools to design and analyze bonded repairs and to assess methods to quantify bonded repair integrity. (Continued Airworthiness)

Structural Health Monitoring:

Structural Health Monitoring (SHM) is the next advancement in inspection technology. The FAA under its Inspection program has funded sensor evaluation programs providing the foundation for sensitivity, durability and repeatability issues to advance SHM use on commercial aircraft. The FAA started the SHM project in anticipation of future use of SHM to help determine if any regulatory needs would be required for use in commercial aviation.

Sandia National Labs (under the direction of the FAA) partnered with Delta Air Lines, Boeing, SMS, and AEM to conduct the first installation of Comparative Vacuum Monitoring (CVM) sensors onto 7 737-700 aircraft, ultimately resulting in a change to the Maintenance Program. Over 7 weeks in February through March 2014 in Atlanta, Delta mechanics installed 10 CVM sensors per aircraft on the center wing box fitting to monitor a cracking problem. Delta will monitor the sensors every 90 days. This incorporation of Structural Health Monitoring (SHM) onto a post-production fleet of aircraft faced technical, financial, and logistical challenges. This is the first application of an SHM sensor on a US commercial aircraft. Delta will save 48 hours per inspection over their 81 aircraft and could realize a cost avoidance of \$2.5 million because the service bulletin requires an extensive disassembly of the interior of the aircraft to reach the center fuel tank and the fittings in question. The CVM sensors can be accessed via a cargo compartment and the inspection will take minutes versus hours.

The Comparative Vacuum Monitoring (CVM) sensor is a small, self-adhesive, elastomeric patch, ranging from dime- to credit-card-sized, that detects cracks in the underlying material. The elastomer is laser-etched with rows of tiny, interconnected channels, to which vacuum pressure is applied. Any propagating crack under the sensor breaches the galleries and the resulting change in pressure is monitored. When a crack develops, it forms a leakage path between the atmospheric and vacuum galleries, producing a measurable change in the vacuum level.



Figure 36: Comparative vacuum monitoring sensor

This undertaking moves past the ‘prototype’ experiments of the past and will provide the certification path required for increased adoption. Delta has been instrumental in investigating what requirements are to be met to incorporate a change in maintenance program, including certification. FAA-AANC (Sandia National Labs) has led the program to facilitate the ‘tech transfer’ and widespread adoption into the industry. The work accomplished will serve as the ‘blueprint’ for the industry to follow: airlines, MROs, regulatory agencies, vendors and academia. This work was recognized by the Airlines for America and SAE winning the 2014 A4A-SAE “Better Way Award”. (Continued Airworthiness)

Fire-Safety of E-Tablets used as In-Flight Entertainment:

The usage of electronic-tablets (e-tablets) as a replacement for the conventional in-flight entertainment system has gained in popularity among airlines globally. Innovative methods of storing and charging e-tablets in galley carts have been suggested or are already in service with some airlines.

The danger of thermal runaway in the lithium-ion-polymer batteries that are used in these e-tablets is well known but the potential fire hazard resulting from e-tablets being stored and charged in galley carts or a similar enclosure has not been established. To examine this potential fire hazard, the Civil Aviation Authority of Singapore and the FAA carried out a series of tests to investigate the behavior of stored e-tablet fires.

The tests were conducted within a galley cart in a fully-operational but non-flyable 737 test aircraft. Thermal-runaway of the e-tablet lithium-ion-polymer battery was initiated by either a heat plate or an external alcohol fire. The arrangement of e-tablets inside the galley cart followed the typical methods of storage proposed by airlines and design organizations. The objective of the tests was to determine a suitable storage configuration for the e-tablets which would prevent the propagation of thermal runaway and to determine the effect that thermal runaway would have on a typical galley cart.

Ten tests were conducted, and the conclusions associated with these tests are listed as follows:

- 1) The risk of lithium battery thermal runaway propagation was minimized by arranging the e-tablets in a vertical orientation and providing sufficient spacing between them.
- 2) Thermal runaway may cause the accumulation of flammable gasses in the galley cart and the risk of an explosion. An explosion can forcefully open a latched galley cart door.
- 3) The uncontained fire or explosion created within the galley cart due to thermal runaway had the potential to emerge out of the galley cart and spread to the adjacent structure and materials of the aircraft cabin (see Figure 37).
- 4) As a result of the uncontained fire, there was a heavy accumulation of smoke in the cabin which had the potential to interfere with firefighting efforts.



Figure 37: Flames emitted from e-tablets within a closed galley cart

The results of these tests provided evidence of the potential fire hazards associated with bulk storage of e-tablets in a galley cart or similar enclosure in the event of thermal runaway in a single lithium battery. Additional work was recommended to determine the desirable features of galley carts to contain a lithium battery fire and prevent the danger associated with fire, smoke intensity and explosion. (Fire Research and Safety)

Measuring Gas Phase Activity of Flame Retardant Compounds in Aircraft Plastics Using the FAA Microscale Combustion Calorimeter:

Flame retardant compounds are routinely added to plastics in order to pass stringent FAA fire performance requirements for ignitability, smoke generation and heat release rate of cabin materials. The most effective and widely used flame-retardants in aircraft interiors are bromine-

containing compounds that slow down (inhibit) the heat-producing reactions of the fuel gases with oxygen in the flame of a burning plastic. These heat-producing reactions occur in the combustion zone of the flame, shown in red on the left hand side of Figure 38, can be reproduced in the combustor of the FAA microscale combustion calorimeter, or MCC, shown on the right hand side of Figure 38. Slowing down these combustion reactions in the flame using gas-phase active flame-retardants reduces the heat release rate of the burning plastic and leads to passing results in FAA fire tests. Unfortunately, some of these compounds, called polybrominated diphenyl ethers, or PBDEs, are being phased out by the Environmental Protection Agency (EPA) because of health and environmental concerns and are no longer available for use as flame-retardants for aircraft interior plastics.

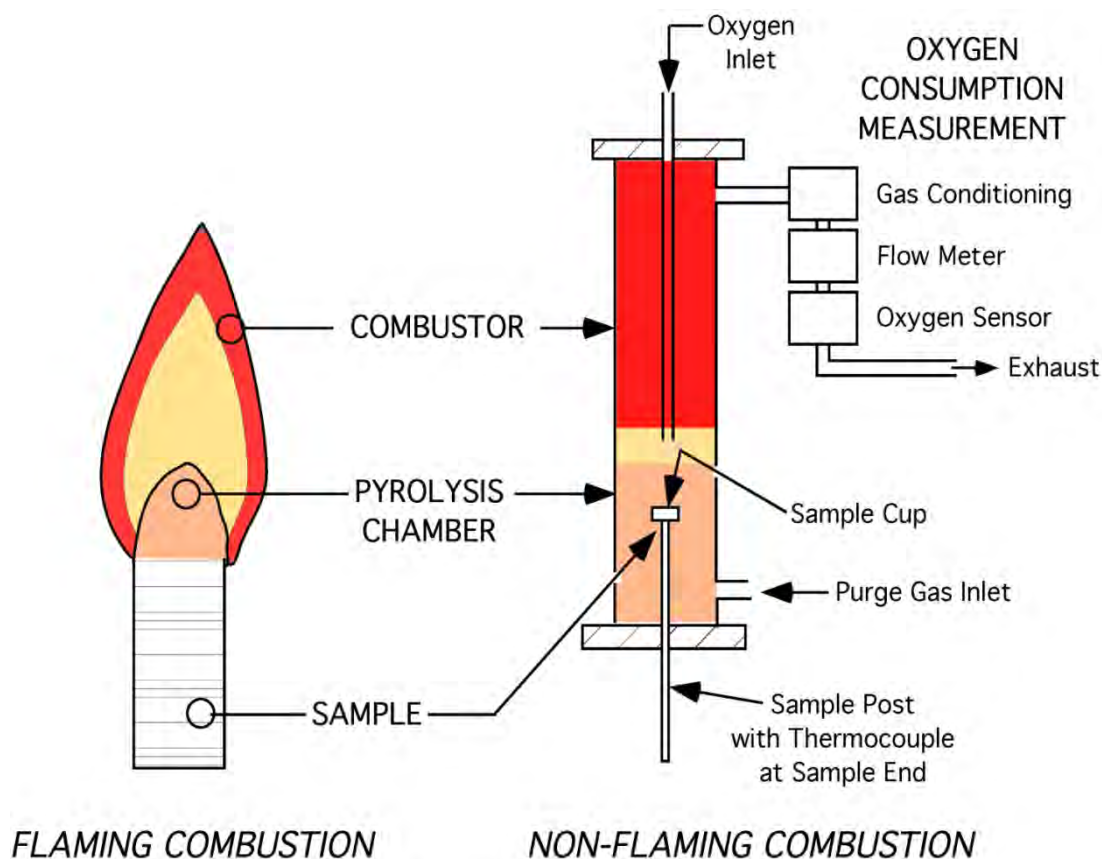


Figure 38: Diagram showing how the MCC reproduces the processes of flaming combustion in a non-flaming laboratory test

To accelerate the discovery of PBDE alternatives we attempted to use the FAA microscale combustion calorimeter (MCC) to measure how much flame-retardant slow down the combustion reactions of polymers in flames and compare these results to fire performance to see if the MCC could be used to screen new compounds for flame inhibition in fire tests. Under standard conditions [1] the MCC generates a gaseous fuel pulse of the flame retardant plastic by controlled pyrolysis of milligram-sized samples in nitrogen, and complete combustion of these

fuel gases at 900°C in excess oxygen. Our approach to screening flame-retardants for gas phase activity was to lower the combustor temperature to slow down the combustion reactions [2]. Measuring the amount of oxygen consumed by flame retardant plastics at each temperature in the MCC combustor allows for calculation of the speed of the heat producing reactions in the flame and the effect of flame retardants on the heat release rate of the burning plastic.

The figure above is a bar graph showing the results of these experiments and calculations for blends of brominated polystyrene with pure polystyrene, mixtures of tetrabromobisphenol-A epoxy with bisphenol-A epoxy, and compounds of red phosphorus flame retardant in nylon. Plotted on the ordinate (y-axis) of Figure 39 are the flame retardant/polymer system and the weight percent of the active flame retardant element (bromine or phosphorus) in the compound. The abscissa (x-axis) is the extent to which the flame retardant slows down the combustion reaction of the polymer in the flame, plotted on a logarithmic scale. Figure 39 shows that bromine slows down (inhibits) the combustion reactions in a polystyrene flame more than a thousand fold, while bromine slows down the rate of the epoxy combustion reactions by only a factor of ten or so. Flame inhibition of nylon by phosphorus is small compared to the bromine systems. This is consistent with the known mechanism of phosphorus activity, which is to increase char formation in the solid polymer to reduce the amount of combustible gases given off during burning. These results indicate that both the flame retardant and plastic fuel is important in determining the flame inhibiting activity of gas phase flame-retardants.

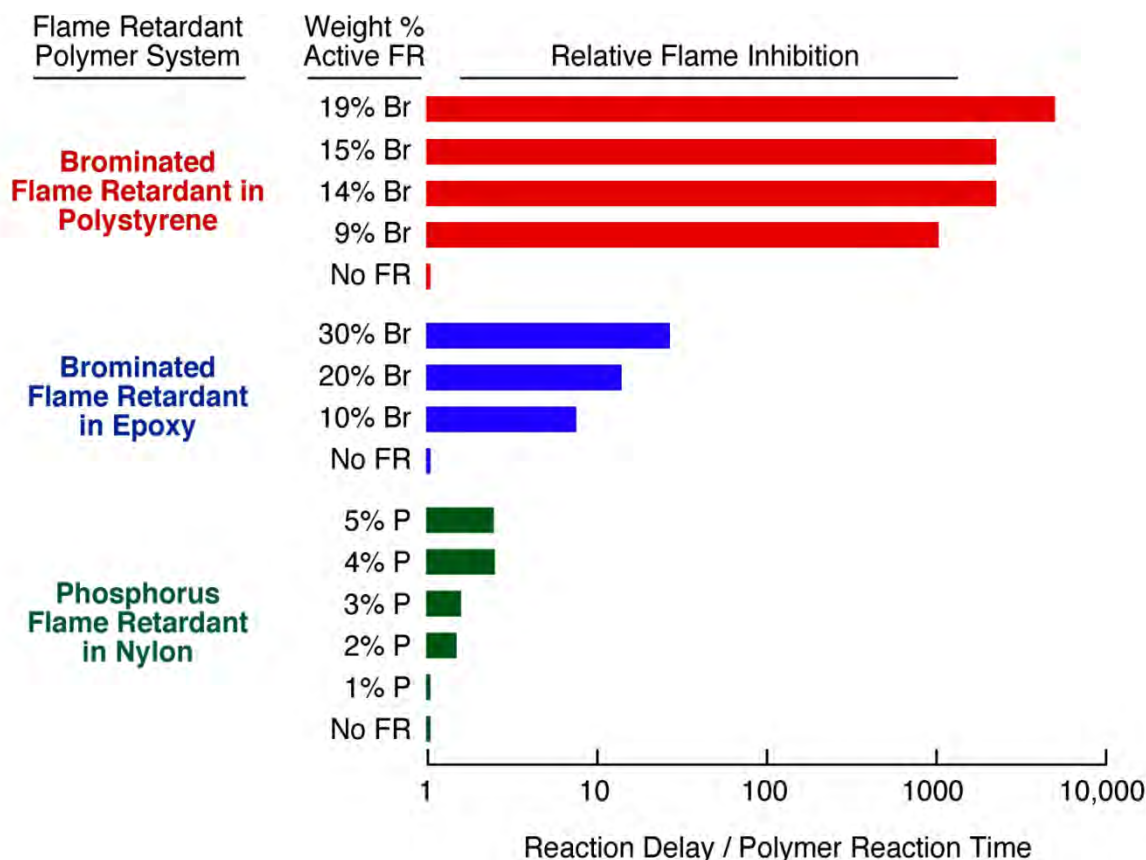


Figure 39: Relative flame inhibition of bromine and phosphorus flame retardants in polymers

The relative flame inhibition of bromine and phosphorus in polystyrene, epoxy and nylon shown in Figure 39 is consistent with fire test results for these systems, which show an increase in fire performance with an increase in gas phase activity. Consequently, we have demonstrated a methodology using a standardized, lab-scale test (the MCC) that is useful for screening PBDE replacement flame-retardants for gas phase activity. (Fire Research and Safety)

Adaptation of the Next Generation Burner to the Aircraft Seat Cushion and Cargo Liner Flammability Tests:

Past FAA research yielded the development of stringent test requirements for seat cushions and cargo liners that expose the material samples to a severe flame produced by an oil burner. The research was driven by full-scale fire tests that demonstrated a 40-60 second improvement in post-crash fire survivability through the use of seat cushions meeting the new criteria. Testing indicated the urethane foam used in the seat cushions was the primary fuel source involved in a cabin fire. Separate research focused on the ability of the protective cargo compartment liner system at preventing in-flight cargo fires from burning through the liner. A new stringent

flammability test for cargo liner burn through resistance was developed to ensure that cargo fires would be confined within the cargo compartment until the aircraft could be safely landed.

During the development of both the seat cushion flammability test and the cargo liner burn through test, the Park DPL-3400 burner became the burner of choice as these tests were standardized and became regulation. Several hundred Park burners were manufactured for this application. However, during the more recent development of a new test for thermal acoustic insulation burn through resistance, production of the Park burner ceased, necessitating the need for a replacement burner. In addition, a new burner was required for laboratories intending to establish either the existing seat cushion or cargo liner flammability tests.

This need for the availability of a standard burner prompted the Fire Safety Branch to develop the next-generation burner that could be built from readily available components. Rather than using an electric motor to drive the blower fan and fuel pump, the burner relies on a pressurized air source and a sonic orifice to meter in the precise amount of combustion air, which provided more consistent flame characteristics over a range of ambient laboratory conditions. Beyond the burner itself, internal components, which impact the profile of air entering the combustion zone, were also examined and evaluated. Ultimately, the burner was modified with two new components known as the flame retention head and static plate in order to achieve an acceptable level of test reproducibility between different laboratories. This was established based on an evaluation of test data on identical materials from a number of laboratories. The retention head/static plate has become the new standardized configuration of the burner for both the cargo liner and seat cushion flammability test.

The adaptation of the next generation burner to the seat cushion flammability test (see Figure 40) and the cargo liner burn through test fulfills the need for a suitable replacement burner for these FAA-required tests.



Figure 40: Aircraft seat cushion flammability test

The existing flammability test methods detailed in the Fire Test Handbook are being revised to include a description of the next generation burner, so that new laboratories will have the opportunity to fabricate or purchase the appropriate burner equipment necessary to conduct these flammability tests. (Fire Research and Safety)

Effectiveness of Cargo Compartment Fire Resistant Containers and Fire Containment Covers against Large Lithium Battery Fires:

Almost all cargo transported in freighters is loaded on pallets that are covered and in cargo containers. A number of activities have resulted in the development of fire resistant covers and fire hardened containers to protect aircraft against cargo fires originating within the loaded enclosures. Previous testing of Fire Containment Covers (FCCs) and Fire Resistant Containers (FRCs) both with and without built in fire suppression systems showed promising results when tested with fire loads comprised of ordinary combustible materials. The test fires were either suppressed through oxygen starvation or, in the case of FRC's with built in suppression systems, completely extinguished. Testing of these potential fire mitigation strategies continued with fire

loads that included large quantities of commonly manufactured rechargeable lithium-ion and non-rechargeable lithium metal batteries.

The configuration for the FCC/FRC battery testing consisted of approximately 5,000 batteries added to the same fire load of ordinary combustible materials used in the initial testing. In the first FCC test involving lithium-ion batteries, the test fire was contained under the FCC for the four hour duration test. When lithium metal batteries were tested under the same conditions, the fire was not contained and the test was terminated after 16 minutes.

The FRC battery tests all included a built in fire suppression system consisting of a dry powder type of suppression agent that was pyrotechnically discharged. Two FRC tests were conducted with lithium-ion batteries. An explosion occurred inside the FRC during both tests. The overpressure and subsequent fire destroyed the FRC s in both of these tests (Figure 41). During the first test, the conditions required for the automatic discharge of the suppression agent were not reached prior to the occurrence of the explosion. The alarm algorithm was changed for the second test and detection and discharge of the suppression system did occur prior to the explosion but did not prevent it. The cause of these explosions was the ignition of flammable gases that were vented by the batteries in thermal runaway that had collected within the FRC.



Figure 41: Burned cargo container

One additional test was conducted under these same conditions with lithium metal batteries. This test did not result in an explosion but the FRC and suppression system were not effective in containing the fire, which burned through the FRC within three minutes. Additional research is underway to better characterize the composition of the gases vented from lithium-ion and lithium

metal batteries during thermal runaway, and to examine the effect of container modifications on explosion containment. (Fire Research and Safety)

Measuring Stored Chemical Energy in Lithium Ion Batteries Using a Bomb Calorimeter:

Rechargeable lithium ion batteries are being used at an increasing rate since their introduction in the early 1990's. This is due to their high energy density and excellent charging and discharging characteristics. Lithium ion batteries are continuously being researched and developed to produce higher capacities. The high energy density of lithium ion batteries (LIB) makes safe shipment of this commodity as cargo on commercial aircraft a concern due to its potential to initiate a fire by thermal runaway, and contribute to a fire by burning of the organic electrolytes and other combustible components. The ignition risk can be mitigated by shipping lithium ion batteries at a reduced state-of-charge (SOC). To demonstrate the safety benefit, work was conducted to determine the relationship between the state-of-charge of the LIB or its rated capacity and the release of stored chemical energy during thermal runaway. This work focused on quantifying the release of stored chemical energy during thermal runaway using a bomb calorimeter purged with nitrogen to preclude any combustion of the battery contents. Data was obtained for the release of stored chemical energy during thermal runaway as a function of state-of-charge and rated capacity, and the combustible gases that are produced were analyzed using gravimetry, gas chromatography (GC), and Fourier transform infrared spectroscopy (FT-IR).

A bomb calorimeter (Parr Instruments Model 1341 Plain Jacket Oxygen Bomb Calorimeter) was modified to accommodate a single 18650 lithium ion battery along with other components required to heat the battery until thermal runaway occurred. Prior to heating the bomb was purged with nitrogen to inert the environment and prevent combustion. The battery was heated with a nichrome wire which produced thermal runaway usually in about 10 minutes. The temperature of the system was monitored until thermal equilibrium was reached. After the battery test the system was cooled and the same heating program was applied to generate a baseline. The difference between the initial and maximum temperature of the baseline is subtracted from the difference between the initial and maximum temperature of the battery run to determine the temperature rise of the system from the battery only. The temperature rise from the battery exothermic reaction is multiplied by an energy equivalent for the bomb calorimeter to yield a net chemical energy release. Temperature measurements of batteries during thermal runaway show that the energy released can be enough to raise the temperature of one battery over 800°C in two seconds without any combustion. The figure below shows the relationship between energy release and battery charge for four types of 18650 batteries. Clearly, at low battery charge the risk of ignition by thermal runaway can be reduced significantly.

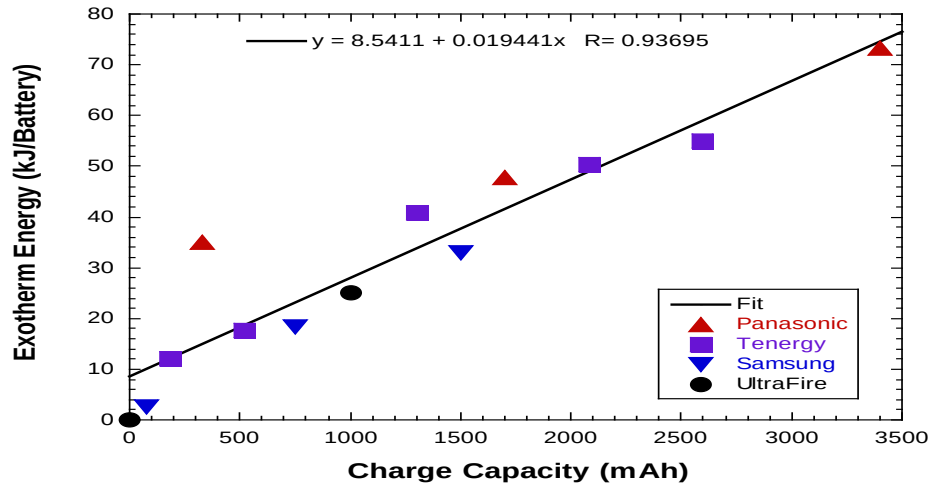


Figure 42: Chart measuring exotherm energy and charge capacity

Weight measurements were made to examine how much of the batteries contents were released as gases. The composition of the gases released is a mixture of flammable and non-flammable components. The flammable gases, as verified by infrared spectroscopy, consisted of methane and carbon monoxide. Gas chromatography identified hydrogen as a major component as well as a collection of low molecular weight hydrocarbon fuels. The non-combustible gas released was carbon dioxide as determined by the FT-IR and GC methods. It was found that the weight of combustible gases released was also directly proportional to the charged capacity of the battery. This data may be used to determine the number of batteries in thermal runaway that could cause an explosion in an enclosure of given volume such as a cargo container. (Fire Research and Safety)

Heat and Mass Transfer Due to a Small Fire in an Aircraft Cargo Compartment:

An in-flight fire may have grave consequences if not detected rapidly and before growing into an uncontrollable size. Early fire detection is not trivial, especially, for the inaccessible areas of the aircraft, such as cargo compartments, where a direct visual inspection is not possible during flight. For aircraft fire safety, it is particularly critical to identify the fire at the very early stages when it is still small and its spread is limited. Understanding the fire dynamics, more specifically, the transport of induced smoke and hot gases as a result of a fire in an enclosure is fundamental in the selection and optimal location of fire/smoke detectors.

For the purpose of this study, a plume of hot-gas mixture generated by a small-fire, placed on the floor close to the center of an empty aircraft cargo compartment, was examined. A computational fluid dynamics (CFD) model was developed, and predictions were made of the temporal and spatial distribution of a chosen set of variables, such as gas temperatures, heat fluxes, and concentration levels of main combustion products, throughout a cargo compartment enclosure. The numerical modeling was carried out using the fire dynamics simulator (FDS) developed by the National Institute of Standards and Technology (NIST). The model results are compared with the available experimental data previously collected during the full-scale fire tests of a representative narrow-body aircraft cargo compartment.

It was demonstrated through this study that the heat flux to the ceiling directly above the fire source (stagnation region) constitutes the bulk of heat loss in the compartment. The study focused on this region since inaccurate predictions of the heat flux, particularly in this region, would yield poor model performance deviating from the experimental data.

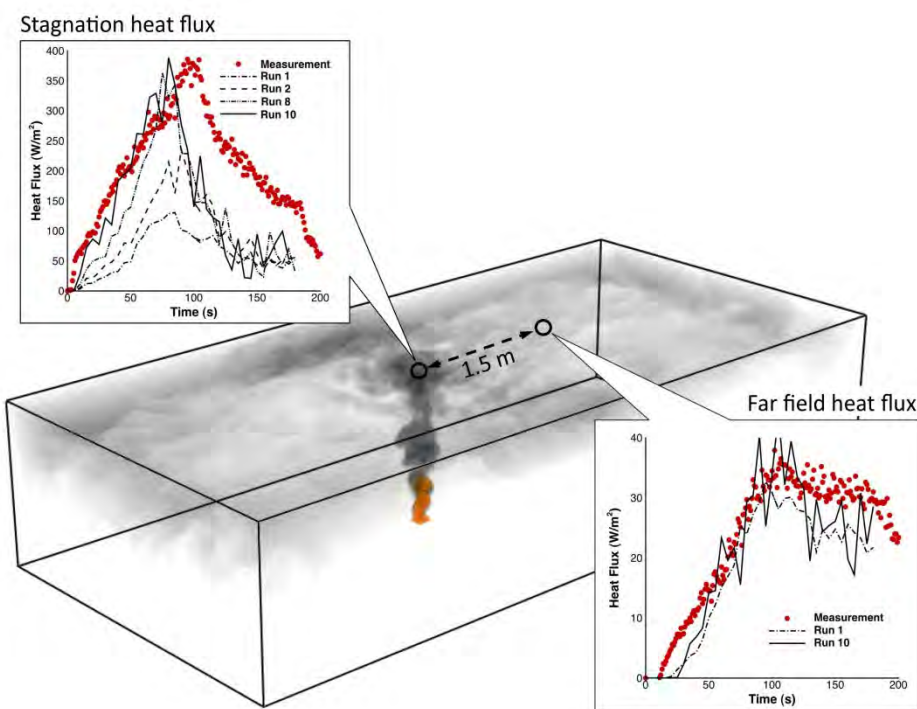


Figure 43: Comparison of Fire Model Heat Flux Predictions with Full-Scale Test Measurements

Figure 43 compares heat flux predictions obtained by the model and measurements from the full-scale fire tests at two locations, directly above the fire source, and 1.5 m away. Although different model configurations were investigated only a selected few are shown (Run1 to Run 10). Measurements from the full-scale tests are displayed with red symbols while simulation results are shown with lines. As can be seen from the figure, the wall heat flux directly above the fire source (stagnation heat flux) is noticeably higher (almost ten times) than the heat flux 1.5

m away (far-field heat flux). Although the model performs well in predicting the far-field heat flux, its accuracy for the stagnation heat flux is very sensitive to the model set-up used. (Fire Research and Safety)

Flammability of Hydrogen at Sub-Atmospheric Pressures and Reduced Oxygen Concentrations:

There is increasing pressure on the entire aviation industry to improve fuel efficiency and reduce harmful emissions. One of the methods being considered to do this is to replace the auxiliary power unit with hydrogen fuel cells to supply electrical power to the aircraft. Hydrogen fuel cells produce electricity directly from the conversion of hydrogen and oxygen into water vapor, which is the only emission produced. The concern with using hydrogen as a fuel is fire safety since hydrogen is easily ignited and produces powerful explosions over a very wide range of concentrations. Therefore, hydrogen's combustion properties were investigated and quantified for the conditions that could be experienced by an aircraft in-flight or on the ground.

Hydrogen's flammability was tested in air at pressures corresponding to sea level, 15,000, 30,000, and 40,000 feet of altitude. At these conditions, the lower and upper flammability limits, maximum explosion pressures, flammability properties in oxygen-depleted air, and limiting oxygen concentrations were measured. All testing was done in a 20 liter stainless steel chamber, based on the Bureau of Mines design for determining the explosion characteristics of dusts and gases. The chamber was evacuated and refilled with the desired test concentration of hydrogen, nitrogen and air, as measured by partial pressures. An ignited mixture was considered flammable if the pressure increased by three percent or more over the initial pressure.

Several tests near the lower flammability limit (LFL) were completed at each altitude. The limit was found to be 4.70 percent H_2 at sea level and decreased as the altitude increased. At 40,000 feet, the LFL was 3.89 percent H_2 . The graph of the LFL as a function of altitude is shown in Figure 44. Similar tests were conducted for the upper flammability limit (UFL) as well. The UFL was 78.18 percent H_2 at sea level, peaked at 78.87 percent at 15,000 feet, and then decreased to 76.87 percent at 40,000 feet. Based on previous studies and additional data collected in this testing it was found that the UFL decreased above this altitude because of the low spark energy used during these experiments. Thus, in these results the UFL at 30,000 and 40,000 feet were actually limited by the spark energy and not the rich limit of hydrogen. This low spark energy was not a factor in the other test conditions.

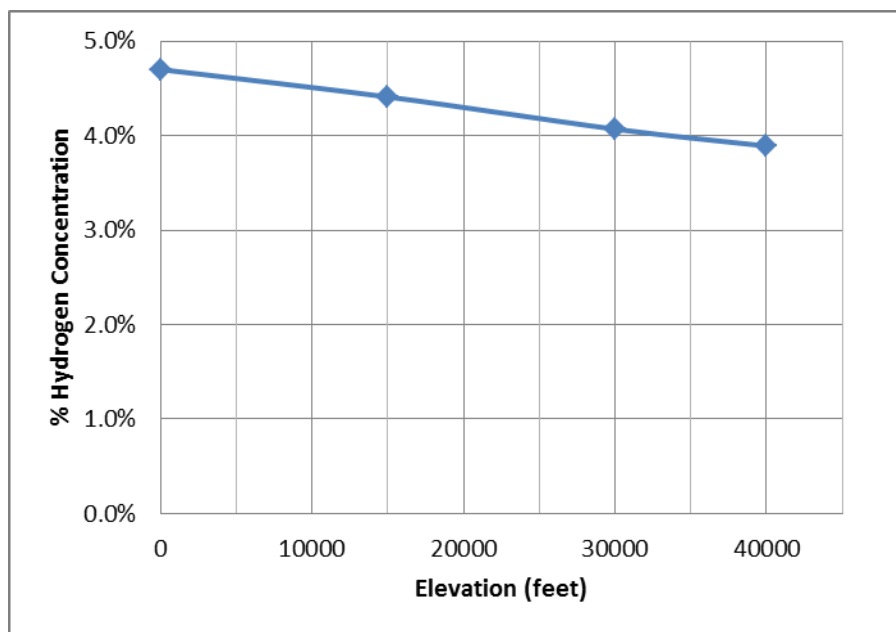


Figure 44: Lower flammability limit of hydrogen in air as a function of altitude

The flammability of hydrogen was also tested in air with varying concentrations of nitrogen added. The full range of hydrogen concentrations were tested with pure air, 20 percent, 40 percent, and 60 percent nitrogen added at each altitude. At high altitudes, the gas mixtures remained flammable across a wider range of hydrogen concentrations, but the lower altitude tests produced much higher peak pressures due to the increased density of hydrogen and oxygen present. As expected, the highest pressure measured of all the tests performed was at a stoichiometric hydrogen and air concentration at sea level. The pressure increased to 100.8 psi over the initial pressure and reached that peak 12 milliseconds after the spark was triggered. This corresponded to a pressure rise of almost seven times the initial pressure. Very powerful explosions also occurred in any tests conducted away from the flammability limits which further highlighted aircraft safety concerns.

Enough nitrogen was added in to reach the limiting oxygen concentration (LOC) for hydrogen at all altitudes as well. This is the minimum amount of oxygen required for hydrogen to be flammable. This was achieved by reducing the amount of oxygen in the air by adding nitrogen, then adding hydrogen to make a stoichiometric ratio with the corresponding amount of oxygen. For example, a test run with a 4 percent oxygen concentration had 8 percent hydrogen and 88 percent nitrogen. The LOC was 4.21 percent O_2 at sea level and decreased as the altitude increased to 3.49 percent O_2 at 40,000 feet. This graph is shown in Figure 45.

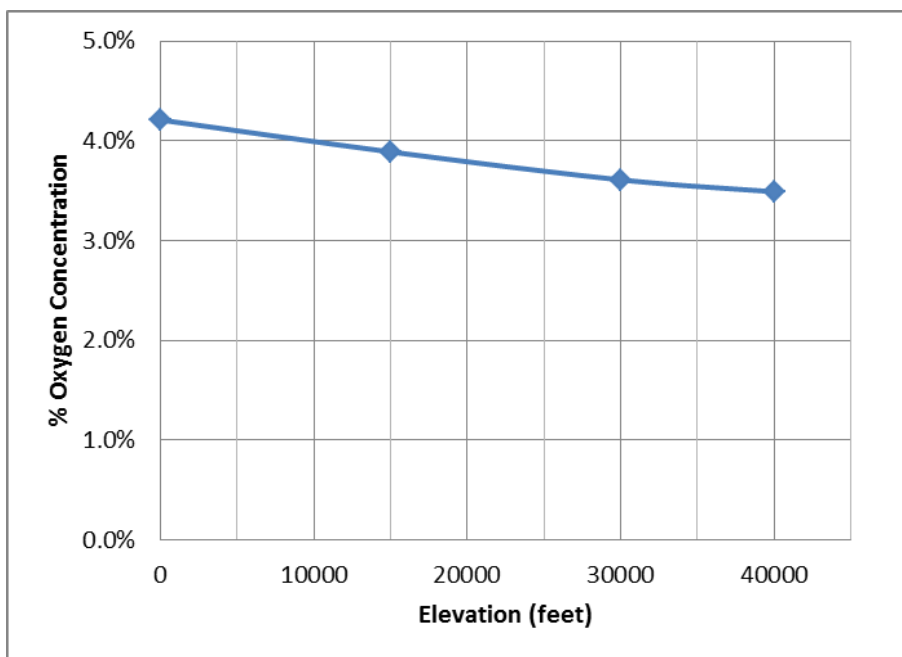


Figure 45: The limiting oxygen concentration of hydrogen as a function of altitude

Overall, it was found that at high altitudes the gas mixtures remained flammable across a wider range of hydrogen concentrations, but at low altitudes the tests produced much higher peak pressures due to the increased density of hydrogen and oxygen. Also, a lower concentration of oxygen is needed to ignite hydrogen at high altitudes, which would require more nitrogen to inert the environment. (Fire Research and Safety)

Document the Results of Preliminary Research on the Role of Startle, Surprise, and Distraction in Jet Upset/Loss of Control and Identify Potential Mitigations:

The objective of this effort was to collate, compare, and combine research on startle, surprise, and distraction from a variety of sources and application areas/task environments, and to provide critical scientific and technical information to the FAA for mitigating the negative effects of startle, surprise, and distraction on the flight deck. The results of this research are intended to inform the FAA in developing a new Advisory Circular (AC) on upset recovery training as well as provide data to support any revisions to AC 120-109, Stall and Stick Pusher Training, and the development of future guidance material for the design of systems, procedures, and training. (Flightdeck Maintenance/System Integration Human Factors)

Analyze and Provide Recommendations on Evolving Methods of Alternative Fatigue Risk Assessment (e.g., voice analysis) that Considers Time on Task Fatigue and Method Validation:

Researchers developed reports and briefings documenting alternative methods of fatigue risk assessment associated with time on task fatigue that may prove to be viable in aviation maintenance operations. The report documents existing and evolving methods of assessing fatigue risk. Some of the evolving methods available in the scientific community, such as voice analysis, are not realistically implementable at this time. The results of the report indicate there are some viable methods of fatigue risk assessment available but improved methods for aviation maintenance are on the near horizon with advances in scientific research. Some assessment methodologies are more appropriate than others and are dependent on the operational environment. Complete recommendations will be incorporated in the end of project report. (Flightdeck Maintenance/System Integration Human Factors)

Safety Issues with Requirements Definition, Validation, and Verification Processes - draft Phase 1 Report:

Identified adverse events that requirements' definition and validation and verification (V&V) may have been a contributing factor, as necessary to identify instances of requirements' errors, omissions, or conflicts in commercial aviation, complex, integrated digital aircraft electronic systems. The study identified requirements' definition and V&V processes, and interfaces to identify the issues and shortcomings. Research considered eight potential error-generating scenarios that could cause a catastrophic condition by identifying possible issues and shortcomings with requirements' definition and V&V processes. Phase 1 of the Final Draft Report is on schedule for delivery in FY 2015. (NextGen – Advanced Systems and Software Validation)

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. 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.

In previous DARWIN[®] versions, risk assessment for inherent material anomalies (for example, titanium hard alpha inclusions) was based on stress, temperature, and geometry information from

two-dimensional (2D) axisymmetric finite element models. However, advances in computational resources in recent years have enabled the design of complex engine components using three-dimensional (3D) finite element models. DARWIN® 8.2 provides new capabilities for life prediction and risk assessment of inherent material anomalies using 3D finite element models. It enables user definition of property region information (material response, anomaly distributions, inspection schedules, and mission regions) directly on the 3D FE model. DARWIN® employs this information to determine the 3D zones in the model via an extension of the autozoning approach that was previously developed for 2D zones. Similar to 2D autozoning, 3D autozoning results include stress, life, and risk information. Zone-level information enables users to visualize 3D contours of the stress variations, life predictions, and risk assessments as illustrated in Figure 46.

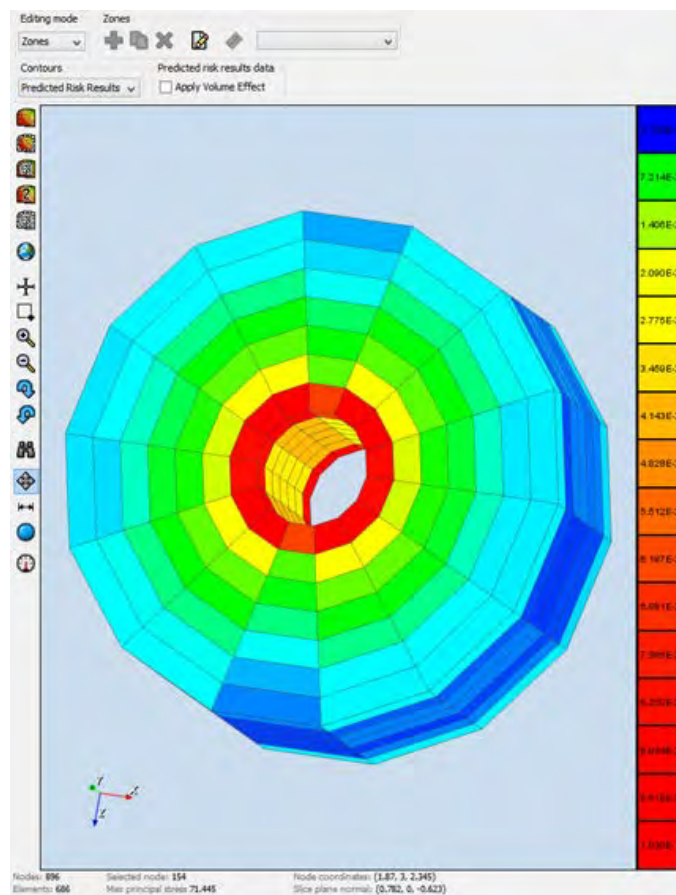


Figure 46: DARWIN® 8.2 provides a new capability to assess the fracture risk of inherent material anomalies in gas turbine engine components using 3D finite element models

Anomalies such as scratches or dents may sometimes be introduced inadvertently during routine inspection and maintenance operations (shop visits). Previous versions of DARWIN® were limited to anomalies that were already present before a part had entered service. DARWIN® 8.2

provides a new capability that enables the user to define shop visit anomalies and to specify their associated timetables and size distributions (see Figure 47). The timetable may be linked to the timetable of inspection schedules if desired. DARWIN[®] tracks risk associated with shop visit anomalies and quantifies its influence on the overall probability of fracture. This new feature provides support for development of a future FAA Advisory Circular for damage tolerance assessments of attachment slots.

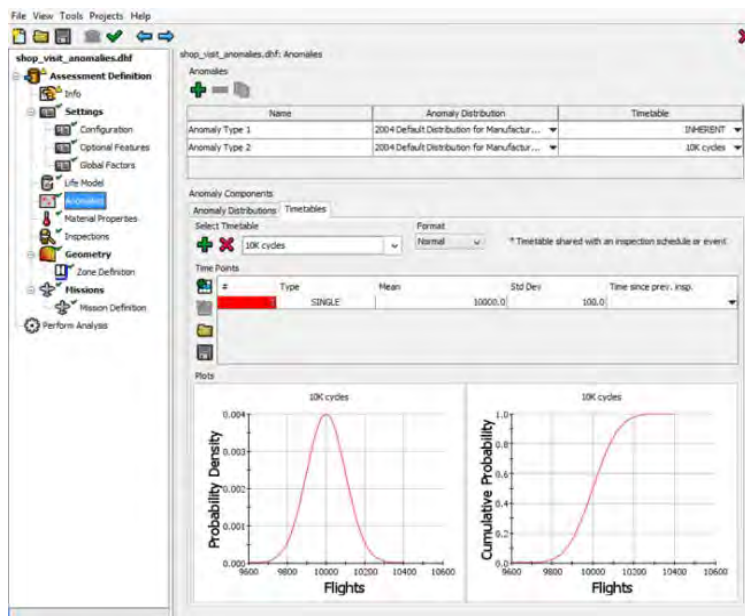


Figure 47: DARWIN[®] 8.2 provides a new capability for risk assessment of anomalies that are introduced during shop visits

DARWIN[®] 8.2 includes a new stress intensity factor solution (CC12) for a quarter-elliptical surface crack at a chamfered corner (see Figure 48). This bi-variant solution is optimal for crack locations where the stress gradient varies significantly in more than one direction. Cracks modeled using CC12 extend over the entire chamfered region. Future DARWIN[®] versions will include a new stress intensity factor solution (currently under development) for cracks that originate at individual angled corners within chamfered regions.

DARWIN[®] 8.2 also includes a number of additional new features that were supported by supplementary funding from non-FAA sources including contracts from DoD agencies and DARWIN[®] commercial licensing revenue. These new features include improved mission mixing to characterize complex usage histories, a new interface to advanced finite element software for 3D fracture analysis, an expanded interface to manufacturing process simulation software for integrated computational materials engineering, and a new probabilistic method for more efficient fracture risk calculations.

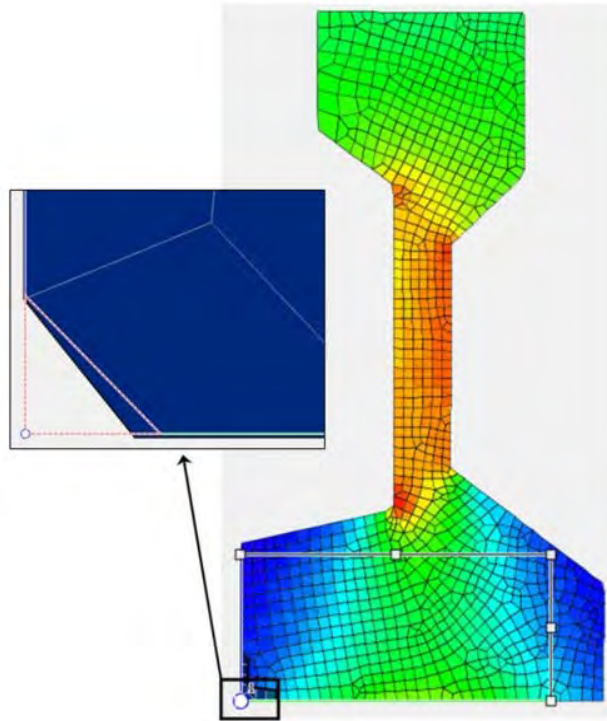


Figure 48: DARWIN[®] 8.2 includes a new bivariate stress intensity factor solution (CC12) for quarter-elliptical cracks at chamfered corners

DARWIN[®] 8.2 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[®] 8.2 will be released for production use in industry. (Propulsion and Fuel Systems)

Altitude Discrepancies:

The Aviation Safety Information and Analysis (ASIAS) Vulnerability Discovery team has investigated the occurrence of en route altitude discrepancies, where an altitude discrepancy is defined as a deviation of 300 feet or more from the assigned altitude or flight level. An altitude discrepancy can be a precursor to loss of separation between aircraft, or even a mid-air collision. Several events can lead to an altitude discrepancy: the flight might be responding to a Traffic Alert and Collision Avoidance System (TCAS) resolution advisory; the pilot might have encountered turbulence or an updraft, and is unable to maintain the assigned altitude; or there may be a miscommunication between the pilot and controller, such as the pilot's responding to a clearance for another flight with a similar call sign.

The Vulnerability Discovery team analyzed radar track and clearance message data and applied rule-based logic to identify potential discrepancies. The data sources are from the en route centers (airspace above 18,000 feet).

The group focused upon large discrepancies (defined as 800 to 2,200 feet off of cleared altitude), but also identified medium discrepancies (defined as 400 to 700 feet off of cleared altitude) and small discrepancies (defined as 300 feet of cleared altitude).



Figure 49: A radar display

There is insufficient detail in the radar track and clearance message data alone to assign an unambiguous cause to each discrepancy, so the team performed a validation of a sample of these events by listening to the recordings of communications and looking at a replay of the situation to see what the controller saw on the radar display.

The ASIAs program is working with the FAA to reduce altitude discrepancies and reduce the risk of a loss of separation by potentially developing a monitoring function that can allow en route Centers to easily identify and follow up on altitude discrepancies. (System Safety Management/Terminal Area Safety)

Evaluation of Motion Cueing Criteria for Flight Simulators:

For a training device to be called a simulator in the FAA, it must physically move. How simulators move varies by simulator. This variance arises from two sources. First, simulator manufacturers decide on how a simulator should move based on some rules-of-thumb; however, the fine tuning of those movements is made subjectively by pilots and engineers. Similarly,

when the FAA qualifies a simulator for training, the acceptability of its motion is also determined subjectively. Since different pilots design and qualify different simulators, this situation can lead to different motion sensations among simulators associated with a particular aircraft type. Accidents such as AA587 that crashed in Queens, NY in 2001 have shown that the accelerations experienced in simulation are often not representative of those in flight.

Subsequently, the NTSB issued a recommendation to promote standardization to minimize the danger of such inappropriate simulator training. In response, the Terminal Area Safety research team conducted exploratory tests to evaluate a set of objective motion cueing criteria in assessing simulator motion fidelity. These criteria are being proposed for a new edition of an ICAO standard on simulator qualification. The experiment used the NASA Ames Vertical Motion Simulator (VMS) with different motion conditions to evaluate whether or not training with motion is valuable for initial training of commercial transport pilots. Sixty-one general aviation pilots trained on four challenging commercial transport tasks under one of four different motion conditions: no motion, small hexapod, large hexapod, and VMS motion. Then, every pilot repeated the tasks in a check with VMS motion, utilizing the large motion envelope of the simulator, to determine if training with different motion conditions had an effect on task performance. New objective motion criteria guided the selection of the motion parameters for the small and large hexapod conditions. Both subjective and objective measures were collected and analyzed. Based on the results, the researchers published a report and presented at 2014 June AIAA Aviation Conference. Evidence suggests that the new objective motion criteria may offer valid standardization benefits, as increases in the training motion fidelity, as predicted by the two conditions covered by the criteria, resulted in expected trends in pilot ratings and objective performance measures. The two principal conclusions of the study were: 1) the objective measures depend on the motion condition in training; and 2) the new objective motion criteria show early promise, as the predicted fidelity improvement between the two conditions covered by the criteria, the small and large hexapod conditions, resulted in expected trends in pilot ratings and objective performance measures after transfer. The findings provide scientific and technical information for the FAA to minimize possible inappropriate training. (System Safety Management/Terminal Area Safety)

Multi-Sensor Surveillance Data Fusion:

Completed Phase 1 - July 2014; Delivered sensor and fusion trackers in Java to incorporate into Technical Center Lab; Completed model runs using more challenging encounter sets to evaluate the initial set of fusion tracker options. Analysis to Date: Five scenarios have been simulated; Tracking errors were compared (horizontal, vertical, heading/speed/altitude rate. Three candidate Kalman filter-based trackers algorithms were selected in Phase I for additional study in Phase 2. (Unmanned Aircraft Systems Research)

Unmanned Aircraft Systems Airspace Integration Joint Test:

Unmanned aircraft systems (UAS) operating today lack access to civilian airspace. There are many reasons for this, but chief among them are a lack of standardized procedures across different UAS platforms and groups. This lack of standard procedures can lead to confusion and increased workload for UAS pilots and Air Traffic Controllers, especially during contingency events when UAS experience a failure. Contingency events, such as lost link and lost communications, demand clear and concise procedures for all parties involved in order to maintain an acceptable level of safety. Accidents and incidents involving UAS often cite a lack of standardized procedures as either a root or proximate cause. The lack of standardized procedures for UAS remains a limiting factor for their integration in the NAS.

To solve this problem, the FAA, in collaboration with the DoD (i.e., U.S. Army, U.S. Air Force, U.S. Marine Corps, NASA, and the U.S. Department of Homeland Security's U.S. Customs and Border Protection) began the initial steps towards testing standardized procedures developed by the military service units for use in the NAS. FAA researchers started with a fast-time modeling and simulation activity led by researchers from the Capacity Analysis Branch, which informed changes in several of the UAS charted routes and procedures. Following the fast-time experiment, led by FAA UAS subject matter experts and principal investigators from the Aviation Research Division, a team of researchers conducted a full-scale, hi-fidelity, HITL (human-in-the-loop) simulation activity at the FAA's William J. Hughes Technical Center. This study, UAS Airspace Integration Joint Test (FT-2), examined the efficacy of standardized procedures for UAS routine and contingency operations (Lost-Link, Lost-Communications, and Lost Detect and Avoid) across all service units. It involved the concurrent use of 4 UAS simulators located at the FAA William J. Hughes Technical Center (Global Hawk - RQ4B, Predator A/B - MQ1/9, Shadow - RQ7, and ScanEagle - RQ21) along with the Airway Facilities Tower Integration Laboratory (AFTIL) configured as Grand Forks Air Force Base "Red River" Tower, the NextGen Integration Evaluation Capability (NIEC) Laboratory configured as Grand Forks RAPCON & Minneapolis Center, and the Target Generation Facility. From July 14 to August 1, 2014, the team completed a week of training for the DoD and FAA study participants (UAS pilots and Air Traffic Controllers from Grand Forks RAPCON/Tower, McGuire Tower, and Minneapolis Center), as well as two full weeks of execution totaling 56 unique scenarios. These scenarios comprised a three-factor experimental design (UAS Group, Operating Condition, and Phase of Flight) with both routine and contingency operations for manned (Loss of Radio Communications - NORDO) and unmanned aircraft. To focus on the efficacy of the procedures, the study made several simplifying assumptions; namely, that UAS filed and flew under Instrument Flight Rules, were equipped with ADS-B surveillance, sported a Detect and Avoid (DAA) capability, and were under direct control from the appropriate Air Traffic Control facility. Both objective and subjective measures were collected and data from

the simulation event was analyzed to calculate both safety and efficiency metrics as well as to answer the following research questions:

1. To what extent do Unmanned Aircraft Standardized Procedures support the DOD operational requirement for UAS flight operations in the NAS?
2. To what extent do Unmanned Aircraft Standardized Procedures support safe flight operations in the NAS?
 - a. For the UAS Pilot?
 - b. For Air Traffic Control (ATC) services?
 - c. For the Flying Public?
3. To what extent do Unmanned Aircraft Standardized Procedures support efficient airspace management of the NAS?
 - a. To what extent do Unmanned Aircraft Standardized Procedures support NAS flexibility, predictability, and timeliness?

Preliminary results from the study indicated some changes in pilot/controller workload as a result of the standardized procedures as well as some UAS platform limitations in flying the procedures. In addition, the study underscored the challenges associated with UAS Lost Link procedures and route de-confliction amongst multiple UAS; although all participants agreed that the standardized procedures were an improvement over current UAS arrival, departure, and contingency procedures in existence today. Furthermore, several FAA researchers participated in the DoD Live Flight portions of the Joint Test which followed the simulation activity, lending valuable contributions and feedback towards test objectives, scenarios, and chase aircraft procedures. To date, the UAS Airspace Integration Joint Test comprised the largest UAS study ever conducted at the Technical Center and was a true partnership involving significant contributions from multiple FAA organizations and federal agencies, who worked together to insure a successful outcome. (Unmanned Aircraft Systems Research)

High Resolution Weather Model Improves Aviation Weather Forecasts:

In-flight icing, turbulence, convective weather, and low ceilings and visibility affect both the capacity and safety of the NAS on a daily basis. Timely and accurate forecasts of these aviation-specific weather hazards require forecast models that are not only accurate but are updated frequently. The FAA in collaboration with National Oceanic and Atmospheric Administration (NOAA), Air Force Weather Agency), and Naval Research Laboratory (NRL) have targeted the development and improvement of weather prediction models and data assimilation systems to

better characterize the state of the atmosphere with the goal of providing superior aviation weather information to enhance NAS safety and capacity. These assimilation and prediction systems utilize all the latest weather observations and advanced supercomputers to create more accurate and timely depiction of the future state of the weather.

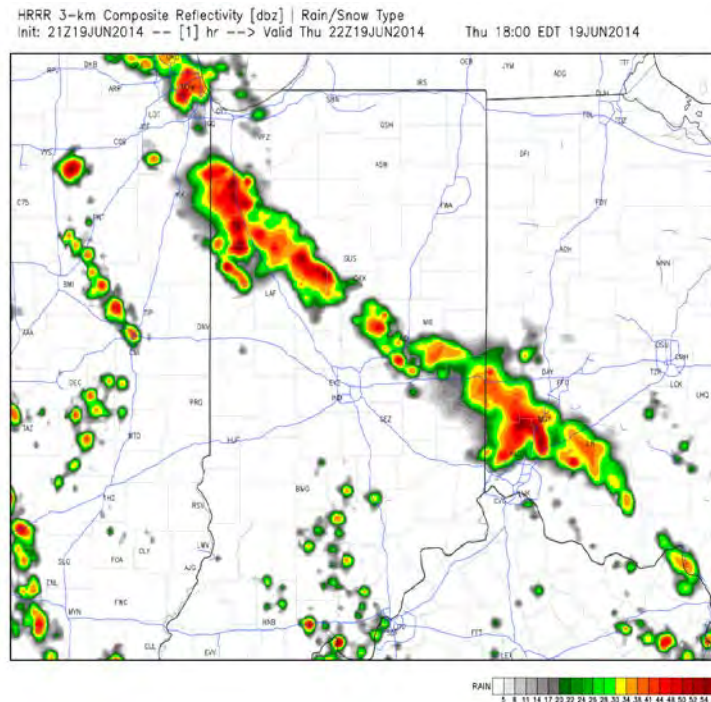


Figure 50: High resolution model forecasts enhance ATM decision making

A key result was the FY 2014 implementation into NWS operations of the hourly-updated High Resolution Rapid Refresh (HRRR). The HRRR is a storm-scale weather forecast model running at three kilometer vertical resolution providing more detailed short-term information about a quickly developing small-scale storm. It utilizes radar information, plus observations from surface weather stations, commercial aircraft, satellites and weather balloons to build a better picture of a storms' structure. The HRRR model forecasts extend out to 15 hours and provide the granularity to depict convective weather storm cells with the permeability information necessary to provide sufficient guidance for Air Traffic Management to make critical traffic flow decisions during convective storms. While the HRRR will have a major impact on convective weather forecasts it will also enhance forecasts of other aviation weather hazards especially terminal area winter weather hazards. (Weather Program)

Avoiding In-Flight Icing Conditions:

In-flight icing was a cause or factor in 140 GA aircraft accidents for the period 2000 through 2013 according to National Transportation Safety Board data. To address this problem, the FAA's Weather Program developed the Current and Forecast Icing Products (CIP and FIP) which provide more accurate and timely diagnoses and forecasts of atmospheric conditions leading to ice accretion on aircraft during flight. After being transitioned to the NOAA, CIP and FIP were implemented operationally on the web-based Aviation Digital Data Service (ADDS), at the NOAA Aviation Weather Center (AWC) in Kansas City.

The Weather Program upgraded the CIP and FIP algorithms to meet NSIP requirements of a high resolution diagnoses and forecast of atmospheric conditions conducive to aircraft icing. These upgraded algorithms, also known as CIP/FIP High Resolution (HiRes) improve the horizontal and vertical resolution and extend the forecast from 12 hours out to 18 hours with a further goal of enhancing safety of flight. In FY 2014, a technical review, safety risk management, and operational evaluation of these algorithms were conducted which validated the scientific validity, mitigation of any safety risks identified, and usability of the new HiRes products; they were then implemented operationally on ADDS.

These automated algorithms gather real-time information from numerous data sources including satellites, radars, weather models, surface stations, and pilot reports, and 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 general aviation aircraft without ice protection and those that fly at relatively low altitudes, less than 24,000 feet, where they are more likely to encounter atmospheric conditions conducive to icing. In addition to availability on ADDS for NAS users, CIP and FIP are also used by NWS forecasters in preparation of FAA mandated forecast products. (Weather Program)

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 capacity and efficiency of the nation's aviation system.

Tests on Subgrade and Aggregate Samples Collected From Three Airport Construction Projects:

Field and laboratory tests were conducted on subgrade and aggregate samples collected from three airport construction projects as part of a long-term study. The FAA has undertaken a project to study alternate methods of characterizing in-situ subgrade soils. The test methods being studied include vane shear (for in-situ shear strength), lightweight deflectometer (for resilient modulus), DPSPA (for elastic modulus), and repeated load triaxial tests (for laboratory resilient modulus). Resilient modulus, in combination with a measure of strength such as shear, could displace CBR as a means of characterizing subgrade soils. The study demonstrated the application potential of different testing techniques for airport pavement subgrade characterization. More testing on different soil types (clays, silts, and sands) is required before reaching any significant conclusions. (Airport Technology Research Program)

Complete the Update of the Airfield Modeling Database With All New Runway, Taxiway, and Gate Data:

Analysts have completed the update of the Airfield Modeling Database with data for all new runway, taxiway, and gate data that was available in 2014. Efforts will continue to update the database as new data becomes available. (Airport Technology Research Program)

En Route Workload Model Evaluations:

At the request of the FAA, the Center for Advanced Aviation System Development (CAASD) initiated research into improving techniques for estimating capacity and identifying congestion for en route sectors in the National Airspace System (NAS). Realizing that controller workload is a significant limiter to sector capacity, CAASD developed a time-on-task controller workload model. The model's workload metric, which is defined to be the amount of time that the controller spends performing air traffic control tasks, was based on traffic volume and complexity and was subsequently used to estimate capacity and identify periods of congestion. As the workload model research matured, the FAA tasked CAASD to explore the use of the workload model output to estimate position-to-traffic (PTT) values. A PTT value is an estimate

of the number of controllers needed to manage sector traffic during a 15-minute period. Consequently, CAASD developed an application that used the output from the workload model to estimate PTT values based on the difficulty and rate of controller task demands and performance times. PTT values are currently generated for each en route sector, which CAASD delivers to the FAA for use as one of several inputs used to determine staffing ranges for the en route controller workforce plan.

In 2010, a Transportation Review Board (TRB) committee reviewed the workload-based PTT modeling process.² The committee found that workload-based PTT modeling is a “marked improvement” over previous approaches and that the workload model represents traffic activity in sufficient depth and resolution to enable reasonable approximations of traffic complexity, controller tasks, and the associated workload. However, the committee recommended that CAASD work with the FAA to conduct a validation effort involving the direct observation of en route controllers to ensure model coverage of tasks and quantify task performance times.

In response to this recommendation, CAASD collaborated with FAA Management Services (AJG) and National Air Traffic Controllers Association (NATCA) leadership to develop and execute a plan to evaluate the en route workload model. The evaluation consisted of two components: field observations and lab HITL experiments. The goals of the evaluation were to:

- Validate model task coverage, task times, and task time scheduling distributions;
- Verify workload and PTT thresholds; and
- Calibrate human performance modeling techniques for estimating workload impacts of proposed changes to the NAS.

The field observations were completed in FY 2013. The lab HITL evaluations began in FY 2013 and were completed in FY 2014. Figure 51 provides a flowchart depicting how data elements collected from the field and lab HITL evaluations are being used to validate or establish values for model parameters in defining a validated en route workload model baseline.

²Transportation Research Board, “Air Traffic Controller Staffing in the En Route Domain: A Review of the Federal Aviation Administration’s Task Load Model,” Special Report 301, Washington, DC, 2010.

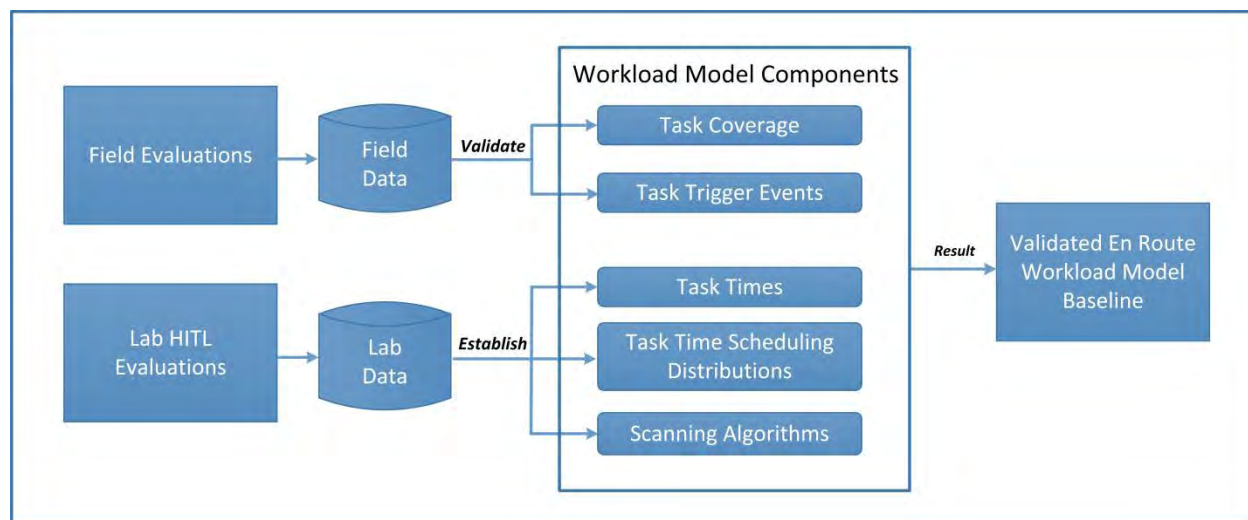


Figure 51: Evaluation Flowchart

Data collected and archived from the evaluations included controller data entry, voice audio, and eye-tracking data (collected from lab HITLs only). The field data was used to ensure relevant tasks were covered in the model and to identify when new tasks were being initiated. The lab data was used to establish task times, scheduling distributions, and to validate the model's scanning algorithm intended to capture the time controllers spend maintaining situation awareness.

A key finding from the workload model evaluation effort is the verification that the model's task coverage accounts for the major contributors of en route controller workload. However, based on evaluation results, several recommendations have been made to further refine the model and improve its accuracy. These recommendations include:

- Replacing task times and scheduling distributions with the values determined from the model evaluation;
- Increasing task coverage by accounting for subtasks such as altimeter setting, pilot requests, ride reports, and traffic calls that can be associated with currently modeled tasks;
- Revising the model's scanning task to include visual scanning and data entry activities; and
- Calibrating workload-to-PTT conversion logic to account for model enhancements.

As a final step in completing the evaluation effort, the overall impact and results from implementing these recommendations in the model will be assessed with FAA management and NATCA. Beginning in FY 2015, CAASD will work with the FAA in developing a formal plan to technology transfer core components of the workload model and PTT application in order to provide the FAA with a production PTT modeling capability. It is envisioned that the production

workload model and PTT application will be compatible with CAASD's research and development architecture, further facilitating the technology transfer of future model enhancements and any additional applications of use. (CAASD)

Strategic Planning for Flow Contingency Management:

Strategic planning under uncertainty is a challenge constantly faced in today's air traffic management system. Hours before a predicted weather event, plans must be made to balance predicted demand with predicted airspace capacity, while maintaining safe operating conditions and minimizing system disruptions. What makes this problem so challenging is that there are significant uncertainties in the predictions of both weather and traffic demand for planning horizons longer than two hours. Currently there are no significant decision support capabilities available to evaluate strategic plans, so planning is necessarily imprecise and conservative.

In recognition of these shortfalls, the NextGen concept highlights the need for advancements in Flow Contingency Management (FCM), which is defined in the FAA's Mid-Term Concept of Operations as "the process which identifies and resolves congestion or complexity resulting from blocked or constrained airspace or other off-nominal conditions". In response to this need, CAASD, under its Mission-Oriented Investigation and Experimentation (MOIE) program, developed a decision support capability termed FCM. The objective of FCM is to transform the strategic traffic flow management (TFM) planning process from one that is *reactive* to one that is *proactive*, by improving predictions of demand, capacity, and congestion; enabling Traffic Management Initiatives (TMIs) to be simulated and evaluated prior to implementation; and developing advanced visualization techniques that improve situational awareness for all stakeholders.

CAASD has led the development of innovative methods and analysis models to provide a real time decision support tool for strategic, more scientific, TFM. Key innovations of this research include the development of demand forecasting models and airport and en route capacity prediction models, both of which required the development of novel prediction techniques. To facilitate real-time decision making, a new simulation model was built that captured these uncertainties while providing a NAS-wide analysis for a 24 hour period in less than 3 minutes. The simulation model captures the interaction between multiple Traffic Management Initiatives (TMIs) that may be initiated, enabling a quantitative evaluation of a strategic plan prior to implementation. Furthermore, a decision support capability was developed that leverages intelligent heuristic algorithms to aid in the identification of TMIs, promoting the identification of a coordinated and integrated strategic plan. These results are communicated via an interactive FCM graphic user interface which captures the information relevant to a variety of stakeholders, as shown in Figure 52. Through these innovations, FCM is the first project to demonstrate the

feasibility of a strategic planning tool for the entire NAS that explicitly accounts for uncertainty in weather predictions.

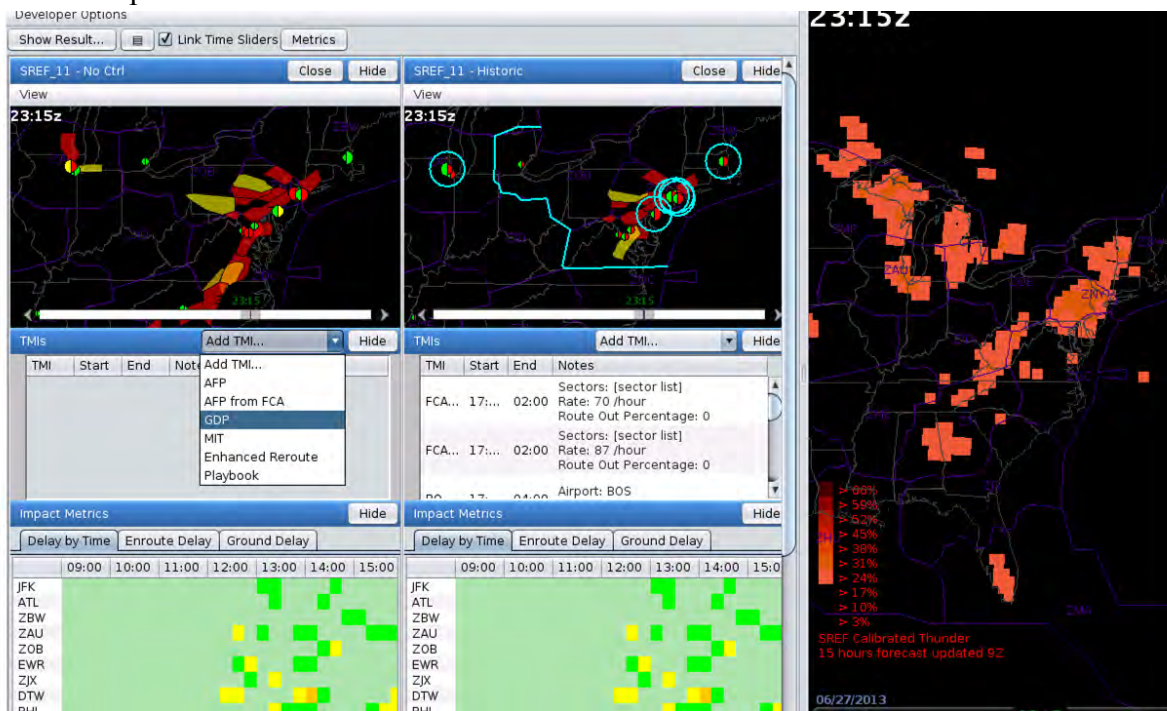


Figure 52: FCM User Interface

Key accomplishments in FY 2014 include:

- The development of an airport configuration prediction model, which leveraged CAASD's collaboration with Dr. Sandip Roy at Washington State University;
- The construction of a historic database for evaluating the similarity of weather forecasts towards the identification of relevant TMIs. This work leveraged collaboration with Dr. Yan Wan at the University of North Texas;
- The development of a framework and model for enabling decision support for the development of TMI plans. Using advanced search algorithms and developing improved methods for evaluation, FCM can provide a set of resolution options to decision makers, reducing workload and improving solution quality; and
- The development of a decision support tool that captures forecast uncertainty, the ability to adjust plans in the future, and the loss of opportunity due to waiting. This allows traffic managers to identify the appropriate set of immediate actions as well as likely actions for possible future implementation. The model development is unique in that it captures the host of considerations under evaluation while quantifying the tradeoffs currently made mentally by traffic managers.

In FY 2014, FCM was used to support an FAA direct-funded project for the Air Traffic Control System Command Center (ATCSCC) on evaluation of reroutes and airspace flow programs (AFPs) in the presence of convective weather. Through this work, CAASD highlighted the value of quantifying the impact on en route and terminal areas due to predicted weather and showed how the TMI design capabilities in FCM could aid in the development and evaluation of strategic TFM plans. The FAA views FCM as a candidate capability for inclusion in the next acquisition and deployment cycle for their TFM system. In support of that objective, CAASD will mature the concept and prototype during FY 2015. (CAASD)

Traffic Flow Management Initiatives Performance Status (TIPS):

Obtaining common situation awareness has been repeatedly identified as an operational shortfall by FAA traffic managers. Traffic managers balance NAS capacity and traffic demand in the face of daily variability and uncertainty. They construct a mental picture of the actual and predicted operational situations by combining observation of many different visual displays (e.g., traffic, weather, airspace) with data from multiple automated information systems. The retrieval of relevant data to develop situation awareness can be a scavenger hunt, and traffic management experience plays the greatest role in determining actions to take. To coordinate potential solutions, traffic managers verbally communicate their mental picture of the operation to others who are impacted by the problem, who in turn have their own views and experience. Differences between these views must be reconciled to reach a decision.

The FAA's CAASD has developed a concept to improve access to relevant information and traffic management collaboration. This concept, Traffic Flow Management Initiatives Performance Status (TIPS), also supports emerging FAA initiatives for data sharing and enterprise information technology (IT) strategies. The application of this research would improve efficiency of traffic management operations and advance FAA acquisition and contracting processes towards the philosophy of "acquiring an application (app) at a time" leading to a leaner, more cost effective and collaborative NAS.

In TIPS, a traffic management portal with quick reference access to relevant operational information replaces the scavenger hunt for data with a comprehensive, shareable, integrated system view. The portal allows users to select and configure apps that reduce the need for mental integration, by providing cues that alert them to potential problems, based on traffic-manager defined thresholds. While geared towards traffic managers and front line managers, applicability of the portal and app framework extends to the flight operator community as well, bringing collaborative decision making (CDM) principles to bear.

Key results and progress of the research to date include:

- Technology transfer of the situation awareness elements of the concept and visualization design to a complementary FAA work program effort supporting near-term operational needs at the Air Traffic System Command Center (ATCSCC).
- Table top exercises with operational Subject Matter Experts to assess collaboration with the concept and explore the intricacies of “common” alert thresholds across multiple facilities versus customization. The experiments indicated that if an information portal was available and its use was encouraged or procedurally required, collaboration and coordination could be initiated sooner, potentially avoiding the need for extensive, reactive restrictions.
- Development and successful prototyping of:
 - A role-based access controlled portal, “ CAASD TIPS Portal Prototype” (shown in Figure 53) using the Ozone Widget Framework (OWF), a government open source software, to host visualizations, or “apps”, that reflect near-real-time operational data.
 - A set of apps which combine existing data streams presenting value-added operational information and indicators of potential problems based on defined thresholds.
- Exploration of the feasibility and design to support workflows that span multiple stakeholders, inside and outside of the FAA, specifically the emerging need for the FAA to accommodate and seamlessly integrate launch and re-entry vehicle operations in the NAS.

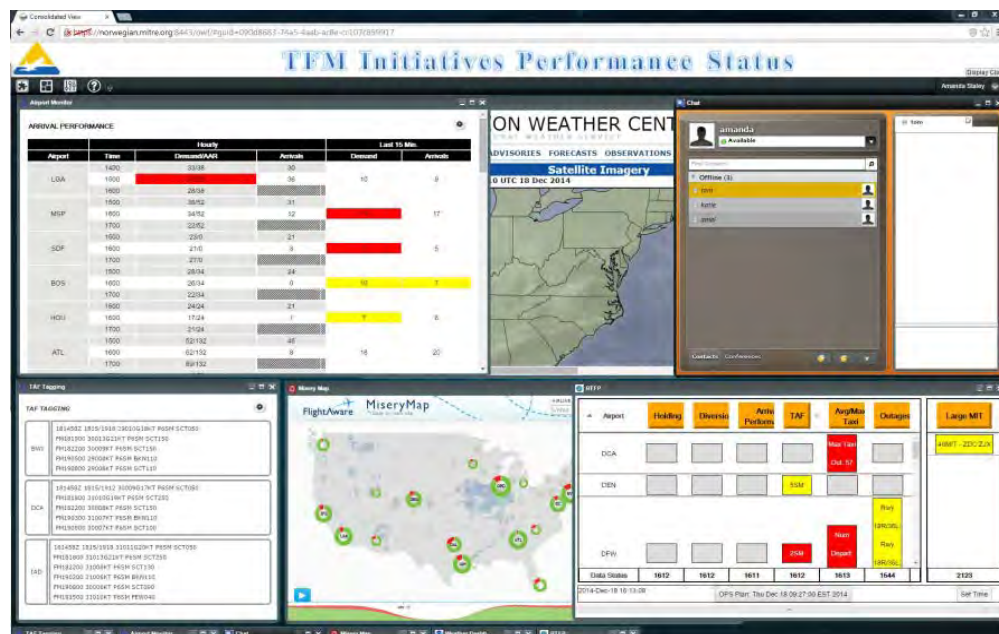


Figure 53: CAASD TIPS Portal Prototype

In 2015, CAASD will examine the proposed application of the portal and apps within traditional and future envisioned traffic management user workflows and identify required changes to policies and procedures, thereby encouraging end user engagement and reducing adoption risk. Research will also explore extending the portal beyond performance monitoring into mechanisms to streamline planning and execution of flow management actions. This will reduce the need to use displays dedicated to individual traffic management tools and enable a more agile future for traffic management capability development. (CAASD)

Complete Research in Compliance to New Human Error Regulation 14 CFR 25.1302:

The report describes other issues to consider when finding or showing compliance with 14 CFR 25.1302, "Installed Systems and Equipment for Use by the Flight crew." This new rule is intended to help mitigate the likelihood of design induced human performance errors by flight crew members. The research project is the first effort to describe other considerations when finding and showing compliance with 14 CFR 25.1302, but is by no means exhaustive. However, it does address many of the most immediate issues that evaluators and applicants may have with finding and showing compliance with the regulation, as identified in a previous FAA funded study. In this report, the requirements and key characteristics of the regulation were analyzed and potential HF considerations were identified and described in greater detail. (NextGen – Air Ground Integration Human Factors)

Provide a Report on the Feasibility and Recommended Equipment Characteristics and Procedural Changes Pertaining to Use of a Supplemental Data Comm Synthetic Speech Display, Enabling Flightcrew to Safely and Efficiently Respond to Data Communications:

The report has been completed, and results indicate that synthetic speech supplemental display aided flight crews, without introducing complications, yielding less head-down time. The researchers also found that the addition of speech may also help simplify some of the Data Comm procedures currently recommended by the International Civil Aviation Organization. The study report includes preliminary guidance for potential use and implementation of synthetic speech on the flight deck. (NextGen – Air Ground Integration Human Factors)

Complete Research for Enhanced Aircraft Spacing for Surface Movements in Low Visibility Operations/Surface Movement Guidance and Control System (LVO/SMGCS) Chart Usability:

Two studies were conducted to identify best practices for the design of Low Visibility Operations/Surface Movement Guidance and Control System (LVO/SMGCS) paper charts and flight crew use of them in extremely low visibility surface conditions. In the Chart Usability study, the researchers gathered information to understand the general usability of LVO/SMGCS charts on flight crew position awareness. In the Airport Markings study, the researchers evaluated different airport marking designs, which may influence the use of LVO/SMGCS charts under those same conditions. For each study, 24 air transport pilots (twelve flight crews) with Cat II or III qualifications performed taxi scenarios in a simulation of Memphis International Airport at runway visual range (RVR) 300 feet/75 meters at night. The RVR and night-time conditions were chosen to represent worst-case conditions for LVO/SMGCS operations. In some scenarios, flight crews were given difficult air traffic control (ATC) clearances that contained appropriate clearance instructions but did not necessarily follow strict ATC clearance protocol. The study was particularly interested in examining the accuracy of flight crew actions under these conditions while using LVO/SMGCS taxi charts. The results of these studies showed that, under extreme low-visibility conditions, an 8.5 x 11 inch (21.59 x 27.94 cm) black-and-white paper LVO/SMGCS chart was sufficient for flight crews to maintain position awareness. Additionally, flight crews generally responded to air traffic control instructions properly and reported their locations correctly. The detailed results of the studies were used to generate a list of recommended best practices for LVO/SMGCS charts and airport markings. (NextGen – Air Ground Integration Human Factors)

Develop Initial Guidance for Aircraft Certification Personnel Evaluating NextGen Avionics for Potential Human Errors and Error Mitigation:

The goal of this research project is support the development of evaluation methods for new technologies, specifically focusing on evaluation processes for certification under 14 CFR 25.1302. As many of the new technologies currently are information technology related, a particular focus was on methods for cognitive aspects of human performance rather than handling qualities, or the physical control. There were three different tasks. Task 1 focused on obtaining knowledge from previous evaluation efforts related to human factors aspects of 14CFR25.1302. The task deliverables included a repository of lessons learned from the certification process, and a catalog of the items in the repository. Task 2 focused on structured, predictive analysis methods to support evaluators and designers in determining which aspects of a new technology may require further investigation. Task 3 focused on methods to accurately characterize the tasks and intended functions, from which to make assessments about urgency, duration and frequency as stated in paragraph (b)(2) of § 25.1302. The work focused on the development of two methods for task analysis in design and evaluation. (NextGen – Air Ground Integration Human Factors)

Complete Research and Recommendations for Developing, Evaluating, and/or Approving Standard Operating Procedures in NextGen:

The annotated bibliography that summarized findings in the literature and relevant regulatory and guidance material was completed. It addressed considerations in the design of procedures with respect to technology, humans, and the operational environment. (NextGen – Air Ground Integration Human Factors)

Provide Wake Separation Recommendations for Airbus 350 Series Aircraft:

On September 30, 2014, The European Aviation Safety Agency (EASA) issued the type certificate for the Airbus A-350 series aircraft, which is being delivered to its first customer in December 2014. The FAA Wake Turbulence Research Office completed its analysis of the A-350 and developed its wake separation recommendations for the aircraft series. These recommendations began the FAA approval process in September 2014. (NextGen – Wake Turbulence)

Wake Re-Cat Phase I Separations Integrated into Air Traffic Control Orders:

Completed the wake vortex data base analyses and determined that the Wake Re-Categorization Phase I separation standards could be used for the separations defined in existing FAA ATC Order 7110.308, 1.5-Nautical Mile Dependent Approaches to Parallel Runways Spaced Less Than 2,500 Feet Apart, and Order 7110.316, Reduced Wake Turbulence Separation on Departure from Heavy/B757 Aircraft Departing Parallel Runways, Spaced Less Than 2,500 Feet, Using Wake Turbulence Mitigation for Departures (WTMD). The Orders were revised with the new wake mitigation separation standards and a supporting safety risk management document was created using these data analyses to support the integration of wake mitigating procedures with the Wake Re-Categorization Phase I standards. (NextGen – Wake Turbulence)

Delivered First Set of Wake Encounter FDR Screening Algorithms:

In June 2014, the initial version of a data screening utility to identify potential wake turbulence encounters in A330 and B737 data sets was delivered to the FAA for its use in further collecting wake encounter statistics. The data screening tool was developed to screen flight data recorder data sets for potential wake encounters during post-flight analyses. It utilizes multiple algorithms to distinguish potential wake turbulence encounters from atmospheric turbulence and other types of upsets. The tool was extensively exercised using research aircraft data sets containing known wake encounters and end-to-end full flight recorder data sets to verify its capabilities to identify potential wake encounters. Future versions of the screening utility will process extraction modules for more specific aircraft types as well as provide a generic extraction module for processing data from any aircraft. The data screening utility provides the FAA with an automated capability to identify potential wake turbulence encounters ranging from reported major impact occurrences to minor non-reported occurrences. The FAA can leverage these data to conduct detailed analyses that may identify “hot spots” for wake turbulence encounters, as well as to support efforts for determining absolute wake encounter metrics for future safety cases. Potentially, the data screening utility can also contribute to post-implementation assessments of NextGen ATC procedures where wake turbulence may be a factor. (NextGen – Wake Turbulence)

Prototyping Platform Developed for Wake Tools Wind Forecast Algorithms:

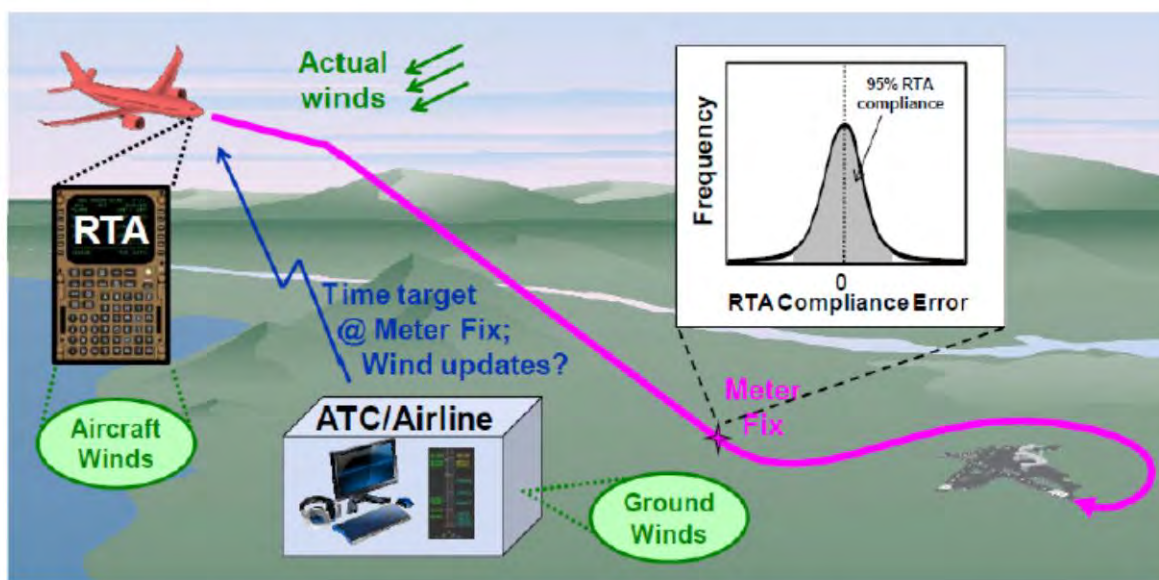
The fast time wind forecast algorithm research platform was completed in May 2014. As research progressed on the utility of wind based wake mitigation decision support tools, there developed a common requirement to forecast the winds that will be along the aircraft flight paths for both tactical and strategic reasons. The existing wind forecast algorithm developed for the

Wake Turbulence Mitigation for Departures (WTMD) application was expanded and recorded in the JAVA language to be more adaptable to varying data input structures such as would be used by the future National Weather Service HRRR weather model and the FAA System Wide Information Management network. The new research platform can be easily modified with new forecast logic and then used to determine the relative impact of these modifications running in fast-time on stored weather data files. The wind forecast algorithm research platform is currently being used to refine wind forecast algorithm parameters to increase the availability of the WTMD system deployed at the San Francisco International Airport. (NextGen – Wake Turbulence)

Impacts of Wind Information Accuracy on Selected NextGen Operations:

Many NextGen applications depend on access to high accuracy wind information due to time-based control elements. Errors in this forecast wind information can significantly degrade performance of certain NextGen operational procedures. The Weather Technology in the Cockpit (WTIC) program developed a Wind Information Analysis Framework to research the relationship between wind information accuracy and selected NextGen operations for a selection of relevant scenarios (i.e., selected winds, aircraft type, and Flight Management System).

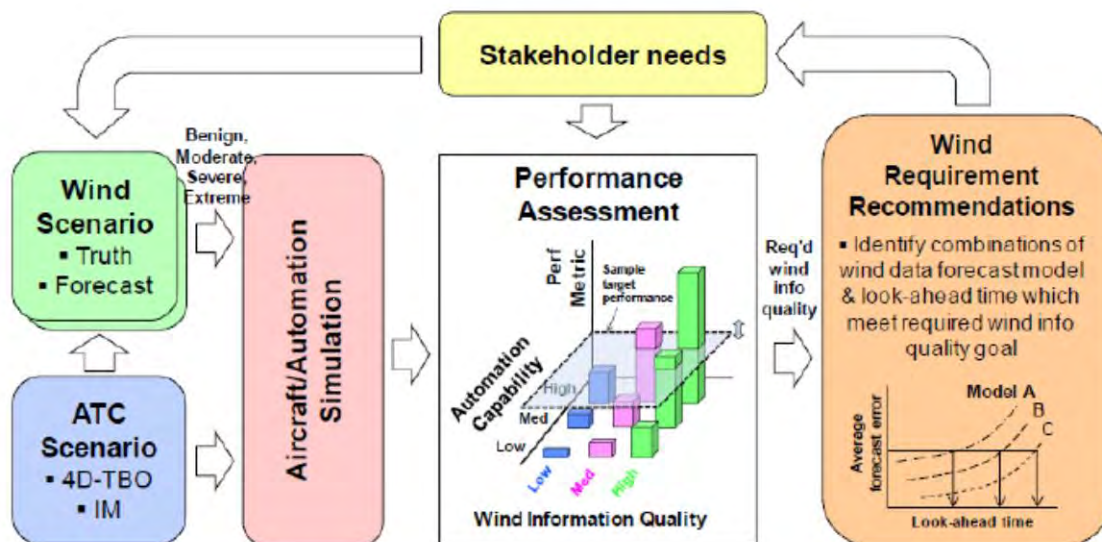
Wind Accuracy



This image illustrates a notional view of how errors in aircraft wind information and ground wind information can adversely impact Required Time of Arrival (RTA) compliance in four-dimensional trajectory based operations (TBO). The results of the wind study provide trade spaces that show wind accuracy tolerances to achieve a specific level of RTA compliance based on the RTA accuracy specified.

Figure 54: Notional view of impact of aircraft and ground wind information on RTA

Results from simulations utilizing the Wind Information Analysis Framework provide the error tolerances that must be satisfied in order to achieve a given target level of performance for the NextGen procedure. This research will be used by the WTIC program as inputs to the recommended Minimum Weather Service standards. These recommendations will be provided to standards development organizations such as RTCA and FAA Flight Standards.



This figure illustrates the simulation framework that was used to develop the Performance Assessment trade spaces and Wind Requirement recommendations.

Figure 55: Wind information analysis framework

The WTIC program successfully completed simulations using the Wind Information Analysis Framework on stakeholder selected NextGen procedures and scenarios. The results of these simulations produced trade spaces showing the relationship of various wind accuracy requirements versus operational performance for the specific operation and scenario. These trade spaces were provided to stakeholder RTCA special committees (SC-206, SC-227) to support their development of wind accuracy standards for industry. In addition, the trade spaces were used as inputs to develop performance specifications for the selected NextGen operations (including time of arrival procedures and interval management). The stakeholder RTCA committees have already begun invoking the research results into their wind standards for NextGen applications. Additional scenarios and NextGen procedures will be evaluated based on stakeholder needs. (NextGen – Weather Technology in the Cockpit)

Weather Technology in the Cockpit Part 121/135 and Part 91 Concepts of Operation:

Development of a Part 121/135 Weather Technology in the Cockpit (WTIC) Concepts of Operation (ConOps) and a Part 91 WTIC ConOps was completed. These ConOps enable the WTIC program to begin functional analyses to produce user needs requirements and to identify operational shortfalls (inefficiencies and safety risks) that are attributable to gaps of MET information in the cockpit. The WTIC minimum weather service will resolve the identified gaps. (NextGen – Weather Technology in the Cockpit)

General Aviation (GA) Shortfall Analyses:

The Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS), which is the FAA's Center of Excellence for General Aviation, conducted initial gap/shortfall analyses of meteorological (MET) products, MET information, pilot training, and causal factors that contributed to unintended transition from visual flight rules (VFR) into instrument meteorological conditions (IMC). Products developed by PEGASAS include an inventory of current weather products and technologies, a weather condition index tool, weather risk matrix, weather scenarios, and Pugh matrix. Recommendations for the WTIC GA minimum weather service will be developed to address the gaps and shortfalls identified in these analyses. (NextGen – Weather Technology in the Cockpit)

Wind Accuracy Recommendations:

Trade spaces quantifying the relationships between wind errors and selected NextGen operational performance were developed through laboratory simulations. RTCA and other stakeholders are already invoking these final trade spaces, and other research results, into RTCA standards. In addition, the research results are being used as inputs to develop performance specifications for the selected NextGen operations (including time of arrival procedures and interval management) in varying wind conditions. (NextGen – Weather Technology in the Cockpit)

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 to a level that does not constrain growth

Airport Cooperative Research Program (ACRP) Accomplishment Statistics:

In 2014, there were 22 ACRP publications issued, which included 13 Research reports, two Synthesis reports, four Research Results digests, one Legal Research digest and two Web-only documents. The Digest reports are used to promote early awareness of project results in order to encourage implementation. The table below lists the Annual Review topic areas of Safety, Capacity and Environment along with the corresponding title of the Research report, Synthesis (S) report or Web-only (W) document.

ACRP Publications

Safety	Capacity	Environment
04-14: Runway Veer-off Location Distribution Risk Assessment Model	03-20: Defining and Measuring Aircraft Delay and Airport Capacity Thresholds	S02-10: Outcomes of Green Initiatives: Large Airports Experience
04-15: A Tool for Developing Airport Terminal Incident Response Plans	03-23: Integrating Aviation and Passenger Rail Planning	02-15: Recycling Best Practices
09-02: Best Practices for Working in or Near Airport Movement Areas	07-10: General Aviation Facility Planning	02-28: Airport Sustainability Practices: Tools for Evaluating, Measuring, and Implementing
	10-14: Being Prepared for IROPS: A Business Planning and Decision-Making Approach	02-32: Understanding Microbial Biofilms in Receiving Waters Impacted by Airport Deicing Activities
		02-33: Guidance for Estimating Airport Construction Emissions
		W02-35: Research Methods for Understanding Aircraft Noise Annoyance and Sleep Disturbance
		W02-37: Integrated Noise Model Accuracy for GA Aircraft

Safety	Capacity	Environment
		02-38: Guidebook for Energy Facilities Compatibility with Airports and Airspace
		09-06: Evaluating Impacts of Sustainability Practices on Airport Operations and Maintenance
		S10-10: Habitat Management to Deter Wildlife at Airports

In addition, there were 102 research problem statements received and 107 panel meetings conducted for statement reviews in 2014. During the July ACRP Oversight Committee (AOC) meeting, 20 new projects were selected for the FY 2015 research program. The panel member nominations for the FY 2015 projects were then issued, the panels were formed, and the first meetings were conducted to develop the Request for Proposals (RFPs) for these 20 projects. (Airport Cooperative Research Program)

Impacts of Alternative Aviation Fuels on Aircraft Rescue and Firefighting Operations:

A literature review of the current and future uses of alternative fuels in the airport environment was completed. This literature review identified where the industry trends were heading in alternative fuels. While all types of alternative fuel sources were analyzed, the primary focus was on the biofuels. The inclusions of alcohols and other changes to the fuel chemistry may have an impact on the effectiveness of current firefighting foams. This review has led to an initial listing of biofuel products that have been subjected to fire testing to determine how current foams perform. (Airport Technology Research Program)

Modeling Results to Support Surface Policy Decision Making:

Long queues of many aircraft waiting in line on taxiways to depart from runways result in delays as well as excess fuel burn and emissions. To reduce the negative impact of such departure queues, the FAA plans to implement Surface Collaborative Decision Making (S-CDM) at key airports in the NAS. With S-CDM, the FAA uses data from flight operators to set movement area entry times for departing flights and to assign a gate departure time for each flight. Before its assigned departure time, each flight is held at the gate. This process reduces the length of physical departure queues by replacing them partially with “virtual” queues, made up of flights held at gates. Virtual queuing reduces fuel burn and emissions, while potentially increasing operator flexibility to re-order departures based on business needs.

The FAA's CAASD has conducted modeling to inform decisions concerning new processes, procedures, and policies (P3) to successfully implement S-CDM. The work analyzed the tradeoffs among several P3 parameters. A key tradeoff involves physical departure queue length. Fuel burn, emissions and flexibility benefits are increased by keeping physical queues shorter, whereas overall departure runway throughput is increased by keeping physical queues longer, thereby reducing the likelihood that the departure runway is needlessly "starved" of aircraft ready to take off. The work built on an FY 2013 analysis in which CAASD investigated how operator flexibility in S-CDM operations depends on such factors as physical departure queue length and departure slot substitution policy. Several metrics were developed to indicate the sensitivity of potential operator flexibility benefits to these factors. The work focused on developing a method for analyzing flexibility in S-CDM operations, rather than on full operational analysis, so the FY 2013 modeling was kept at a fairly low fidelity level.

In FY 2014, CAASD increased the level of modeling fidelity and focused on understanding several specific operational parameters of interest to the FAA and Surface CDM Team:

- Earliest Off-Block Time (EOBT) Accuracy: This is the accuracy of the operator's estimate of the earliest possible time that a flight can push back from the gate.
- Target Queue Length (TQL): The desired length of the physical queue at the end of the runway. Upper and lower thresholds with respect to TQL determine when the departure queue management begins and ends.
- Static Time Horizon (STH): The time period before a flight's Target Movement Area entry Time (TMAT) when changes to the TMAT or flight substitutions are limited.

The work investigated these parameters within the context of the traffic demand and capacity of Phoenix Sky Harbor International Airport (PHX). By modeling actual traffic, the analysis predicted the departure queue length for a given TQL and upper and lower thresholds. Figure 56 below shows unmetered (no S-CDM) and metered (S-CDM) cases with a TQL of 6 flights and upper and lower thresholds of +/-3 flights.

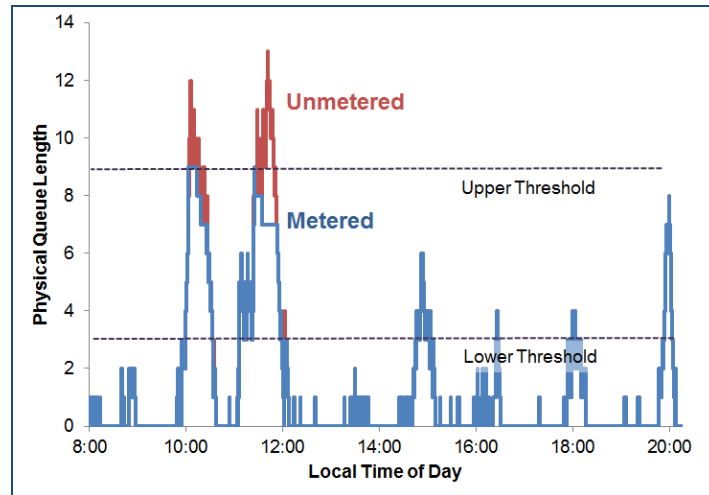


Figure 56: Modeled Departure Queue Length at PHX for October 10, 2012

The above figure (Figure 56) illustrates simulated queue length as a function of time, assuming completely accurate EOBT information. Simulations that model random EOBT inaccuracies showed greater variability in queue length. In some cases the queue size reaches zero, starving the departure runway, despite flights being available that could have taken off if they had left the gate earlier. In these cases, at least some subsequent flights are “late” for their departure slots and departure throughput is reduced as a result of virtual queuing. Iteration across multiple days illustrated when the benefits of a shorter physical queue may outweigh the risk of a late departure.

Key findings, based on the analysis of 2013 flight data from PHX, include the following:

- A shorter target queue length leads to more fuel savings. For example, a target queue length of 6 flights saves 2,300 kg of fuel, 63 kg of local emissions, and 4,711 kg of CO₂ per day.
- However, decreasing the target queue length or lowering flight operators’ accuracy in predicting EOBT while keeping the other constant increases the probability of a late departure.
- In addition, the longer into the future airlines must predict their EOBT, the more inaccurate those EOBTs become.

Collectively, results indicated that the target queue length, look ahead time for which airlines are required to predict EOBT, and static time horizon (STH) settings need to balance the benefits of less fuel burn versus the possibility of a late departure. From this work, the FAA has an analytic framework for assessing S-CDM P3 trade-offs at PHX that is adaptable to other airports and projected future traffic levels as well. The framework can be used to support decisions regarding

P3 parameters (such as EOBT, TQL and STH) settings and to estimate future fuel savings, emissions, and flexibility benefits of S-CDM. (CAASD)

Direct Measurements of Aircraft Particulate Matter Data and Development of Internationally Approved Methodology:

Due to the temperature and thrust of the jet exhaust, sampling and measurement of non-volatile particulate matter emissions (nvPM) from aircraft engines is a challenging endeavor. After many years of experimentation, the Society of Automotive Engineers Aircraft Exhaust Emissions Measurements Committee (SAE E31) has published an Aerospace Information Report (AIR 6241) detailing the sampling system for the measurement of nvPM. FAA has sponsored the development of the North American reference nvPM measurement system, which consists of collection, transfer and measurement sections (see Figure 57).

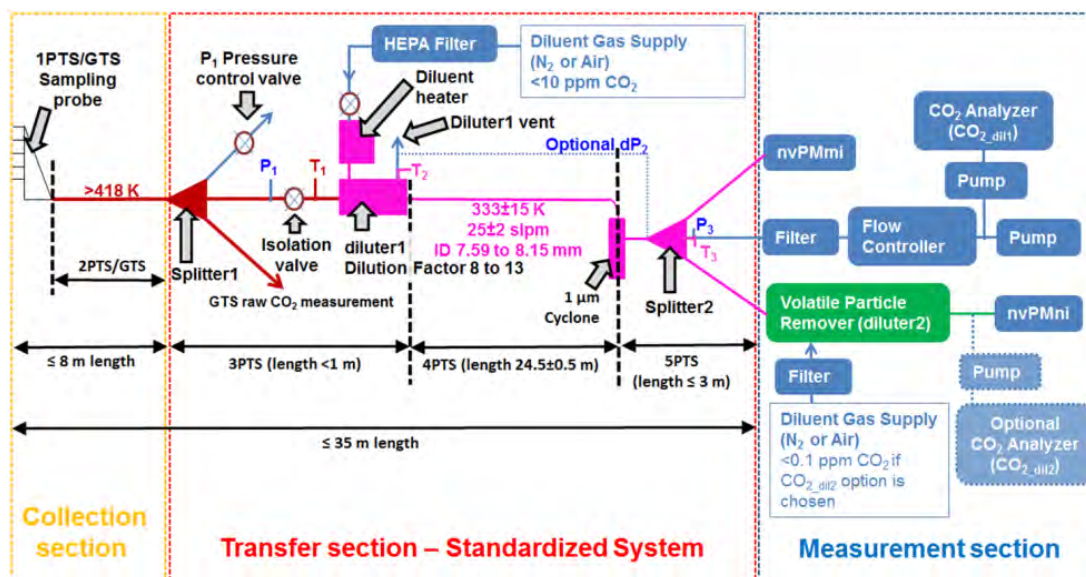


Figure 57: Components of the North American Reference nvPM Measurement System

As part of evaluating the methodology and the robustness of the system toward the development of an Aerospace Recommended Practice (ARP), the North American reference nvPM measurement system has been deployed at various aircraft engine manufacturers across North America and abroad. In the past 12 months, direct measurements of nvPM were performed at the SR Technics maintenance facility in Zurich, Switzerland; at the Pratt and Whitney facility in Hartford, CT; and at the Honeywell facility in Phoenix, AZ. These demonstration/inter-comparison studies continue to provide information regarding the variability of the individual sampling and measurement systems. Datasets from these initial measurement activities are provided to the International Civil Aviation Organization Committee on Aviation Environmental

Protection (CAEP) Particulate Matter Task Group (PMTG) to facilitate development of future aviation PM regulations. Non-volatile PM emissions data from measurement campaigns planned at Rolls-Royce, IN; General Electric Aviation, OH; and Pratt and Whitney, CT, in the next 12 months will help finalize the SAE Aerospace Recommended Practice on aircraft nvPM measurement methodology and inform ICAO CAEP nvPM standard setting process. (Environment and Energy)

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

Aviation noise may have non-auditory effects such as contributing to cardiovascular disease, causing annoyance, and causing sleep disturbance. To better understand the potential effect aviation noise has on social welfare and health, the FAA has been conducting research to better understand the relationship between aviation noise and different non-auditory responses. Specifically, FAA researchers are looking at the effects of aviation noise on cardiovascular disease and sleep disturbance. In addition, researchers are exploring annoyance beyond just fixed wing aircraft, looking at annoyance from rotorcraft and potential annoyance from the potential supersonic civil aircraft market. To do this, the FAA will evaluate the long-term cardiovascular health impacts of noise exposure. This study aims to expand the understanding of the relationship between aircraft noise exposure and cardiovascular health by linking noise exposure data with an existing longitudinal health in the Women's Health Initiative (WHI) cohort for which detailed individual data and high geographical resolution are available. In addition, the FAA will explore the characteristics of the rotorcraft aircraft to determine noise abatement procedures which will reduce annoyance from rotorcraft aircraft while also looking to see if it can be determined which characteristics of the rotorcraft lends it to be perceived as more annoying than fixed wing aircraft at the same noise level. Finally, the FAA is exploring the human response to different shaped sonic booms to determine if there is a potential for acceptability of certain "low booms." (Environment and Energy)

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

The Aerospace Information Report 6241 (AIR 6241) compliant (Non-Volatile Particulate Matter) nvPM measurement system is currently undergoing a thorough evaluation. During FY 2015, the North American reference system will be inter-compared with engine manufacturers' nvPM system to inform the development of the Aerospace Recommended Practice (ARP). The ARP will be balloted in FY 2015 by the Society of Automotive Engineers Aircraft Exhaust Measurements Committee (SAE E31). Measurement campaigns are planned at Rolls-Royce, IN; General Electric Aviation, OH; and Pratt and Whitney, CT, to characterize engine nvPM emissions and to perform inter-comparison of measurement systems. Results will inform the

development of ARP and ensure a timely completion of the document. (Environment and Energy)

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

Climate impact of aviation has a large spatial variability from emissions to radiative forcing and surface air temperature. Such spatial heterogeneity and local maxima and minima are not captured well by simple climate models that predict global mean impact of aviation on surface air temperature and radiative forcing. Therefore, a more comprehensive tool to estimate regional climate impacts of regional aviation emissions perturbations is being developed. Two complex climate models are being utilized to inform the development of this tool which when completed can be used globally to capture the regional radiative forcing and temperature changes for various policy scenarios. The first beta-version of this tool is planned for completion in 2015. (Environment and Energy)

Improve Understanding of the Impacts of Aircraft Emissions in the Airport Vicinity:

Reducing the air quality health impacts of aviation emissions despite aviation growth is one of the E&E goals of FAA. Health impacts due to aviation emissions are mainly due to PM2.5 and Ozone that are formed as the emissions interact with the background. While significant health impacts are defined to include premature mortality and hospital admissions over large areas, the impact of operations at a specific airport in its vicinity is of considerable interest and will need a different metric. Using a combination Community Multi-scale Air Quality model equipped with the direct decoupled method and a statistical approach, impacts of aviation emissions contributing to over 99 percent of the total fuel burn will be quantified this year. This tool can then be exercised on year-to-year basis to track airport specific impacts and to understand the result of various policy options. The tool is expected to be complete in 2015. (Environment and Energy)

Methods to Quantify Aviation Emissions Impact on Surface Air Quality:

One of the FAA Environment and Energy goals is to achieve an absolute reduction of significant air quality health and welfare impacts attributable to aviation, notwithstanding aviation growth. The year-to-year changes in significant health impacts therefore need to be quantified more accurately and consistently. In the past 12 months, a tool based on the Community Multi-scale Air Quality (CMAQ) modeling framework was developed, evaluated and used to estimate health

impacts for two sample years. This tool will continue to be used to track the trajectory of health impacts for base (2005, 2010), current (2014) and future (2018, 2025) years.

From the baseline significant health impacts, policy options will need to be considered to accomplish the Air Quality E&E goal. To evaluate the reduction in significant health impacts for the various policy options, efforts to develop NAS wide and airport level rapid analysis tools began in the past year and the work is continuing in this year. These rapid analysis tools quantify health impacts for units of pollutants generated by aviation emissions. Specifically, the airport level tool quantifies the distribution of primary and secondary particles and ozone around airports with a view to develop a metric in addition to significant health impacts that can be used to quantify surface air quality impacts of aviation emissions. The NAS wide rapid analysis tool will provide aggregated significant health impacts for various policy options. The development of both these tools is nearing completion and they are expected to become operational by Q2, 2015. (Environment and Energy)

Demonstrate Continuous Lower Energy, Emissions and Noise Engine Weight Reduction and High Temperature Impeller Technologies:

The Continuous Lower Energy, Emissions and Noise (CLEEN) program is the FAA's principal NextGen environmental effort to accelerate the development of new aircraft and engine technologies and advance sustainable alternative jet fuels. The CLEEN Program is a key element of the NextGen strategy to achieve environmental protection that allows for sustained aviation growth. The FAA selected companies to participate in CLEEN through a cost-sharing program. These companies are working to develop technologies that will reduce noise, emissions, and fuel burn and enable the aviation industry to expedite integration of these technologies into current and future aircraft 2015 onward as the CLEEN technologies will continue to enter the fleet after 2018. These technologies include sustainable alternative jet fuels; lighter, more efficient gas turbine engine components; noise-reducing engine nozzles; advanced wing trailing edges; optimized flight trajectories using onboard flight management systems; and open rotor and geared turbofan engines.

Under CLEEN, in FY 2015, Honeywell will conduct a series of engine ground tests to demonstrate the CLEEN engine weight reduction and high temperature impeller technologies they have developed under the program. These technologies reduce aircraft mission fuel burn by enabling increases in engine efficiency and reducing engine weight. The CLEEN technologies are projected to contribute 5 percent toward an overall 15.7 percent reduction in fuel burn resulting from an engine upgrade relative to baseline engine technology. Endurance engine tests during FY 2015 are planned to bring these technologies to technology readiness level (TRL) 6,

completing their technology maturation under the CLEEN Program. (NextGen Environmental Research – Aircraft Technologies, Fuels, and Metrics)

Evaluate Novel Future Alternative Jet Fuels to Ensure Their Compatibility with Existing Aircraft and Fueling Infrastructure:

The FAA continues to work with manufacturers and fuel producers through CLEEN and the ASCENT Center of Excellence to test and demonstrate alternative jet fuels. In June 2014 the third alternative jet fuel was approved for use by ASTM International, Synthesized Iso-Paraffins (SIP) are jet fuels made from sugar. Their approval is due, in part, to the testing and evaluation activities funded by FAA. There are an additional 6 fuels currently under testing and evaluation via FAA funded programs that could be approved in the next 2 years. (NextGen Environmental Research – Aircraft Technologies, Fuels, and Metrics)

Assess the Environmental Benefits of the First Round of Continuous Lower Energy Emissions and Noise Airframe and Engine Technologies:

In FY 2014, a new project under the Aviation Sustainability Center of Excellence (ASCENT) has kicked off to continue efforts to model and assess the environmental benefits of aircraft technology, including those under the FAA's CLEEN Program. This effort will continue modeling of CLEEN technologies, building upon those modeled previously under the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence Project 36, with input from the companies developing these technologies. The project will start by working with government, industry, and academia experts to establish consensus on scenarios and associated assumptions to be evaluated. This will inform any additional technology and aircraft modeling work that will be completed to enable these assessments. Finally, the technologies and vehicles will be assessed to look at the impact of technologies on environmental performance metrics at the vehicle and fleet level. (NextGen Environmental Research – Aircraft Technologies, Fuels, and Metrics)

Initiate Continuous Lower Energy, Emissions and Noise Phase II Activities to Demonstrate Technologies That Can Reduce Energy Use, Emissions, and Noise:

On September 29, 2014, the FAA's Office of Environment and Energy released the Screening Information Request (SIR) for the Continuous Lower Energy, Emissions and Noise II (CLEEN II) program. CLEEN II is a follow on program to CLEEN and will focus on developing aircraft technology to reduce energy, emissions and noise and the advancement of alternative jet fuels.

The response period for CLEEN II closed on February 2, 2015 and awards are expected to be made in late summer of 2015. Prior to releasing the SIR, FAA's Office of Environment and Energy released a Market Survey and held a Bidder's Day to gauge interest and receive commentary from the aviation industry. (NextGen Environmental Research – Aircraft Technologies, Fuels, and Metrics)

Ceramic Matrix Composite (CMC) Acoustic Nozzle:

The CLEEN program is the FAA's principal NextGen environmental effort to accelerate the development of new aircraft and engine technologies and advance sustainable alternative jet fuels. The CLEEN Program is a key element of the NextGen strategy to achieve environmental protection that allows for sustained aviation growth. The FAA selected companies to participate in CLEEN through a cost-sharing program. These companies are working to develop technologies that will reduce noise, emissions, and fuel burn and enable the aviation industry to expedite integration of these technologies into current and future aircraft 2015 onward as the CLEEN technologies will continue to enter the fleet after 2018.

These technologies include sustainable alternative jet fuels; lighter, more efficient gas turbine engine components; noise-reducing engine nozzles; advanced wing trailing edges; optimized flight trajectories using onboard flight management systems; and open rotor and geared turbofan engines.

Under the CLEEN Program, Boeing has developed and demonstrated two new aircraft technologies. The two technologies are an Adaptive Trailing-Edge on the aircraft wing and a Ceramic Matrix Composite (CMC) acoustic nozzle at the engine exhaust. The adaptive trailing edge is estimated to reduce fuel burn by up to 2 percent, while reducing aircraft certification cumulative noise levels by up to 1.5 EPNdB. The ceramic matrix composite nozzle is estimated to reduce fuel burn up to 1 percent, while providing noise attenuation on parity with a metallic nozzle. Boeing has also completed research to determine effects of alternative jet fuels on aircraft fuel systems.

In July 2014, Boeing completed a three week flight test of its prototype CMC nozzle (see Figure 58). The testing was conducted in Moses Lake, WA on a 787-8 aircraft. Preliminary results indicated acoustically treated CMC can meet or potentially exceed performance of current metallics, and that the CMC material system exceeds temperature capability of superalloys at a weight 20 percent lighter than titanium resulting in reduced fuel consumption. This technology also enables more advanced propulsion system architectures capable of achieving additional fuel savings.



Figure 58: Boeing's ceramic matrix composite nozzle installed on a ground engine test stand

CMCs comprise a ceramic matrix reinforced by a refractory fiber, such as silicon carbide (SiC) fiber. CMCs offer low density, high hardness and superior thermal and chemical resistance. That and their intrinsic ability to be tailored as composites make CMCs highly attractive in a vast array of applications, most notably internal engine components, exhaust systems and other “hot-zone” structures, where CMCs are envisioned as lightweight replacements for metallic superalloys. (NextGen Environmental Research – Aircraft Technologies, Fuels, and Metrics)

Evaluate the Environmental and Economic Sustainability of Future Alternative Turbine Engine Fuels:

As part of Project 47 of the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER), an FAA Center of Excellence, researchers from MIT published a study in March 2014 on the environmental and economic feasibility of a set of fermentation and advanced

fermentation technologies for producing drop-in jet fuel from sugary, starchy and lignocellulosic biomass. It was found that fermentation and advanced fermentation fuels have the potential for significant reductions in lifecycle greenhouse gas emissions from conventional fuels, and that their minimum selling price could approach economic competitiveness with conventional fuels. This effort builds on previously completed analytical work that evaluated the lifecycle greenhouse gas emissions and economic cost of production for fuels that could be produced from vegetable oils, biomass, and waste products.

Over the course of the last year, PARTNER researchers also published research on the climate impacts from changes in surface albedo due to land use change. The study finds that changes in surface albedo have the potential to dominate the climate impact of biofuels and concludes that accounting for changes in surface albedo is necessary for a complete assessment of the aggregate climate impacts of biofuel production and use.



Figure 59: Boeing 787 ecoDemonstrator including CLEEN Program technologies and alternative jet fuels

As a follow-on to the work of PARTNER, a new project was initiated by FAA under the new Aviation Sustainability Center (ASCENT) of Excellence for Alternative Jet fuels and Environment), with a team consisting of researchers from Washington State University, MIT, Purdue University, Pennsylvania State University, University of Illinois at Urbana-Champaign, and University of Tennessee at Knoxville, to investigate near- and long-term barriers for large-

scale deployment of sustainable alternative jet fuels for the full range of pathways being considered for ASTM approval. The project will consider the entire supply chain including feedstock production, feedstock transportation, feedstock conversion to jet fuel and co-products, blending and jet fuel use by aviation. The research team will quantify the feedstock availability and potential for sustainable supply from various regions, identify options available for the use of the feedstocks and quantify the relative economic and environmental costs and benefits associated with the various feedstock uses.

During the past year, the International Civil Aviation Organization (ICAO) Committee of Aviation Environmental Protection (CAEP) stood up an Alternative Fuel Task Force to quantify how alternative jet fuels could help the aviation industry meet its ambitious CO₂ emissions reduction goals. The aforementioned research that is being conducted by the PARTNER and the ASCENT Center of Excellence has been and will continue to be central to this international effort. (NextGen Environmental Research – Aircraft Technologies, Fuels, and Metrics)

Acronym List

Acronym	Definition
0-9	
2D	Two-Dimensional
3D	Three-Dimensional
3D PAM	Three-Dimensional Path Arrival Management
4D	Four-Dimensional
A	
AC	Advisory Circular
ADDS	Aviation Digital Data Service
ADS-B	Automatic Dependent Surveillance – Broadcast
AEDT	Aviation Environmental Design Tool
ARTCC	Air Route Traffic Control Center
ASIAS	Aviation Safety Information Analysis and Sharing
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
ATL	Hartsfield-Jackson Atlanta International Airport
ATM	Air Traffic Management
C	
CAASD	Center for Advanced Aviation System Development
CACRC	Commercial Aircraft Composite Repair Committee
CAMI	Civil Aerospace Medical Institute
CDTI	Cockpit Display of Traffic Information
CFR	Code of Federal Regulations
CIP	Current Icing Product
CLEEN	Continuous Lower Energy, Emissions, and Noise
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
COE	Center of Excellence
CSET	Composite Structural Engineering Training
CWSU	Center Weather Service Unit
D	
Data Comm	Data Communications
DSS	Decision Support System
DRNP	Dynamic Required Navigation Performance
E	
EDMS	Emissions and Dispersion Modeling System

Acronym	Definition
EMS	Environmental Management System
EOBT	Earliest Off Block Time
F	
FAA	Federal Aviation Administration
FEA	Finite Element Analysis
FEM	Finite Element Method
FIP	Forecast Icing Product
FCM	Flow Contingency Management
FMS	Flight Management System
G	
GA	General Aviation
GE	General Electric
GWU	The George Washington University
H	
HITL	Human In The Loop
I	
IFR	Instrument Flight Rules
J	
JAMS	Joint Advanced Materials and Structures
JPDO	Joint Planning and Development Office
L	
Li-ion	Lithium-ion
LSTC	Livermore Software Technology Corporation
M	
MMPDS	Metallic Materials Properties Development and Standardization
N	
NARP	National Aviation Research Plan
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NDI	Nondestructive Inspections
NDIR	Non-Dispersive Infrared
NEPA	National Environmental Policy Act

Acronym	Definition
NextGen	Next Generation Air Transportation System
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
NTSB	National Transportation Safety Board
O	
OEE	Office of Environment and Energy
OEM	Original Equipment Manufacturer
OSU	The Ohio State University
P	
PED	Portable Electronic Device
POD	Probability of Detection
R	
R&D	Research and Development
RAP	Rapid Update
RNAV	Area Navigation
RTA	Require Time of Arrival
S	
SAE	Society of Automotive Engineers
SMS	Safety Management System
STH	Static Time Horizon
T	
TRACON	Terminal Radar Approach Control
TFMS	Traffic Flow Management System

Acronym	Definition
TQL	Target Queue Length
U	
UAS	Unmanned Aircraft Systems
UCSD	University of California San Diego
U.S.	United States
W	
WSU	Wichita State University
WJHTC	William J. Hughes Technical Center
WTMD	Wake Turbulence Mitigation for Departures